An Examination of Multiple MicroGeneration Technologies used within an Experimental Home

A tire–bale home leverages green technologies for energy independence

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***Abstract*—The concept of microgeneration [1] can be extended into homes which use a variety of techniques to generate energy using green concepts. This paper examines one such experimental house that uses active and passive systems to generate energy for the home while putting surpluses back onto the grid. This house is a proving ground of building and energy concepts with a goal of demonstrating feasibilities in multiple green technologies.**

***Index Terms*—home systems, passive solar, tire bales, thermal mass, solar, net metering, net zero energy, NZEB**

I. Introduction

In the mountains of Colorado, the authors have designed and created/built an experimental house that incorporates a variety of green technologies. The house was completed as a first of a kind construction using tire bales [2] for the structural base. This construction removed over 170 tons of waste in the form of tires, glass, aluminum, and plastics from Colorado's landfills. Further, the house uses a passive solar, thermal mass heating concept as a primary heat source; lighting concepts in the house are CFL or LED systems, and Energy Star rated appliances are used as well. Finally, a 6–panel solar array (PV) electric system was installed to supply electricity to the house but feeds excess energy to the grid using Net Metering technologies. The ultimate goal of the house and its systems are to have a near zero energy footprint and a lower fossil fuel impact, as well as to demonstrate the feasibility of a variety of home–based microgeneration systems.

This paper builds on previous research work reported to IEEE [3] on this experimental house and its systems by examining data we have collected keeping in mind that the data collection and analysis are still in the early stages. However, thus far, the data indicates that the technologies in combination offer viable options for homeowners wanting to explore microgeneration without giving up the conveniences of the grid. The efficiencies of such homes also offer advantages by helping to reduce the need for new generation capacity.

This paper will summarize the basic building concept. The work will then explore the variety of green related systems used in the house. Following the energy use data and associated analysis will be presented which includes generation, heating vs. outside temperature, and cost information. Finally, the paper will outline future data collection, system improvement plans, and how interested parties can expand on the concepts this house system explores.

II. Introduction to Building with Tires

Using tires to build homes has been around since 1977 when architect Michael Reynolds created Earthships [4]. Variations on Reynolds' theme have been achieved in recent years such as this tire bale home [5]. The basic idea of these green building concepts is to use materials at hand (human cast–offs) to build homes and structures, materials which might otherwise impact the environment by being "dumped" in landfills. These homes can offer savings in energy usage—to name only one of their advantages.

Figure: South exterior view and portion of courtyard, Hagar's tire bale home

In 2006 several engineers interested in exploring the next generation of building with tires started and then completed in 2008 the first occupied house built with tire bales used in this fashion. Tire bales replaced the rammed earth approach of Reynolds' Earthship design, using more tires—approximately

17,000 used tires for this 2,700 sf home versus 6,500 tires for Dennis Weaver's 16,000 sf Earthship). The bales serve as structural support elements and add thermal mass for passive heat storage. The house also has heavily insulated walls and some automated window covering systems, which allows blocking of heat loss in winter and venting of excess heat during warmer months. No air conditioning system is needed; however, Grand County's building codes required baseboard electric heaters even though in four winters these heaters have been used less than 10 times or 40 hours during minus 31 C (minus 25 F) or less nights. The house does have a single non–catalytic, wood burning stove, which is used frequently on long cold nights or cloudy days.

While much of the engineering that went into house can be considered experimental and we, as builders, faced numerous design challenges, in 4 years of living in it, the house has not shown us any different issues than those of traditional homes. The microgeneration concepts incorporated within an overall "home" system have functioned well.

III. MICROGENERATION AND ENERGY SYSTEMS

It is largely accepted that no single technology will be the dominant answer to green energy generation and conservation. This house demonstrates a variety of concepts, both larger and smaller. In this section, we outline the more prevalent ones in use within this experimental tire bale house. Taken together, these contribute to the data found in this paper. These include:

- A variety of recycled building materials
- Thermal mass storage of passive solar heat
- Passive solar heating
- Passive venting systems for cooling
- Low energy use lighting systems
- Energy Star appliances
- High efficiency wood burning stove using recycled wood
- Automated blinds for heat retention and cooling
- Solar array using microinverters
- Option to add more smart home features and
- In home greenhouse ability.

