

A Stove-Top Generator for Cold Areas

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Abstract

This paper discusses the development and test of a prototype thermoelectric generator which is designed to use the heat of existing wood fired stoves that are typically used in the area for home heating. This generator is being developed by the Royal Institute of Technology, in Sweden, to provide small amounts of power to homes in the remote northern areas of the country which are beyond the electric grid. The paper will discuss some of the aspects of the generator design, as well as the early results obtained and some of the lessons learned from the first home test site in Skerfa, Sweden, which is located near the Arctic Circle. The bismuth-telluride thermoelectric modules used in the generator are also discussed.

Background

In Northern Sweden there are a few hundred families living in houses in areas where the electric utilities will not connect them to the grid. The cost of grid connection is estimated to be between \$5,000 and \$120,000 per house and therefore it is not economical.

The government of Sweden supports this type of rural living since it believes that a populated countryside is good for the nation. They support these families in many ways by charging them the same basic price for services as is charged to people in populated areas. However, this support does not include electricity.

Most of the homes in this area of Northern Sweden are old mountain farms which have been in continuous use for many generations without electricity but, of course, the residents desire some of the advantages and conveniences that electricity provides. Currently they use kerosene lamp for light, wood stoves for heat and small gasoline powered motor generators for electricity. However, most of the people believe these generators are too noisy, require too much maintenance, and have high fuel cost in Sweden.

Another problem with the motor-alternators that are available is that their output characteristics do not match the load requirements of the farm homes. Their output is generally higher than the demand requirements. If the generators are used to charge the storage batteries, they are only run for short periods of time.

The Engineering Design group at Sweden's Royal Institute of Technology undertook the problem of providing several hundred watt hours per day of electric power. They started by investigating the different methods for producing small amounts of electric power with the energy sources available. The result of this investigation⁽¹⁾ was to select thermoelectric technology as the conversion means and the home wood stove as the heat source.

Problem Definition

Typical houses in Northern Sweden are somewhat large, made of wood and are well insulated. The farmhouse in Skerfa, Arjeplog, Sweden that was selected for the test is shown in Figure 1. In the harsh winter season snow is present from November to May and during this period some families stay in an area of the house close to the kitchen and do not heat the entire house. The main source of heat in these farm homes is usually a large wood stove located in the kitchen.



Figure 1. Test Site in Skerfa, Sweden

Because the houses are located above the Arctic Circle, there are only a few hours of daylight in the winter which precludes the use of photovoltaic systems. To save energy during this period, only a few rooms are illuminated.

Families who live in the area were surveyed to determine their main desires if electricity were available. The results in order of importance were:

- Having lights such as provided by a 12 V small fluorescent light
- Power for a TV 2 to 2.5 hours a day
- Power for a water pump to pump water from the lake, river, or well into a pressurized storage tank in the house
- Power for a vacuum cleaner once or twice a week
- Operate small tools to make repairs
- Power for small kitchen appliances such as a food processor

The general opinion of the population was that providing the first three items would satisfy 95% of the families' desires.

A survey of the available temperatures associated with the cast iron wood stove are provided in Table 1. The positions referred to in Table 1 are shown in Figure 2.

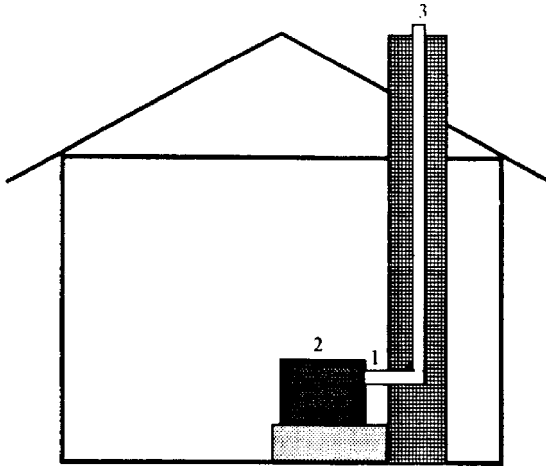


Figure 2. Temperature Positions

Table 1

Position	Location	Source Temperature	Sink Temperature
1	Behind stove	300-500E	20E
2	Stove top	150-300E	20E
3	Top of chimney	140-200E	Sub-zero

The daily demand for electricity was estimated to be between 200 and 300 watt-hours. This was based on providing power for 4 to 5 low-wattage lamps and a small TV. One lamp in the kitchen would be on most of the day while the lights in the other rooms would be on for only a few hours a day. Power generation from the woodstove heat source could be accomplished during 12 to 14 hours a day so that a device capable of producing 20 to 40 watts would be sufficient including the losses for a DC/DC converter.

Generator Design

The generator design developed was based on the use of two HZ-20 modules produced by Hi-Z Technology, Inc. in San Diego, California. The properties of this module, which is shown in Figure 3, are presented in Table 2.

