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Integrated Multisource Renewable Energy System Design: A Student Project

Dr. Herbert L. Hess, University of Idaho, Moscow
Dr. Brian K. Johnson, University of Idaho, Moscow

Brian K. Johnson received the Ph.D. degree in electrical engineering from the University of Wisconsin-Madison in 1992. Currently, he is a Professor in the Electrical and Computer Engineering Department, University of Idaho, Moscow. His interests include power electronics, power system protection, and power systems transients. Dr. Johnson is a registered professional engineer in the states of Idaho.

Mr. Rishabh Jain
Amrit Dahal

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Abstract

Project GREEN (Going Renewable, Energy Efficient Naturally) is a senior engineering student design project designed to create a sustainable energy system for a youth camp. By combining various electrical energy sources (solar, hydro and wind), as well as geothermal units and biomass for heat, the camp can provide its own energy to run with minimum draw from the Grid. The system will nearly offset the peak demand of the building of concern. Because this design levels the camp's enormous demand charges, the electricity bills will be reduced by more than half.

Introduction

The director of a YMCA camp in Cascade, Idaho, is considering a commitment to appropriate forms of on-site renewable energy as its primary source. The load is strongly summer peaking. The camp's main multipurpose building, named The Barn, has the heaviest, but representative load. Water heating is the most significant load of the building. Therefore, making The Barn "green" was selected as a pilot project. Figure 1 shows the power usage both at the campsite for The Barn and for the total campsite. Reducing the electrical energy draw from the public utility creates significant savings, not just for the energy bill, but also by reducing the demand charge. It lays the groundwork for creating a demonstrator self-sustaining community with net energy independence.

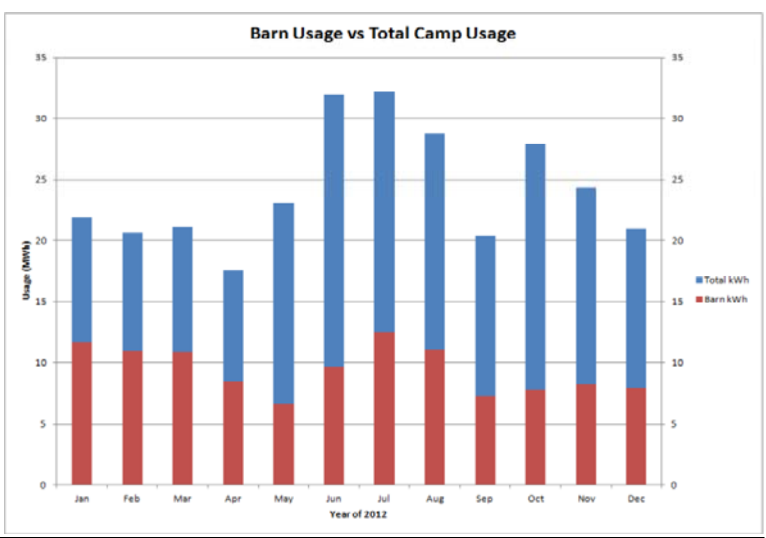


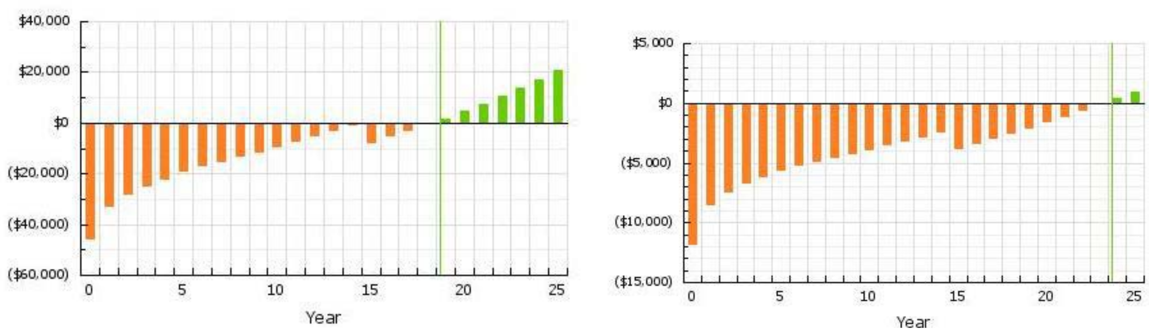
Figure 1. Energy Consumption at Camp Site

Energy Sources

Cascade is located in the mountains at an altitude of 1650 meters above sea-level, with deep geothermal resources, near a desert, and with significant wildlife and vegetation. The whole Cascade area is ripe for harvesting energy from various sources.

