# The Carriage House:

# Renewable resource integration of energy and water in a cold climate

# MARTIN R. YOKLIC<sup>1</sup>, STEFANIE VAUGHAN GERSTLE<sup>2</sup>

<sup>1</sup>University of Arizona, Environmental Research Laboratory, Tucson, Arizona, USA myoklic@ag.arizona.edu <sup>2</sup>Architect, Tucson, Arizona, USA

ABSTRACT: The objectives of this applied research project are 1) show how the sustainable resources of forest biomass, solar energy, harvested rainwater, and small diameter logs can be integrated in a system that provides most or all of the energy and water needs of a typical cold climate residential household, 2) effectively interpret the results and convey the sustainable potential to the public. This project validates that 1) the grid interconnected combination of the BioMax, wood pellet energy system (5Kw peak) with solar energy via photovoltaics (3kW) can provide the majority of the power needs for a residential unit in a cold climate, 2) rainwater can be stored (2500 gal. cistern) and reliably filtered and disinfected for potable use, 3) systems to save energy and water are safe, reliable, and provide sustainable security, and 4) these technologies are available and work well in cold climates like in the project's location in Madison, Wisconsin. USA.

Keywords: integrated design, passive solar, active solar, rainwater harvesting, photovoltaic, CALPAS3

# INTRODUCTION

Energy and water are critical and strategic resources. The residential sector accounts for 22% of the annual energy consumption in the USA. Average per capita water consumption exceeds 100 gallons per day nationally. While conservation is important and has provided gains in energy and water efficiency, integrated systems are emerging that can use our resources more efficiently. This project examines how renewable energy, rainwater harvesting and the waste from forest thinnings can be integrated for residential sustainability in cold climates.

#### BACKGROUND

Wood products made from small diameter logs, harvested rainwater, and energy from wood waste and the sun are all plentiful and renewable resources. The thesis of this research is that these resources, if effectively harvested and managed, are sufficient to provide a sustainable support system for cold climate housing - reducing reliance on fossil resources (energy and groundwater), while making better use of forest resources. Products and technologies to harness and use these resources are available. However, putting them together requires an integrated approach to building design and engineering. The project is designed to illustrate this integration at the residential scale and to validate systems performance.

For this research a building the scale of a contemporary double car garage/workshop (Fig.1) has been designed and constructed to house the potable

rainwater and renewable energy systems. The project also showcases small diameter log products (SDL) advanced construction methods. A primary objective is to introduce and build acceptance of these sustainable products and show how they can be integrated into the contemporary housing market.



Figure 1: Carriage House South Elevation

The building, called the Carriage House, is located adjacent to a model residence designed for research and demonstration of innovative forest products, on the grounds of the USDA Forest Products Laboratory in Madison Wisconsin, USA. Together, the Research/ Demonstration House and the Carriage House, a matching secondary building, typify a house in the suburban upper Midwest region of the USA. By combining state of the art renewable energy technologies and innovative rainwater harvesting systems, the research evaluates whether net-zero energy and optimal rainwater use is achievable in a cold climate. The cost, efficacy and reliability of these systems are being evaluated while their potential is demonstrated.

#### **BUILDING DESIGN AND PERFORMANCE**

The frequency and devastation of large forest fires have necessitated changes in the management of forest resources in the USA. Essentially, forests are being cleared of smaller understory trees to prevent them from laddering fires to the larger trees. This new management strategy has increased the availability of small diameter logs (SDL). Incentives for producing products made from SDL are needed and the Forest Products Laboratory is leading in this market development effort. The Carriage House is a small part of this program and was designed to showcase the use SDLs and SDL products in the construction.



Figure 2: SDL Wood Frame during Construction



Figure 3: Interior SDL Structure and T&G Roof Decking

The following section addresses: 1) the integration of the SDL structural system with contemporary construction 2) the passive solar design response to cold sensitive systems that will be housed in the space, 3) the renewable energy systems employed and 4) the rainwater harvesting and management systems.