The passive solar heating of the house is fundamental to the house design and overall living concept. Although 2,700 sf of living space is a heated area, 500 sf is used primarily as walking space and used to grow plants (vegetables) indoors since it provides the greatest amount of solar heating. This square footage and the solar gain could have been increased if we had used slanted glass. However, issues of snow levels at the building site negated this design option. The solar heating does lead to temperature fluctuations within the house on a daily basis (which also means that the air moves naturally–through convection and without mechanical means). The daily fluctuations range from lows at 13 C (56 F) and highs of 29 C (85 F). The thermal mass tends to hold a temperature of 19 C (67 F) plus or minus 2 degrees. Additional heating is accomplished with the wood burning stove during low or very low temperatures. When inside temperatures are higher than 22 C (73 F) (at the living level on the lower side of the rooms), one or more of the north windows and a few of the lower south windows (low and high on the structure) can be used to vent excess heat. We have not found a need for traditional heating or air conditioning, although we may need to start the day wearing a sweater but by mid–to–late afternoon; we put on much lighter clothing (t–shirts and shorts).

The use of various low energy lighting and Energy Star appliances are common in many homes and businesses now. This house leverages those too. Additionally, the natural light during daylight hours means that much of the house needs no electric lights on. We achieved this by designing an open floor plan and half glass block walls to move light into areas such as bathrooms and closets. Taking advantage of these "smart" design choices and low energy products minimizes energy use and allows the scope of microgeneration to remain smaller than more closed in traditional houses.

A secondary heat source, used primarily from late November to late April, is a non–catalytic wood burning stove that uses soapstone sides to allow 8 hours of burn time but radiates heat for up to 12 hours. It is highly efficient emitting just 1.9 grams of particulates per hour and pumps out 50,000 BTUs of heat for the 1,375 sf kitchen/dining/living space. There are days when the outside temperature never reaches above minus 17 C (0 F) but the sun is shining and no other heat is needed. Then there are nights when wood burning is needed and through the use of a combination of heating techniques, the house remains between 17 and 21 C (64 and 70 F)—depending on how much and how long the sun shines, outside temperature, and wind. Chart 4 shows an inside–outside temperature profile over a cold two month period.

Many people feel that burning wood results in some level of air pollution and that it is not overly green. However, the wood burning stove produces less particulates than that of older wood stoves. Plus, we use deadfall wood found within 1 mile of the home. These trees are not part of the fossil fuel cycle, yet offer the heat boost needed for a home at an elevation of 8,200 feet above sea level. As we expand either solar or wind generation capabilities, it is possible that the use of wood might be needed less.

Several home design choices were made to aid in energy production, use and conservation. A problem that many solar homes have is heat loss through the windows when the sun is not available (cloudy days or at night). We have 22 automated blinds, which allow the majority of blinds to be quickly raised or lowered. This can retain heat or in the case of excessive gain, block some sun. The blinds have an R factor of 4.7, which holds in quite a lot of 'stored" heat. A long term goal is to have the automated blinds tied to a sun sensor. The rest of the windows (35 total windows) have R 4.7 rated window blinds too but they are not automated at this time. While we wait and research these technologies, we are noting that 10 minutes of sunshine with the blinds open on an average temperate day of 1 C or higher (30 F) can add 2–5 degrees of added (free) heat to the house.

This house has 25 windows on the south side (6–feet tall x 3–feet wide, almost floor to ceiling), plus 2 sets of glass French doors, a very large U–shaped glass front door with 2 sidelight windows (next to the front door), and 9 picture windows stacked over operating awning windows in a single frame. In total, we have a 23.5% solar gain, which is low given that ideally we want 25% solar gain for the house. There are also 5 large motorized windows on the north side of the house situated about eight feet above the living space. We also have large windows on each end of the house (east and west) and smaller windows there beside them. All of the windows are installed in an arrangement to allow a natural flue effect—north to south, or cross ventilation east to west.

Some of the window and blinds have the ability to be tied to sensors as part of a smart house concept, though to date, we have not implemented these ideas. We like to follow the engineering ideal of "Keep it simple" (KISS), although we did wire and plumb the house to support smart house concepts. We are always looking for improved technologies.