Electrical Power Sources

Various renewable sources can replace consumption from the grid, supplanting both energy draw and power demand. *This will reduce the electric bill significantly.*
Solar- The solar energy available in the Cascade is about 4-5 kWh/m^2/day. With a solar panel efficiency rating of 15%, this provides about 0.6-0.75 kWh/m^2/day. With a two-decade rated life, most solar panels are a viable source of energy for this application with little maintenance. The load is strongly summer-peaking. More than 90% of the camp's energy consumption occurs in 110 days between mid-May and Labor Day. Due to the high latitude, more than 70% of the usable annual solar irradiation occurs in this period. This yields an available solar irradiation to about 700W/m^2/day while the camp is in operation. A cost estimate was done between a 50kWh/day system covering about 130 m^2 and a 10kWh/day system covering about 25m^2. The total costs and estimated payback periods of using the two solar panels systems is shown in Figure 2. This present value payback estimate includes an inverter replacement at year 15, lengthening the payback period. Manufacturer-estimated maintenance is included. By year 19, the 50kWh/day system pays itself off; By year 25, $20,000 annually will be saved, almost half of the acquisition cost. Conversely the 10kWh/day/ system pays itself off by year 23 and saves about $1000 by year 25. Available space for installation of solar panels strongly influences this decision.[1,2,3,4,5,6]



(a) (b)

Figure 2: Payback Period for (a) 50kWh/day and (b) 10kWh/day Solar Power Systems.

Hydro – Hydroelectric generation is considered to be a very efficient source of electrical power. Horsethief Reservoir is a local artificial lake that abuts the camp. The reservoir has both the water volume flow (0.07m^3/s) and elevation drop (20 meters) sufficient for continuous microhydroelectric power generation. Penstocks are already in place as part of overflow management. Placing generators in tandem where maximum energy transfer occurs also minimizes ecological impact in this case. A manifold design provides scalability and flexibility. Figure 2 shows the total present value costs, including manufacturer-recommended maintenance, and paybacks associated with different scalability. As shown in Figure 3, a positive payback in thirty years requires at least three units.[7,8]

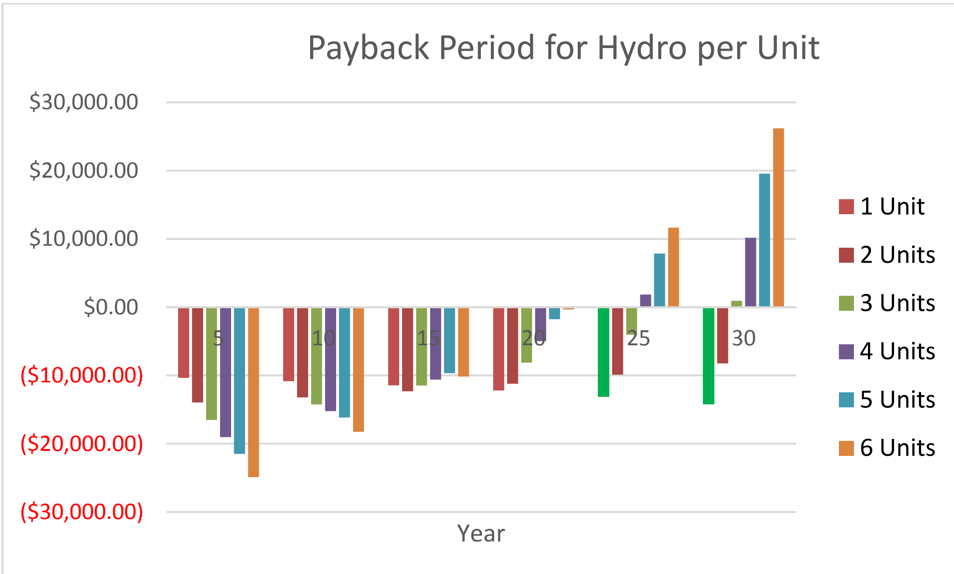


Figure 3: Payback Period for Multiple Unit Hydro Power Generation Systems.

Wind- The camp is located in a canyon, shielding it from prevailing winds, like much of the developed portion of the region around it. This makes wind an impractical source for generation. Figure 4 shows that a 5kW turbine, when considering a present value amortization of its economics, doesn't pay itself back during its rated life. However, most of the children who use the camp have seen the many wind turbines that dominate the local countryside. A wind turbine is therefore included for educational purposes. A weather station was also installed on the roof of the Barn, to get the wind speed data for Summer.[1,2,9,10]

Local geothermal hot water does not contain sufficient energy for electricity generation. However, it does provide opportunities as heat. An available and abundant biomass is also a convenient heat source.