**Structural System and Assembly** The structure is made from SDL log columns and trusses. Figs. 2 & 3 depict the building frame during construction. The Building Cross-Section in Fig. 4 details the solar sunspace and location of the cistern. The infill walls use traditional framing and insulation systems. The SDL trusses are exposed on the interior and a laminated T&G decking also made from SDLs forms the roof system.

Construction Systems and Assemblies as simulated: FOUNDATION

Concrete grade beam on piers with  $1\frac{1}{2}$ " R7.5 rigid perimeter insulation vertical on the grade beam and 2'-0" to the interior under the concrete paver flooring.

# STRUCTURE

SDL 6" Diameter Posts and Trusses with custom ¼" steel plate connectors.

WALLS

Wood-Plastic composite siding, Tyvek building wrap, 2" Hunter H-Shield-NB rigid insulation with nailable sheathing R9.1,  $\frac{1}{2}$ " OSB structural sheathing, 2x4 framing in between the structural posts with R-13 fiberglass batts and  $\frac{1}{2}$ " gypsum board.

#### ROOF

Shingles, 3½" Hunter H-Shield-NB rigid insulation with nailable sheathing R 19.1, ½" OSB structural sheathing, 2x4 SDL laminated T&G decking.

# WINDOWS

Vinyl covered wood, fixed and operable; south windows (interior & exterior) have double pane clear glass, other windows have double pane low-e glass.





Building Performance The Carriage House is an unoccupied space; the interior temperature does however

need to be remain above freezing due to exposed rainwater disinfection system inside. CALPAS3 hourly simulation software with the generic COLD.GMY weather file was used to assure the building would remain above freezing in winter[1]. This program was selected because it will simulate the impact of the attached sunspace as a heat source for the building. The model was adjusted to reflect the materials actually installed and to optimize the design for the desired performance (interior temperature not below 35 degree F/1.7 degrees C).

The building was first simulated like a utility building without insulation and minimal windows and then insulation, south windows and the sunspace were incrementally added to the model.

Building parameters were adjusted as noted in Table 1 for these various simulation schemes:

- A: Base case building without insulation in the walls, roof or foundation; omit south windows (at party wall to Sunspace); omit Sunspace (party wall to sunspace modeled as exterior wall).
- B: Building without insulation in the walls, roof or foundation; include south windows; omit Sunspace.
- C: Building without insulation in the walls, roof or foundation; include Sunspace.
- D:Base building as-built with insulation; omit south windows and Sunspace.
- E: As-built with insulation and Sunspace

	Insulation [U] Values			[Btu/°F•Ft <sup>2</sup> •Hr]	
	Wall [U]	Roof [U]	Fdn [F2]	Wdw Clr [U]	Wdw Low-E[U]
Α	0.2669	0.2483	0.73	N/A	0.37
В	0.2669	0.2483	0.73	0.49	0.37
С	0.2669	0.2483	0.73	0.49	0.37
D	0.0431	0.0432	0.70	0.49	0.37
Е	0.0431	0.0432	0.70	0.49	0.37

Table 1: Scheme Parameters

Table 1 delineates the insulation values of wall systems and materials installed. Clear glazing is used on the South Elevation and Low-E glazing elsewhere. Heat pump heating was modeled in the simulation and no cooling was required. When modeling the sunspace, direct gain through the south windows of the sunspace party wall is not included (See Fig. 4).

Installing 32 square feet of clear-glass south facing windows produces a 7.5% improvement in building performance. Converting the windows to an attached sunspace with 163 square feet of glazing and a temperature operated fan to heat the building, Scheme C, produces a 10.9% (1,247 KBtus) improvement over the base case. Scheme D models the building with the insulation added as installed and at 61.3% (6,160 KBtus) creates the greatest jump in building energy performance.

However adding the sunspace and insulating the building creates a synergistic improvement of 80.5% (9,231 KBtus) over the base case building which is greater than the additive improvements would indicate. See the graphs in Figs. 5 and 6.



