SOLAR-POWERED HOUSING FOR EMERGENCY/DISASTER RELIEF

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ABSTRACT: Hurricanes "Katrina" and "Ivan" exposed critical weakness in energy supply in the U.S. disaster response system. This paper will discuss the concept of solar-powered modular housing for nation-wide disaster relief. Auburn University has performed a design study that demonstrates feasibility of the concept. Now the plan is to build two 398 ft^2 "Katrina Cottages", equip them with solar hot water heating, 2 kW of solar electric panels, and a battery storage system to demonstrate housing for disaster responders and refugees. These units would be inhabited, installed at two locations in Alabama, and have a smart control system that maximizes energy use with minimal wasted energy and be monitored for one year. Combined with federal and state tax credits, the units will demonstrate a viable business. This paper will discuss energy payback time, stand-alone operation, system effectiveness and economic viability. Performance projections and lifetime financial analysis will also be presented.
Keywords: Stand-alone PV systems, Energy options, Solar Powered Housing

1 INTRODUCTION

Hurricanes "Katrina" and "Ivan" exposed critical weakness in energy supply in the U.S. disaster response system. In the Katrina hurricane in 2005, power was lost for months in many areas of New Orleans and furthermore the disaster response teams had a limited number of diesel generators to supply their own power needs. Furthermore the fuel for these generators was expensive and, as a bottom line, the electricity that was generated cost about $1.00/kWh. The same was true to a lesser extent with Ivan striking Houston in 2008 due to improvements in the disaster response system. However, in both cases, no housing was readily available for displaced families or emergency responders. As a result of Katrina, the Federal Emergency Management Administration awarded $388M for Gulf Coast states to propose housing and other remedies for this omission. Mississippi received $288M and developed the concept of a "Katrina Cottage" to house residents temporarily. About 7,000 of these cottages were built.

This paper will discuss the concept of installing solar power on these Katrina cottages for nation-wide disaster relief (Fig. 1). This upgrade takes the form of a stand-alone solar powered cottage that can house first responders and/or displaced residents after a severe naturally disaster. The scope of activities includes solar energy system design, systems modeling, intelligent controls and testing, and consumer education. This paper describes a design study that demonstrates feasibility of the concept. Energy payback time, stand-alone operation, system effectiveness, and economic viability will be discussed. Performance projections and lifetime financial analysis will also be presented. The model used at the Space Research Institute is called PV-Design Pro-S and G v. 6.0. This tool is exceptionally versatile as shown in Fig. 2. The "S" is used for a stand-alone

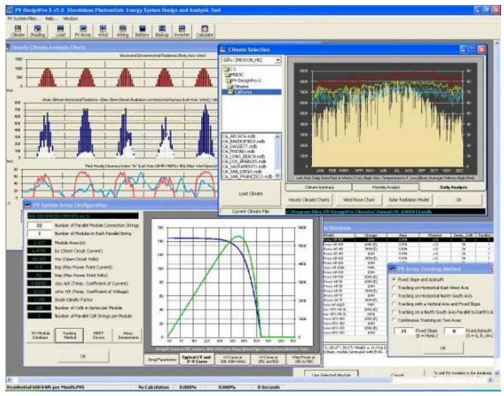

Figure 2: Screen shot examples of the PV Design Pro-S photovoltaic energy system

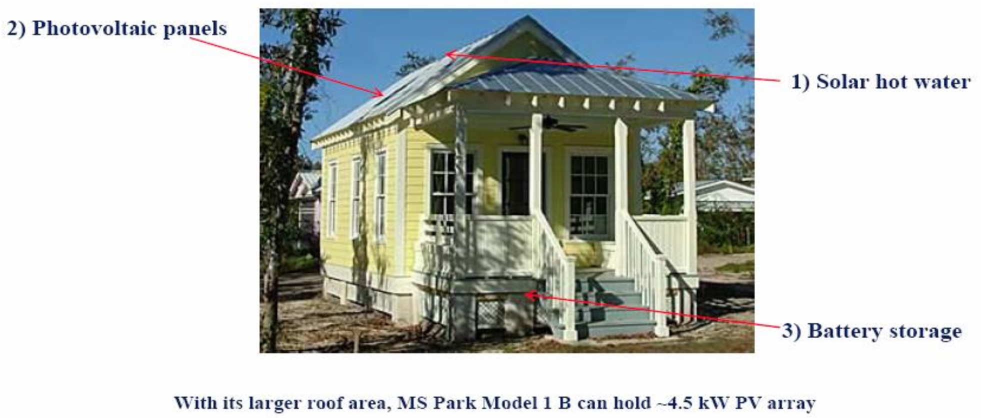

Figure 1: Katrina Cottage Park Model 1 B

system and the “G” version is used for a grid-connected system.