Geothermal-A natural underground reservoir near the camp site produces hot water at about 95°F. This temperature is too low for an efficient thermal power plant, but it works well to heat the living space. Unfortunately, the incumbent geothermal well is too far from The Barn even for space heating. A student advanced the idea of a greenhouse based on geothermal heating as shown in Figure 5. A greenhouse can produce food for the kitchen, providing educational activities and a sustainable foot source. A detailed design indicated that this is a feasible and economical use of the geothermal resource. [11,12,13]

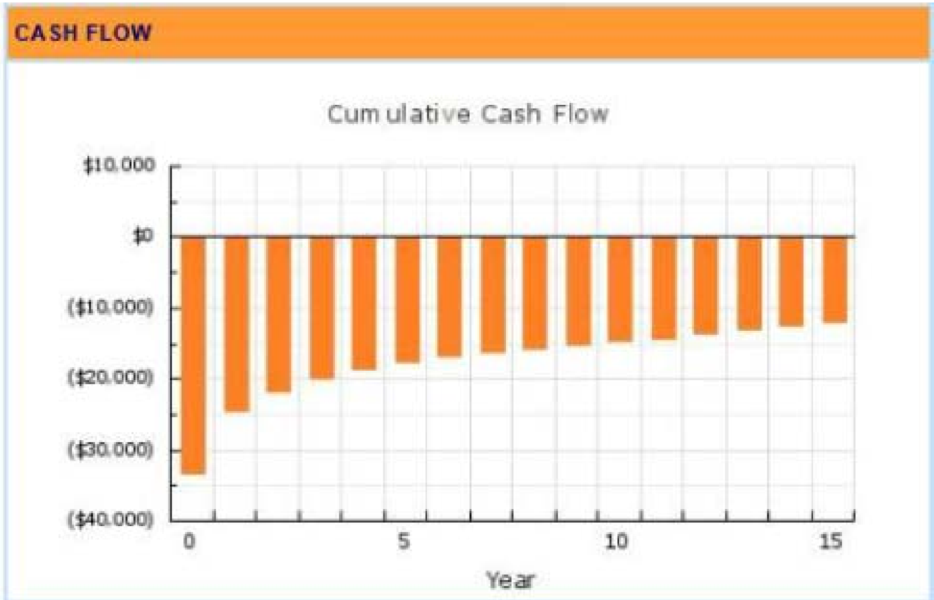


Figure 4: Cash flow of a 5kW wind turbine.

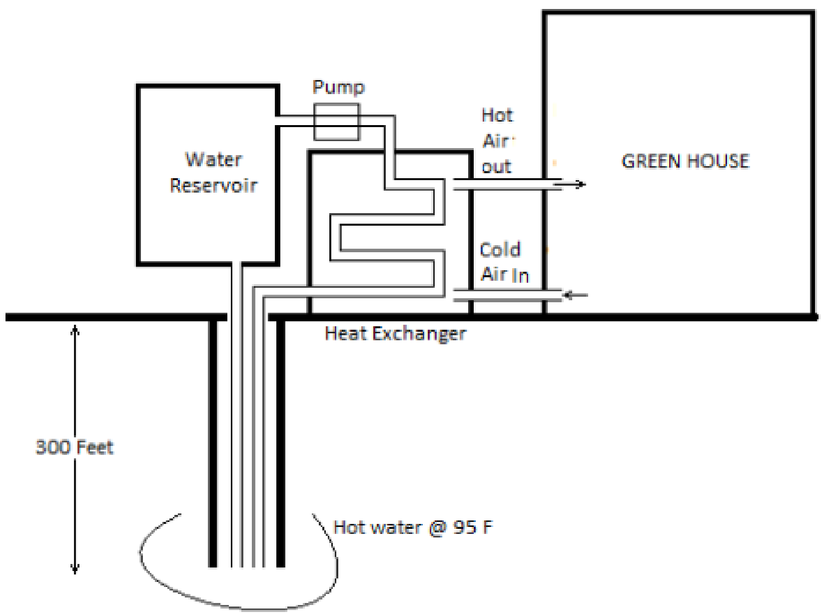


Figure 5: Proposed Geothermal Transfer

Biomass- The YMCA Camp must safely appreciate its abundance of trees. Careful and regular trimming produces a great deal of softwood slash, a superb quality biomass. An average of 360kg/day of wood yields an estimated energy of 3,700,000kJ/day. For the average consumption of 5500 gallons of hot water per day, this would provide more than enough energy for a 60°F rise in temperature. An integrated water heating system begins with a heat exchanger to capture heat from the geothermal source. Then, the biomass unit further increases the temperature of this hot water to suitable levels for showering and cleaning. Smoke from a biomass unit is considered by some to be a source of air pollution. However, recent technological advancements provide nearly smokeless operation in a modular design. Biomass may also produce electricity. In the situation at hand, the heat is the more valuable output. Heat from biomass is less expensive, so it can replace or supplement the incumbent electric hot water heaters. As an added bonus, the ashes left behind have good use as fertilizer and pest repellent. [14,15, 16]