Figure 5: Monthly KBtu's Used for Heating



# **RENEWABLE ENERGY SYSTEMS**

Two renewable energy systems are being employed and evaluated. One is a 3kW roof integrated photovoltaic (PV) array that is mounted on the south facing roof is shown in Fig. 1. Power is conditioned with a 3600w inverter. The electricity will be metered back into the local utility grid taking advantage a PV installation incentive program. The PV system sized to power the plug loads of a typical residence.

The second renewable energy system, housed in west bay of the Carriage House, is a wood pellet gasification/ electrical generation system called a BioMax. This 5kW household scale system uses waste wood products to produce electrical energy and heat. It will supply supplemental electrical power to the Research/ Demonstration House.

Together, these renewable energy systems can produce enough electricity and heat for a reasonably efficient residence in a cold climate like Madison. Wisconsin; demonstrating the net-zero energy potential for this region. Fig. 7 shows the systems and equipment locations.



Figure 7: Carriage House Floor Plan

#### **RAINWATER HARVESTING & MANAGEMENT**

Rainwater harvesting is coupled with the municipal water supply system to have a secure and reliable water supply for typical household water needs. Most of the water can be supplied by the harvesting system.

Both the literature and vernacular examples have validated the efficacy for using rainwater for all typical household uses. In cold climates like Madison, Wisconsin irrigation needs are limited, therefore, harvested rainwater can be managed for the potable and non-potable uses. Non-potable uses including: washing clothes, flushing toilets [2], and bathing. Potable uses of rainwater have been shown to be viable with disinfection and quality monitoring.

Any comprehensive rainwater harvesting and management program must consider the climate, physical and site constraints, and technical considerations including water quality and local regulations. All will have an impact on system design.

The duration of storage in a cistern coupled with first flush systems, which diverts the first few gallons of catchment runoff, have been shown to produce water with quality measures that meet or exceed municipal drinking water standards. However, disinfection technologies are recommended for potable use of this water. Disinfection methods includes: thermal [3], chemical (chlorination), ultraviolet treatment [4] or a combination of these.

The water harvesting systems in this project demonstrate state of the art technologies for utilizing rainwater to offset municipal water demand and potentially provide all household water needs in emergency situations, providing a level of water security. Average total household use (family of 3) in Madison is 192 gallons (0.73 cubic meters) per day [5]. On an annual basis this is 70,080 gallons. The rainfall harvest potential for his project's 3,200 square foot (297 square meters) house approx 61,835 gallons (234 cubic meters) annually given Madison's 31 inches (0.79 meters) average annual rainfall [6]. Thus, effective management of rainwater harvest could supply over 75% of the water demand for a family of 3 in Madison. See Fig. 8.



Figure 8: Rainwater Harvest Potential by Number of Persons in the Household

The rainwater management systems in this residential demonstration project are designed to address potable and non-potable uses separately.

Non Potable System This system was designed and configured to be compact for installation inside the house's garage. The close proximity to the laundry area and W.C. facilitated connection to these non-potable uses. It includes a 300 gallon tank that stores rainwater from a portion the adjacent roof. The tank is fitted with an overflow for excess rainfall. The control system includes a demand activated pump and relayed valve connection to the municipal supply with appropriate back flow prevention. A low water level sensor in the tank connects to the control relays. When rainwater in the tank falls below the sensor level the control system closes the tank input valve and opens the valve from the municipal supply. This system is designed to be useable in areas where rainfall frequency does not provide a reliable supply.

**Filtration/Disinfection System** The main cistern (2,500 gallons, 9.5 cubic meters) is located under the east bay of the Carriage House. The feed from the rooftops are equipped with first flush devices. This rainwater collection system was specifically used to determine the efficacy of producing high-quality water via a point of use (POU) water treatment device. In this project, two types of first flush devices were used. The first device was a simple bypass unit that collected rainwater until it was full upon which water was diverted to the storage

container. This device diverted approximately 75 L of rainwater and was manually drained after each rainfall event. The other device was a ball valve assembly that allowed initial roof drainage to bypass the storage tank until the ball in the assembly filled with water and closed the diverter. The bypass volume ranged from 40-80 L for a given precipitation event. After the ball drained completely via a small pinhole, the diverter would spring open for the next rain event.