The generators that were built and tested, each used two HZ-20 modules connected electrically in series. The nominal output voltage of 4.76 Volts from the modules is converted upward to a nominal 13.5 Volts by a DC/DC converter and was used to charge four 6 Volt lead acid Exide batteries connected in series/parallel to provide a 12 Volt power source.

The generators tested consisted of a 270 x 100 mm aluminum heat collector plate 8 mm thick with two HZ20 modules were mounted on the plate. A 0.254 mm thick wafer of Al₂O₃ was placed on each side of the module for electric isolation and Wakefield thermal grease was used on each side of the insulation wafer. A single aluminum extruded heat sink measuring 270 x 105 mm and 85 mm high was placed on the insulated modules. Two styles of heat sink were used in the

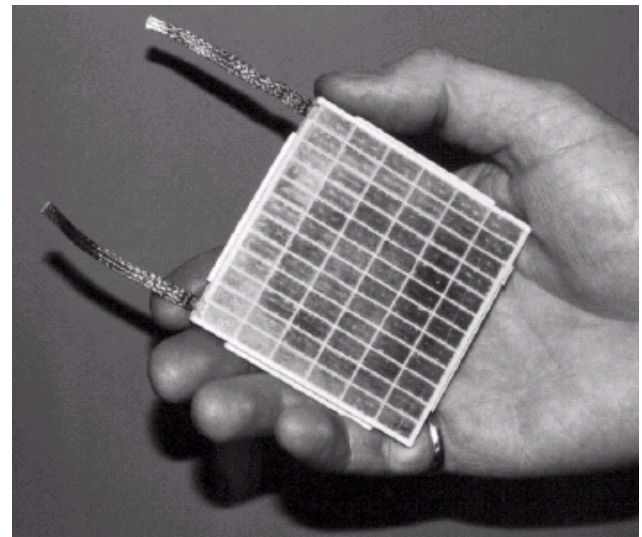


Figure 3. HZ-20 Module

prototype generators, one heat sink contained eleven vertical parallel fins and the other contained nine parallel vertical parallel fins as well as a number of shorter angled parallel fins.

Table 2. Properties of the HZ-20 Module

	Value
Width and Length	2.95" (7.5 cm)
Thickness	0.2" (0.508 cm)
Special Order	
Weight	115 Grams
Compressive Field Stress	10 ksi (70 Mpa)
Number of Active Couples	71 couples
Design Hot Side Temperature	230EC (450EF)
Design Cold Side Temperature	30EC (85F)
Maximum Continuous Temperature	250EC (480EF)
Minimum Continuous Temperature	none
Thermal Conductivity	400EC (750EF)
Heat Flux	9.54 W/cm ²
Power*	19 Watts
Load Voltage	2.38 Volts
Internal Resistance	0.3 S
Current	8 Amps
Open Circuit Voltage	5.0 Volts
Efficiency	4.5%
*Minimum value at design temperatures and matched load	

The heat sink was cooled by a 12 Volt fan, which is mounted above the heat sink to blow cooling air down over the heat sink extrusion. Here fans ranging from 0.9 Watts to 2.2 Watts were tested. The 2.2 Watt fan was ultimately selected for use.

The heat sink and the collector plate were pressed against the modules by four sets of Bellville spring washer stacks, which pressed against the end of the heat sink fins. A stud passed through each spring stack and heat sink and was threaded into the collector plate. The spring force was adjusted to provide about 14 kg/cm² of pressure on the module by a nut on the upper end of the stud, which presses against the spring stack.

Test Results

Temperature of the stove top varies with both position and time. It is dependent on how and when the fire is laid, and to some extent, the outside temperature because that affects the frequency of adding new wood.

The temperature was measured at full fire and normal fire conditions for locations across the stove top. Table 3 presents the variations in the stove top temperature.

Table 3. Stove Top Temperature Variations

Location	Full Fire	Normal Fire
Left Front	320-340EC	195-20EC
Left Rear	335-350EC	210-220EC
Right Front	220-230EC	160-165EC
Right Rear	180-190EC	145-150EC

The left-rear position was selected to install the generator. This selection was made not only because of the high temperatures available, but also because it did not interfere with the family's normal use of the stove. Figure 4 is a picture of the stove with the generator in the left rear of the stove. The person shown loading fuel into the stove is Mrs. Lasko, one of the occupants of the farm.

A data logger was used to record the temperature variations to the stove, the heat sink, and the ambient as a function of time between 7:20 am and 10:10 am. These variations are shown in Figure 5.

Experience showed that the best generator output was obtained during the morning hours when the ambient temperature was low and the stove was being fueled frequently. During this time the output of the generator was about 10 Watts. As the temperature in the kitchen stabilized during the day, the output decreased to between 4 and 7 Watts. This generator output supplied the battery with a net input of from 1 to 5 Watts.

It was found that the generator with the heat sink with all vertical fins performed better than the one with a combination of vertical parallel fins and angled fins. This generator was



Figure4. Wood Stove With Generator at Left Rear

therefore left for the field testing for the 1995/1996 winter season.