This concept has the potential to develop new emergency housing products that will enable better disaster responsiveness of the nation. Success will lead to retrofitting many existing cottages and enable the development of “mini-grids” for a power system. This initiative can serve as a model for the use of photovoltaics (PV), solar hot water heating and energy savings on dwellings and facilities across the U.S. This project also has the potential to stimulate the marketplace for photovoltaic power and provide new, low cost solar installations with innovative systems controls which will help reduce U.S. use of foreign oil. It is possible and practical now due to the energy crisis, fuel costs, weather instability, and PV explosive growth. In addition, because the Park Model 1A can be installed virtually anywhere, it is suitable for housing first responders at virtually any disaster in the country including floods and earthquakes.

2 BACKGROUND

In the last three years, an amazing upsurge has taken place in the use of cost-competitive photovoltaic technologies for terrestrial applications. Because of the existing 30% U.S. Government tax credit for installing photovoltaic (PV) and/or solar hot water systems coupled with tax incentives in a few states, the use of solar technologies on dwellings and facilities is increasing and this is helping reduce the U.S. reliance on foreign oil and also the need for new power plants fueled by coal or oil. However, even with these incentives, most states in the U.S. lag behind Europe and Asia in implementing solar technologies for new distributed, stand-alone applications, grid-connected systems and in consumer education. The limitations that exist in many states could be mitigated by demonstrating the many opportunities of solar power and how a cost-effective strategy could be implemented to accelerate the use of photovoltaic and other solar-based power systems.

One major opportunity exists in supplying energy and housing for emergency first responders in a disaster scenario and in housing displaced residents. In the wake of Hurricane Katrina and Ivan we have seen the devastation that can occur during and following an extreme act of nature. How much better could the situation have been if our first responders had appropriate housing and power readily available? Using the existing PV knowledge base we are developing a new strategy to enable solar to help offset our dependence on foreign oil while making the nation better prepared for disaster relief. This effort is directed toward solving the critical weakness in energy supply in the U.S. disaster response system that was exposed by Hurricane Katrina. Energy crisis, fuel costs, weather instability, and PV explosive growth make this possible and practical now. The present cost of PV electricity in the U.S. is approximately 16-18¢/kWh. Module prices are decreasing (see Fig. 3), the silicon supply is recovering, and the DoE expects the nation will achieve grid parity by 2012.

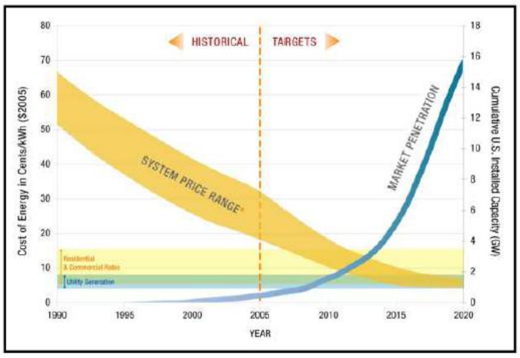

Figure 3: PV System price range with market penetration (DoE)

3 KATRINA COTTAGES

U.S. Department of Homeland Security in September of 2006 started an alternative housing pilot program to identify and evaluate alternatives to and alternative forms of FEMA disaster housing. The Alternative Housing Pilot Program encouraged innovation and creativity. It sought alternatives that could be produced, transported, and installed in a timely manner, and in quantities appropriate to meet the projected needs of a catastrophic disaster situation. These alternatives needed to be adaptable to a variety of site conditions with minimal requirements for site preparation. This housing solution would facilitate sustainable and permanent affordable housing. The modular Park Models and Mississippi Cottages developed by the State of Mississippi were superior to all other proposals that were submitted to FEMA. Four different styles were proposed: Park Model 1A, Park Model 1B, a 2-bedroom Mississippi Cottage, and a 3-bedroom Mississippi Cottage.