The living space floors are a colored and highly polished concrete with added local aggregate and a few colorful marbles and shells, which makes it look like natural stone. No materials cover the floors except for a few small area rugs or cushioned mats in the kitchen. This allows more even interior heating of the thermal mass and release of the heat when needed. Also, the walls throughout the living spaces are covered with clay, a natural "green" product (minimal mining and production). Low or no VOC paints were used in the bathrooms since those areas can contain moisture and are more closed in.

Nearly all of the construction materials and approaches used were chosen to minimize long–term energy impacts. This, of course, starts with the use of tires, which became the primary building material (by weight) of the house. Also, besides the tires, large amounts of rocks found on site, and recyclables from friends, such as bottles (plastic and glass) and cans were used to fill some of voids in the tire bales which saved on concrete. We recognize that concrete is not the most energy efficient or "green" building product to use. However, we chose to use it for the wall and floor materials and when used by itself without any coverings on it (ceramic tiles, rugs, wood, or other insulating materials) carbon offsets are only with the amount of concrete used versus on both the concrete and other covering materials.

Next, much of the wood used in construction such as the south walls, roofing, tie–in points, and a few interior walls was either engineered wood produced from sustainable forests or was local beetle kill trees [6] (a naturally occurring resource in Colorado). Finally, where possible, house mechanical systems were chosen to minimize energy impacts. This includes an on–demand hot water heater (we can supplement with solar hot water in the future); heating systems with no moving parts, and easy maintenance electrical and plumbing. The combination of building materials and design options means that the house has a lower overall carbon imprint than similar homes in Grand County.

IV. ENERGY AND COST DATA

Figures 1 through 4 illustrate how four homes in Grand County differ in energy use. Home–A is a 2–story wood structure built in 1977 that does not use any outside energy production techniques and has electric heat. Home–B is a single–story metal structure built in 1999 and does not use any outside energy production techniques and uses a combination of electric heat and wood stove. Home–C was built in 2003, used the ARXX construction (insulated concrete forms), is well insulated, and uses propane radiant heat. Home–D (our home) is described further within this paper. None of the homes have air conditioning.

A. Annual electric use for 3 different types of homes (energy is purchased from the supplier/grid)

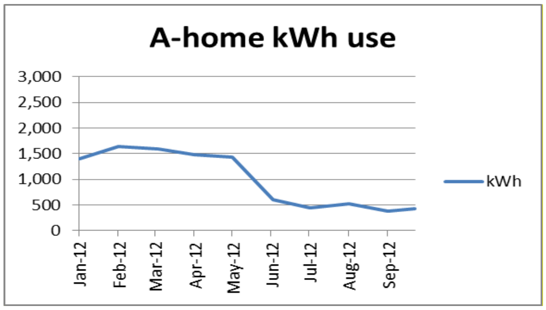

Figure 1. Home–A energy use in kWh (wood structure)

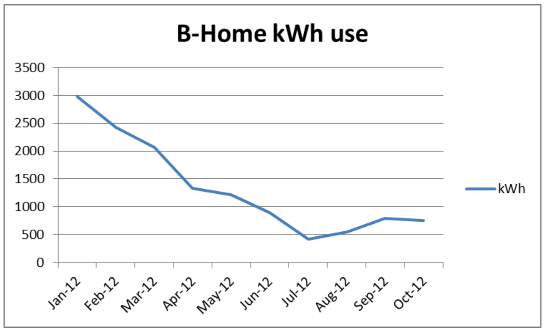

Figure 2. Home–B energy use in kWh (metal strucuture)

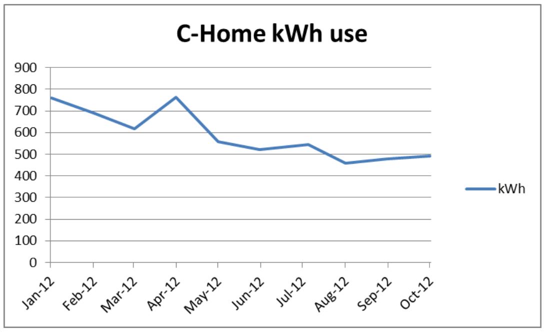

Figure 3. Home–C energy use in kWh (ARXX strucuture)