Problem Areas and Possible Solutions

The results provided here are for the first prototypes. Many lessons have been learned from these tests and changes will be made to improve the generator's operation.

One problem that must be faced is that the top to these old cast iron stoves are not very flat and, in addition, the flatness changes with the temperature. This can cause a large temperature drop between the stove top and the heat collector. Several Recommendations have been given to remedy the non-flat problem. One is to articulate the heat collector so that it can conform to the stove top more easily. Another is to provide a compliant pad possible made of copper felt or other materials between the stove top and the bottom of the heat collector.

A related problem is that the current generator merely sits on the stove top under its own weight. The heat transfer would be improved if it could be clamped to the stove top with some type of spring loaded device.

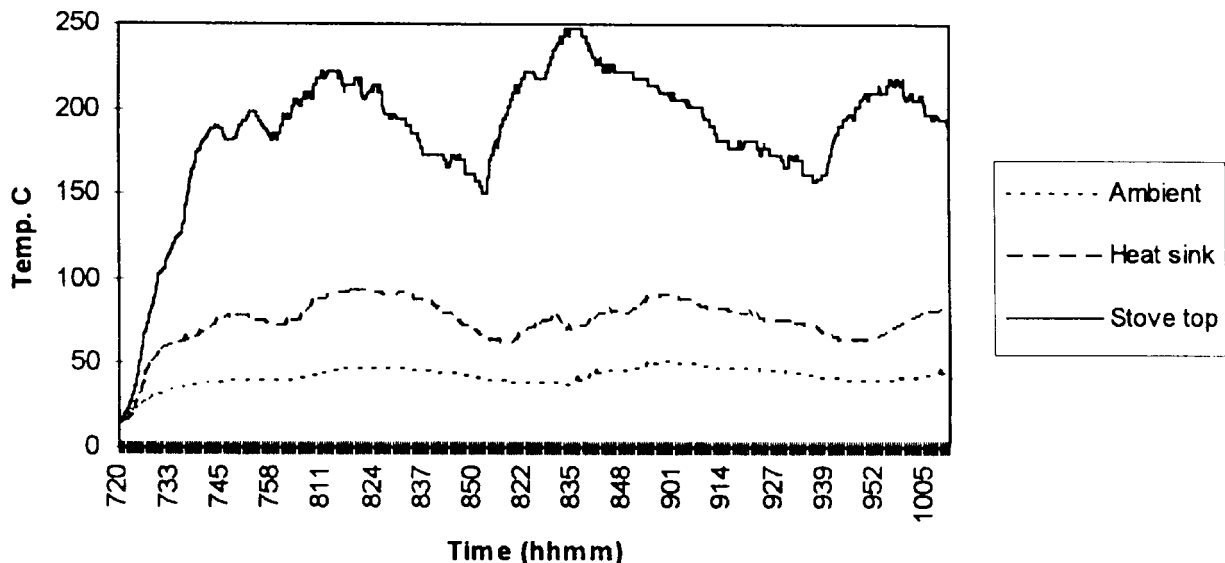


Figure 5. Variations of Stove Temperature With Time

Another option may be to make the heat collector and circular burner as one piece. In this way the heat collector would be heated directly by the fire and hot bases in the stove. This would require the removal and replacement of the existing burner cover when the generator is used.

Cooling air for the heat sink is obtained from a point directly over the stove top. The air temperature in this location is much higher than the ambient and therefore causes a higher heat sink temperature, which results in a lower module efficiency. Experience has shown that, over small temperature variations, one can obtain twice the increase in power by lowering the module cold junction temperature than can be obtained in raising the hot junction temperature the same amount. This is because the peak in the figure-of-merit (Z) curve is near 100EC and, for the same temperature difference across the module, one gains more in average Z as the hot temperature is decreased than one loses from the decrease in Carnot efficiency.

One possible solution to the heat sink problem is to locate the fan remotely away from the stove top air. Cooler air would then flow to the heat sink through a lightweight duct and lower its average temperature.

Another area that needs improvement is the DC/DC converter. These devices are usually designed for optimum operation at a fixed voltage input. Since the output of the stove top generator changes over a relatively wide range during its operation, it is off optimum much of the time.

What may be required to solve the DC/DC converter problem is a fuzzy logic or smart controller which can sense the operating conditions of the generator and automatically adjust the DC/DC converter to provide optimum performance for the current input conditions.

Conclusions

The stove-mounted generator for use in remote areas is operating. While the power output today is less than the modules can produce, the prototype generator can easily be modified, as discussed above, to improve the output of the design.

The best results are that the occupants of the farm where it is installed are pleased with the unit. They now have electric light and can watch some TV during the long winter night.

An unverified side benefit of the generator is that it may have decreased the amount of fuel the Laskos burn. This is because the small fan used to cool the generator heat sink also circulates air around the kitchen. This results in air mixing which provides a noticeably more uniform room temperature and a higher comfort level.

Acknowledgement

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Reference

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