The Park Model 1A (Fig. 4) has 398 ft^2 of living space, whereas the 1B has 728 ft^2. The major attractiveness of the Model 1 A is that it can be installed in virtually any location in less than one day and requires no special site preparation or licensing. In addition, it can comfortably house up to four people and, as designed, uses energy efficient appliances. The floor plan is shown in Fig. 5. This model is already energy efficient. It comes equipped with Energy Star® appliances throughout; it has an R-11 floor, R-19 walls, and an R-30 ceiling. The windows are vinyl with low-e coatings and the doors are steel energy-savers. Finally there is a 30 gallon hot water heater. With the addition

Figure 4: Park Model 1A Katrina Cottage

of solar power and battery storage energy usage can be reduced and it will be operational after a disaster event where normal power may be out for days up to weeks.

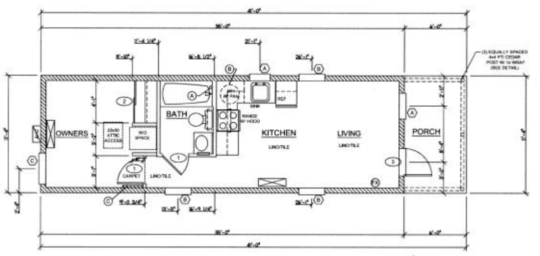

Figure 5: Katrina Cottage Park Model 1A Floor Plan

4 SOLAR SYSTEM DESIGN

First responders' requirements consist of access to power, communications, and water. They need housing from which to function effectively and they need to be able to work effectively without an operating electrical grid. In addition, eliminating noisy and expensive diesel electric generators would be most desirable. There are also the issues surrounding displaced residents – i.e. where can they be temporarily housed and what will be the quality of those living conditions. These issues must be addressed in designing a solar system to be used for disaster relief. Also minimal modifications to the existing cottage design would be important. Putting together several cottages to form stand-alone "community" power is also under review and would be a huge asset in disaster relief.

We took the following design approach for the Park Model 1A Katrina Cottage: First, we added improved insulation, then a solar hot water system. That was the easiest way to save a significant amount of electrical energy and maintain the quality of life desired. Next, we modeled the installation of a 2kW PV system with potential grid connection (when power was restored). The array size was limited by the available roof area and the solar hot water system. One additional benefit of the PV system is that it allows for constant ventilation in storage which will eliminate any undesirable emissions from the building. The PV system also provides the potential to supply energy to the local grid while stored. Furthermore, these units can be united into an energy-efficient community on a mini-grid at either the storage or disaster site. To ensure power at night or in inclement weather, a battery system was installed. The end result was a self-sustaining living space – just add potable water! The design appeared to be cost effective, especially with the addition of an "intelligent control" system that learned to control the energy usage of the appliances that could be based on cost of electricity.

In detail, these system additions include adding a 16 ft^2 solar hot water heating system with the existing 30 gallon hot water heater. This adds ~$3k to the cost but significantly reduces electrical energy. Adding a 2kW photovoltaic power system with a 4kW inverter on a south facing, 30º tilted roof allowed for continuous ventilation in storage, plus excess power. The roof area (210 ft^2) limits the PV system area. If necessary, the PV system can be doubled in size with a shed design roof. The cost depends on the PV modules chosen. Higher efficiency panels increase upfront costs but reduce life cycle costs. Adding a battery storage system allows grid-independent operation plus night power, but would increase the cost by approximately $4k. This type of system provides emergency responders a living place and energy system. The Park Model 1B with its larger roof area holds a 4.5 kW photovoltaic power system (Fig. 1) without modification.

5 ANALYSIS

5.1 DESIGN PRO-G

The analysis of the Park Model 1A Katrina Cottage modified with solar heated hot water and a 2kW PV system on the roof and a small battery storage system has been completed. These additions had a dramatic effect on the business case for these houses.