Demand Charges

Public utilities charge their commercial customers for the energy consumed. For commercial and industrial customers, utilities add a demand charge, a billing component based on the greatest 15-minute rolling average power consumption within the billing period. The YMCA Camp drew its electric hot water for showers and cooking. These activities occurred within a narrow time window every morning and afternoon during camping season. As a result, the demand charge on the electric bill rivaled and often exceeded the energy charge. Biomass-based hot water displaces electric hot water, saving both energy charges and demand charges. If the biomass fully replaces electric hot water as designed, the savings is more than half of the annual $27,000 electric bill.[17]

Team Process

Based on the sponsor's written survey of local resources and loads, team initially verified the task at hand. In the third week of the project, the team visited the YMCA camp. The team inspected, recorded, and analyzed energy bills from 2012, the only year since recent major construction, to understand nature of the load. Measurements of water flow from the nearby Horsethief reservoir overflow pipe, architecture plan of the building, operation timings, architecture details and surrounding transformer datasheets were recorded. Annual solar irradiation, rainfall and other environment based details were obtained from the concerned government agencies. Then, each team member was assigned as coordinator of one of the resources. The project would be collectively designed and all students will participate in every resource assessment and design. However, the coordinator will make the final decision for the respective resources. Therefore, the students researched in depth about their key topics, discussed them with the team members, and each gained leadership and management experience.

Total Costs and Benefits

Estimated costs of installing the various systems presented in this article are presented in Table 1. These retail cost estimates are typical of installations of this size. However, over time their benefits grow. As seen in Figures 1 and 2, solar and hydro power will save a lot of money after several years. As described previously in this paper, biomass-based hot water replaces electric hot water, saving more than half of the annual $27,000 electric bill. Payback is about eleven years, a number typical of renewable energy projects or perhaps slightly less than average. This calculation doesn't include the annual savings from demand charges of $12,000 or more. The only system in this project that does not pay for itself is the wind turbine.

Table 1: Installation Costs

System	Cost
Solar	$56,000
Hydro	$38,000
Wind	$10,000
Geothermal	$30,000
Biomass	$9,400
Total	**$143,400**

For payback calculations, the time depreciation in the value of money has been considered using standard tables. Additional maintenance charges are involved based on the manufacturer recommended duration before repairs/other maintenance. The YMCA and the City of Cascade are tax-exempt organizations. Therefore, tax credits were not considered in the analysis.

The team of students performed this design for their senior electrical engineering design capstone project. All of the data collection, design, and analysis was completed by students. They wrote up a full commercial design proposal and presented it to the YMCA Camp and the City of Cascade, Idaho on May 2, 2013.[18] The proposal was enthusiastically received. Funding was arranged for installation to begin the following fiscal year. However, in the final stages of the budget process, the project was tabled for a year. It now awaits funding.

Assessment

The project had great expectations of being funded. Unfortunately, its funding was tabled for at least a year, so a detailed assessment of the effectiveness of the technical design itself is not yet possible.

The pedagogical effectiveness is another story. One could quote the students' enthusiastic comments about the project and the learning that they experienced. The assessment of the design's technical merit by the sponsor and the City of Cascade's engineering and political leaders was most encouraging. Post-graduation results show more effectively the real value of the project as a learning vehicle Did this project really inspire them to continue into renewable energy design or did they depart from it?

The six students on the project[18] made the following decisions for their immediate post-graduation endeavors:

1. Post-graduation employment at a renewable energy consulting company.
2. Post-graduation employment at a generator manufacturer.
3. Graduate school in renewable energy.
4. One more semester remaining to finish a baccalaureate degree; future beyond that undecided.
5. Post-graduate employment at a protection and relaying manufacturer as a designer of protection for renewable energy systems.
6. Graduate school in power electronics.

One could reasonably conclude that the project was a pedagogical success for most of the students who participated.

K-12 Outreach

Because the camp is a children's camp, outreach to K-12 is an important and obvious part of the endeavor. The YMCA plans to make the energy system, when eventually built, an integral part of the K-12 education program of the camp. That is under their design, implementation, and supervision and, therefore, a project for the future and beyond the scope of the engineering part of this project. To help with teaching K-12 students, the engineering students did build a small (1 meter by 1 meter) interactive, hands-on mockup of the system. That is the subject of a future paper.

Conclusion

A YMCA camp in the mountains near Cascade, Idaho, wants to commit to renewable and sustainable energy sources. Solar photovoltaic and microhydroelectric generation provide such renewable sources to produce electricity. Geothermal and biomass are best employed to yield heat energy to displace electric hot water. A well-designed system reduces energy draw from the public utility and cuts the utility's demand charges, saving a lot of money. The goal of zero net draw from the public utility is within reach. Combining various renewable sources optimally makes the camp not only self-sustaining, but educational. The Barn and the YMCA Camp itself provide an ideal palette for creating promoting a sustainable energy picture.

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