The point of use filtration/disinfection system was assembled from off the shelf filtration and UV disinfection units as shown in Figs. 9 & 10. The components of which included a typical pressure pump/tank system, a 20-micron spun polypropylene progressive-density cartridge filter (Pentek, PD 25-20 POLYDEPTH<sup>®</sup>), a 20 in. 5-micron spun polypropylene progressive-density cartridge filter (Cole-Parmer), an activated carbon impregnated paper cartridge filter (Pentek, C1-20), and a high capacity ultraviolet sterilizer (WaterGroup Companies, Inc., PURA® UV20-1). The UV20-1 model is equipped with a 22 watt UV lamp. These components are mounted on a board as part of an interpretive display (Fig. 10). For system test results see [10].

Point of Use water treatment systems similar to the one used in this project have been demonstrated [6,7,8,9] to be an effective and practical option for purifying water against known bacterial, viral and protozoan pathogens. These purifiers have been demonstrated to clear 99.9% or more of bacterial, viral and protozoan contaminants. Linden et al. showed effective inactivation of protozoan cysts when treating a variety of water sources with a low UV dose similar to that imparted by our UV disinfection unit [11].



Figure 9: Rainwater Disinfection System



*Figure 10: Water Filtration System as Part of Interpretive Display.* 

**Other Rainwater Quality Considerations** Research has shown that the quality of roof harvested rainwater depends on many factors. Water quality in rainwater management systems starts at the rainwater catchment surface and continue to the storage tank and on to the filtration/disinfection unit.

The roof surface material is very important. Reflective roof coatings should have a potable use rating (NSF International, 2007). NSF International has developed a protocol that tests materials used in rainwater catchment systems. Testing involves exposing catchment system products (i.e. roofing materials, coatings, paints, liners and gutters) to extensive accelerated outdoor weathering. Products meeting the requirements of this protocol are deemed not to impart contaminants to test waters at levels greater than those specified in the U.S. EPA's Drinking Water Regulations and Health Advisories. It is advised, however, that rainwater harvested from newly roofed buildings should be tested periodically before processing for potable use. Asphalt shingles and zinc plated roofing systems, for example, produce undesirable residuals for some time after installation. Lead flashing should be avoided. Care should also be taken to clear the catchment surface of any debris, including litter from overhanging plantings and biological waste from birds as they are the primary deposition pollutants in roof rainwater harvesting systems. It is also recommended that the catchment surface be cleansed from time to time to prevent build up of particulate debris from local air pollution, including dust and residuals from automobile and industry. Leaf litter can be managed with plant maintenance, where as dust, air pollutants, and animal waste should be addressed by means of a first flush system. Many devices have been developed for achieving first flush, most are viable but all require continued monitoring and maintenance. It is also recommended that the outlet of the cistern should allow

for at least six inches of sludge settling. Regular tank cleansing and maintenance is also recommended.

Perhaps the issue of most concern for potable use of harvested rainwater is maintenance and monitoring of the filtration/disinfection unit. It is not uncommon to see heterotrophic regrowth in these Point-of-Use devices [7, 12]. We plan to alleviate the regrowth of heterotrophic bacteria by constantly bleeding a portion of the filtered water back into the cistern to prevent filter fouling. The other option we will use as necessary is to disinfect the unit with monochloramine.

#### DISCUSSION

Residential Photovoltaic systems are becoming more affordable, through incentives and acceptance. Energy efficiency in building envelope design is recognized as an essential part of the sustainable energy equation. Together they provide the opportunity for moving closer to net-zero energy at the residential scale. Advances in building energy modeling and cost reductions in PV are helping to move these technologies into the mainstream. Yet, many remain skeptical or do not understand how these work together. This project is accessible to the public and is designed to help bridge the gap between research and application.