The solar system modeling program PV Design Pro-G was used to study 21 costal locations subject to hurricanes including Florida, Alabama, Mississippi, Louisiana, and Texas. The Katrina Cottage roof angle was fixed at 30º for all locations. An arbitrary house load totaling 6,330kWh/yr was created. For the purpose of comparison with an emergency diesel-fueled system, a diesel fuel cost of $8.00/gal was used. At this fuel price, the cost of electricity from a diesel-fueled 3 kW U.S. Army Tactical Quiet Generator is $0.72/kWh. However, even at today's price of about $2.35/gal, the cost of electricity drops to$0.20/kWh. For the PV system, the existing 30% U.S. Government solar tax credit was coupled with the existing tax incentives in a few of the Gulf Coast states. With these assumptions, the cost of electricity on the Model 1A was between $0.13 and $0.24/kWh with a payback time of about 4 years and an IRR of 95%.

For the 21 locations studies along the Gulf Coast, a 2.1 kW system supplied 39.9 to 44.4% of the load as shown in Figure 6. The effective cost is approximately $0.241/kWh for a 195 W module costing $899. The cost with no sales tax and a 45% tax credit is reduced to $0.133/kWh. Of course these values will depend upon the cost of alternative fuels that might be available. Thus this study is applicable across the Gulf Coast region.

No attempt was made in this study to maximize the

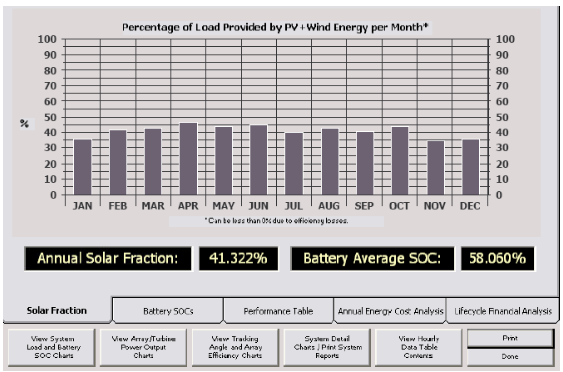

Figure 6: Percentage of load provided by PV

use of electricity by use of a smart control system. The use of solar technologies on dwellings and facilities is increasing due to cost reductions and can lead to new business and tax revenues for interested states. This project can potentially stimulate the marketplace for PVs in Alabama and the Gulf Coast region and provide new, low cost solar installations with innovative systems controls which aid disaster responsiveness and can promote new applications on modular housing.