B. Annual electric use for Home-D

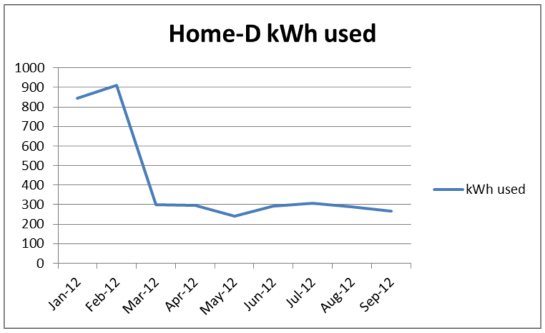

Figure 4. Home–D energy use in kWh

The chart in Figure 5 indicates that the combined microgeneration features of the house substantially lower annual energy use compared to a few other houses in Grand County, including one energy efficient home. As we expected, peak electric use is during the dark and cold winter months. Other months show low usage in all homes, though a factor here is two of the homes do not have occupancy during summer months. The data also indicates to us that we should be considering other microgeneration techniques to get to net zero.

Figure 5 illustrates the energy produced by the solar array that feeds directly into the house systems and Net Meters back to the grid.

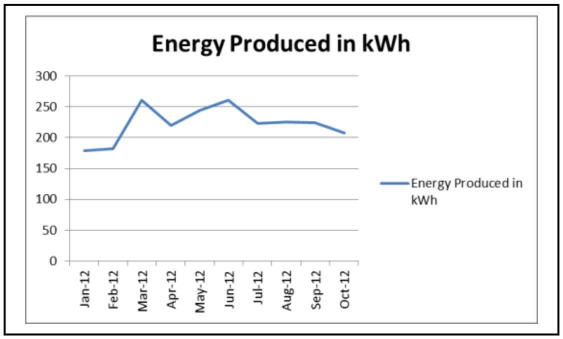

Figure 5 Energy produced by 6–PV panel solar array

Figure 6 reports the inside and outside temperatures 12 noon sampling during January and February 2012. It does not show the extreme of temperatures, which typically occur at 6 am (lowest) and 4 pm (highest).

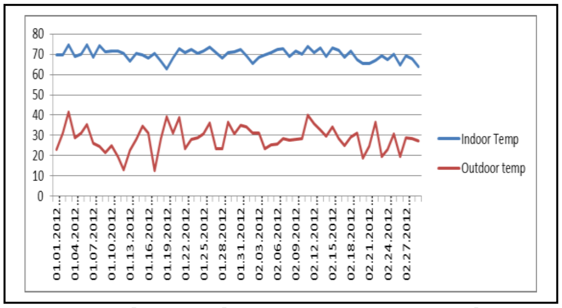

Figure 6 Inside–outside temperatures Jan–Feb.2012

Daily/monthly variations in Figure 6 are due to hours of sunlight and weather. On days when there is less generation, there is more use of other systems, such as the grid and the wood burning stove to maintain interior temperatures. The chart does show consistent interior temperatures even while outside temperatures are what most people would consider cold. Passive solar–thermal mass concepts work to keep a consistent interior temperature with no (in the case of this data) electric heat, although in these time periods the wood stove is in use between 6am and 8am or from 6pm to 12pm.

C. Dollar Cost of this house vs. others in this area

The average cost of building a home in Grand County Colorado currently is upwards of $250 per square foot, depending on materials, finishes, and other factors. The cost to build this energy efficient house was $235 per square foot (finishes added to this). However, we believe that we have a showcase of possibilities and an ideal laboratory—not to mention a great place to live.

The local electric co–op charges a $25 monthly fee to have an account with them and then they charge $0.099 per kilowatt hour (and some minor taxes, 2012 rates).

V. ANALYSIS CONSIDERATIONS OF THE TECHNOLOGIES

We believe that this data demonstrates viability for the type of structure that we built. Further the data also demonstrates that this type of structure does not need or use as much energy as a conventional stick home. And that so far, the microgeneration techniques used meet our current personal needs.