Rainwater harvesting and use has even older roots in the traditions of the region. But its acceptance as a viable, secure source of water is questioned. This project is designed to showcase how technology can bridge between the traditional use of rainwater and a contemporary source for residential water needs whether for irrigation, nonpotable household uses and even potable use with careful development and management of the filtration/ disinfection system.

Finally, climate change has placed challenges to our perception of how we manage forest resources. A shift in forest management strategy has created a new resource in woody biomass from the slash and small diameter logs that may be processed into useful forest products. The slash can be used in new technology like the BioMax for heat and energy production and the products from SDLs should be developed and integrated into the building industry instead of being wasted.

Showing how these systems work and can be effectively integrated through collaborative design, engineering and technology development is an essential part of this effort. The Research/Demonstration facility at the USDA, FS Forest Products Laboratory will help interpret this idea.

#### CONCLUSION

This project has shown that the integration of building systems with renewable energy and rainwater harvesting systems can achieve net zero energy and supply nearly all of the water needs for a residence in cold climates like that of Madison Wisconsin. As the interest in sustainability increases and technologies such as those shown and evaluated in the project become more available and acceptable, the payback periods for such fully integrated sustainable systems will becoming shorter. More importantly the impact of this project is expected to be in demonstrating the possibilities and potentials, for the development of sustainable energy and water at a residence even in the cold winter conditions of the upper Midwest.

**ACKNOWLEDGEMENTS.** This research and development project was made possible through a cooperative agreement between the University of Arizona (UA) and the USDA, FS, Forest Products Laboratory (FPL). Technical support was provided by the UA National Science Foundation Water Quality Center.

#### REFERENCES

1. Berkley Solar Group, (1984). CALPAS3 V3.12, Building energy computer simulation software.

2. A, Fewkes, (1999). The use of rainwater for WC flushing: the field-testing of a collection system, *Building and Environment*, 34: p. 765-772.

3. Birch, J. D., K. E. Thomas, (1998). Water disinfection for Developing countries and Potential for Solar Thermal Pasteurization, *Solar Energy*, 64:p 87-97.

4. Abbaszadegan, M., et.al., (1997). The disinfection efficacy of a point of use water treatments system against bacterial, viral and protozoan waterborne pathogen, *Water Resources*, 31:p 574-582.

5. 2001 Annual Drinking Water Quality Report, Madison Water Utility, Water Quality Section, June, 2001

6. Average rainfall calculated from Madison, Wisconsin 1960-1995 rainfall data, National Climate Data Center. www.ncdc.noaa.gov/oa/ncdc.html

7. Adams, V., G. D. Harris, D. L. Sorenson, and M. S. Curtis. (1987). Ultraviolet inactivation of selected bacteria and viruses with photoreactivation of the bacteria. *Water Resources*, 21:p 687-692.

8. Wolfe, R. (1990). Ultraviolet disinfection of potable water. *Environmental Science and Technology*, 24:p. 768-773.

9. Pozos, N., K. Scow, S. Wuertz, and J. Darby. (2004). UV disinfection in a model distribution system: biofilm growth and microbial community. *Water Resources*, 38:p. 3038-3091

10. Jordan, F. L., R. Seaman, J. J. Riley, M. R. Yoklic, (2008). Effective removal of microbial contamination from harvested rainwater using a simple point of use filtration and UV-disinfection device. *Urban Water Journal*, 5:3 p209-218.

11. Linden K. G., Shin G., and M. D. Sobsey, (2001). Comparative effectiveness of UV wavelengths for the inactivation of Cryptosporidium parvum oocysts in water. *Water Science and Technology*, 43:p. 171-4.

12. Morin, P., A. Camper, W. Jones, D. Gatel, and J. C. Goldman, (1996). Colonization and disinfection of biofilms hosting coliform-colonized carbon fines. *Applied Environmental Biology*, 62:p. 4428-4432