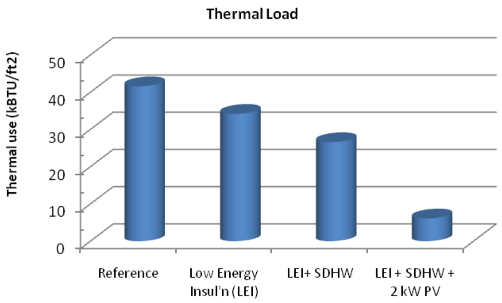

Figure 7: Thermal Load Modeling for Park Model 1A

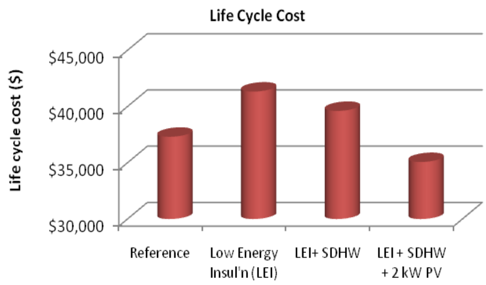

Figure 8: Life Cycle Cost of Park Model 1A

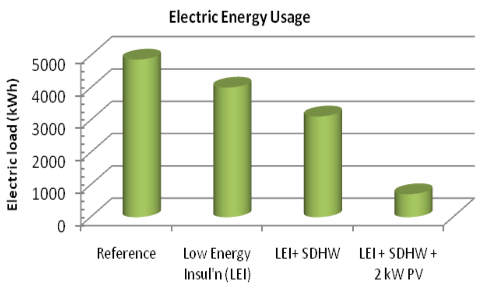

Figure 9: Electric Energy Usage of Park Model 1A

5.2 ENERGY 10

DoE's Energy 10 modeling was completed using the MS Park Model 1 A in Mobile, AL. These energy calculations suggest total electrical energy savings or 104 GWh/yr for 25,000 units. Also 10,000 stored units produce approximately 11 GWh/yr which equates to a savings of $1.6 million at $0.15/kWh price. This can be seen in Figures 7-9 which show the thermal load, electrical energy usage, and life cycle cost for four cases: a reference, a cottage with low energy insulation, one with additional solar hot water, and the final case with the addition of 2 kW PV. These figures show the benefits of installing solar hot water heating and a 2 kW PV system. Fig. 7 shows that each addition of technology reduces the thermal energy load. This in turn makes the house more efficient and reduces the amount of energy that must be supplied from the PV system or the solar hot water. Fig. 8 shows that the life cycle cost increases over the reference case until the PV system is included, then the life cycle cost drops by about 15%. Finally, Fig. 9 shows the significant decline in energy usage with each addition of technology. Total energy usage drops by about seven-fold as shown in Fig. 10.

6 FUTURE PLANS

We plan on building at least two of the Park Model 1A 398 ft^2 Katrina Cottages, equipping them with solar hot water heating, 2 kW of solar electric panels, and a battery storage system to demonstrate housing for disaster responders and refugees. This demonstration will provide a fully functional, grid-independent habitat on arrival at site. These units would be inhabited, installed at two locations in Alabama, and have a smart control system that maximizes energy use with minimal wasted energy and be monitored for one year. Through development of Intelligent System Management software, there can be time-of-day usage control. These cottages would demonstrate options for different usage scenarios: stand-alone operations for first responders, PV grid connected for family living and community benefit, and "clustering" of several units with intelligent control. Total energy production of these units would be monitored and would be compared to model predictions. Cost data and energy benefits would be calculated. Battery lifetime capacity and cycling would also be monitored. This project would demonstrate the benefits to the local community and the power company. Provisions for connection to the grid will also be provided and monitored.

The next step would be to prepare for mass production and to optimize the construction design for manufacturing and systems integration including rapid deployment, efficient conversion from first responder format to residence format, and expansion of unit to add square footage.

Another benefit to this design it that the arrays would provide enough power to allow both constant ventilation and energy to the local grid while they are being stored. Other innovative use of this type of housing can also be envisioned for the local community.

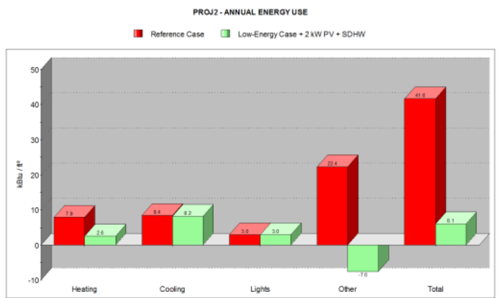

Figure 10: Energy-10 Summary

The active use of these resources would be a huge improvement over the large number of unused trailers being stored in Hope, Arkansas and have a formaldehyde buildup.

Research topics would also include module design and installation for this class of use, inverter reliability, and intelligent home energy management with weather prediction. These new system controls with predictive ability that are integrated with user habits and lifestyle will substantially reduce energy demand from the grid. This project would develop integrated guidelines for installing solar power systems and intelligent house energy controls on new and existing construction to maximize the energy produced. SRI would demonstrate and promote the use of solar technologies across the State and ensure consumer safety and system reliability.

7 CONCLUSION

With this project's unique location, ease of replication of this design and ability to be expanded, this project has the potential to be the prototype for other similar undertakings across not only the state but also the country. Combined with federal and state tax credits, the units will demonstrate a viable business base. The solar powered Katrina cottages would enhance FEMA rapid response/responders. They are fully functional, grid-independent habitats on arrival at site. Disaster response is a critical issue in the Gulf States area. The Katrina cottage baseline makes an attractive option for both housing first responders and subsequently "refugees". The cost is modest for a full system including solar hot water heating, solar electric (photovoltaic) panels, inverter and battery storage system, not to mention pay back times are short. When not in use, the house can be continuously ventilated. We think this is an important addition to disaster responsiveness and would like to demonstrate its potential.