A. Viability of microgeneration using these approaches

The data illustrates that a mix and match approach of microgeneration and energy saving for heating, cooling, and lighting, and power generation is proving successful. By employing a variety of microgeneration techniques and energy saving features demonstrates the viability of combining technologies. The charts show a warm house which uses less energy while generating electricity to feed into the grid.

B. Cost return

Any technology or set of technologies must ultimately be cost effective. Fossil fuel technologies are becoming less cost effective, hence the interest in the green technologies. The house cost is similar to others of its size and level of quality but is less expensive overall to operate as the data shows. We estimate the payback on the solar array to be about 4 years from date of installation (July 2010). The house itself is saving money over the cost per square foot since it almost heats and cools itself. This lowers the overall cost of ownership over traditional homes. Also, the microgeneration facilities in use in the house can help lower the demand and peaks on the grid, which can lower everyone's costs by negating the need for unused excess capacity.

VI. FUTURE PLANS AND ANALYSIS

The research on this house is on–going: adopting more microgeneration, data collection, and other analyses. As with many engineering demonstration projects, we have a variety of plans to increase the overall green of the home and will be collecting the associated data. Plans for future energy generation include:

- Adding a wind generation system (determination of viability is underway)
- Adding solar hot water
- Installing an on/off grid switching capability
- Adding smart systems where needed
- Reviewing other energy systems for feasibility.

We are looking toward more options and expanding microgeneration abilities, as well as finding usage efficiencies. However, a determining factor in any plan or future system is cost to benefit rationale. It is not enough for us to be green just to be green. Economics must be a driving factor.

We are interested in the kinds of data and analysis we should be performing to increase the understanding of such homes, green technologies, and microgeneration as well as how to teach others about trying something new and green. The determining factor may be cost, but supporting data is always useful.

Specific data expansion and analysis we are interested in includes:

- Longer term study of temperature vs. heating sources;
- Cost of heating source vs. benefit;
- Impact of different insulation technologies on such homes;
- Impact of smart or other green energy systems on efficiencies of the house;
- Impact of tire bale building technologies on more general building and Civil Engineering projects; and
- Can the house get to a zero fossil fuel footprint?

We have a blog [http://hagartirebales.wordpress.com] and a Web site [http://hagartirebales.com] and have been working on an informational book to help other builders and researchers with this type of house and the technologies that we have used. We continually answer questions from people from around the world who have an interest in building projects such as ours. The kinds of data and information we would include in a book are of interest to us as engineers as well as to a community who want something different than traditional, less efficient housing. However, we value other people’s feedback and suggestions.

VII. SUMMARY

The specific building approach and technology is not for everyone, but may be of interest to people who have built similar homes and expressed interest in the concepts we are exploring. The data we have gathered so far points to concept viability, but much more data with this and other such homes is still needed.

Many people have expressed interest in energy savings such as we are realizing, as well as green building concepts. We are making concepts that we used available on the Web and soon in a book. Our hope is that everyone can apply some of the technologies to current and future homes. We have the advantage of being engineers, who are used to experimentation and problem solving. We hope what we learn can be used by others around the world.

As a society, we feel that a variety of technologies and the ability to leverage naturally occurring as well as man–made products designed for the local environment should be used in making homes and other structures. Green technologies can offer energy solutions now and in the future. However, engineering data must support any technology. The house was built to showcase a variety of technologies, collect data, and explore new techniques, which have not been tried before. The fact that the house is standing, generating energy, and is a really great place to live offers both subjective and objective evidence of the viability of the concepts we have presented.

ACKNOWLEDGMENT

The data collection and analysis are done by the authors but we gratefully acknowledge the contribution of other homeowners who shared their data with us.

The house was architected, designed, and general contracted by Jon and Laura Hagar. Michael (Mikey) Shealy [5] drew the blueprints and provided some engineering advice to us during construction. Mikey started our journey and helped us to find Lenard Jones, P.E., who provided the civil engineering analysis and approvals. We owe Leonard a debt of gratitude for his sage advice. Unfortunately, Leonard died suddenly in 2007. Finally, this house was built by many supporting contractors/vendors, friends, and volunteers to whom we offer great thanks.

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