Comparative Analysis of Heating Methods for Iowa's Farm Shops

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Abstract

This project was based on the comparison and analysis of different methods for heating farm shops located in Iowa. Information was collected from companies who manufacture or sell heating systems, and farmers that own and operate such heating systems. Research came from company representatives, websites, and customer testimonials. Graphs, charts, and tables allowed for easy comparison of numerical data. This information was used to figure the owning and operating costs of 3 types of heating systems that can be in combination with 5 different fuels. This information will also be used to identify advantages and disadvantages of the systems and fuels. The 3 systems are Radiant Hydronic, Forced Air, and Geothermal. The 5 fuels are Liquid Propane, Waste Oil, Corn, Wood, and Electricity. Upon completion of this project, it has been determined that there are many variables that need to be considered when selecting a heating system for a farm shop. There is not a clear cut heating system that should be used in all farm shops. The owners have to make the final decision on which type of heating system is best suited to them.

Keywords

Waste Oil, Liquid Propane, Corn, Wood, Geothermal, Electric, Radiant, Heating

Introduction

With the rising costs of fossil fuels, the operating cost of heating consequently goes up for systems dependent on these fuels (Carolus, 2005). This study is going to evaluate a variety of different heating systems which utilize alternate fuels, as well as compare them to the current fossil fueled heaters. It is important to know this information when building a new farm shop or updating an existing system because heating is one of the major operating expenses. Farmers could benefit from a non-biased source of centralized information when looking for more efficient systems, or even alternative sources of fuel with steadier outlook prices. To cover this topic, the base for informational reference is Iowa farm shops that utilize an average sized farm shop of 2,000 ft^2, and a generous 20 ft ceiling height for a total of 40,000 ft^3. With these shop dimensions, the size of the required heat source was calculated to be a minimum of 70,000 BTU/hr.

Systems

Radiant Hydronic

Radiant Hydronic systems utilize water, or some sort of aqueous solution, to carry heat from a boiler unit through a series of pipes placed either under a floor, embedded in a concrete floor, or hung from a ceiling (Shelter, 2006). The focused area in this project dealt strictly with in-floor hydronic systems. In this particular system the heat in the boilers is transferred to the liquid. Then the liquid warms the floor through radiation – or contact.

One of the biggest advantages of the in-floor hydronic system is that the entire floor is warm, much like the sun shining on the floor. Another of the advantages, since the system burns in an enclosed firebox, the relative humidity of the air in the building doesn't decrease as much as it does with an open flame (Alpine, 2006). This is conversely a problem with excess moisture from washing equipment, or melted snow because water will hang around for a longer time. The boilers can be placed just about anywhere, because the flame is enclosed and the system is only heated to about 130 degrees (Shelter, 2006). Hydronic systems are a little more complex than just an open flame, but they are quieter because they don't have to move air (Shelter, 2006). Also, hydronic systems can have an efficiency of up to 96% (Heat, 2006). This system also helps keep the shop air somewhat clean because it doesn't have moving air stirring up dust.

Initial costs for a system capable of heating a farm shop located in Iowa that has a volume of about 40,000 cubic feet would amount to about $2,000 in tubing, valves, thermostats, and expansion tank (Alpine, 2006). Since water could be used in this system as the medium for heat transfer, that cost is negligible. The cost of a hydronic system can increase greatly with the addition of more valves, more thermostats, zone-heating, and including anti-freeze in the solution. Also, the cost of the boiler unit is going to vary slightly based on the fuel type that is selected.

Forced Air

Forced air convection heaters operate on the principal of using a flame to heat the air (BN, 2006). This system is different from that mentioned above because it doesn't heat objects, just the air. Comfort is one advantage to this system, as well as accelerated evaporation of standing water, quick recovery time, and low maintenance. Most of the time these heaters hang from the ceiling, up away from objects that could overheat. In the same sense, no floor space is wasted, but because heat rises, and heat is produced at the top of the room, they are relatively inefficient. Forced air heater's efficiency is only about 73% (Heat, 2006). Their recovery is much better than that of radiant heaters because of the warm air in direct contact with your skin immediately after stopping the air loss from opening a door. Another advantage to this system is the ability to reduce extra moisture in the shop from washing equipment or melted snow because of an open flame and low relative humidity. With the forced air system, lost heat is able to be recovered quickly. With the radiant heat option, owners will always have a warm floor, but heat recovery is going to be slower. There is also the option of combining the two options, offering the best of both options.

There are a few drawbacks to this system. As mentioned before, forced air systems are generally located near the ceiling, so heat does not reach the floor efficiently (BN, 2006). Another flaw is the noise that is created from the fans needed to force the air to move. Convection heaters are relatively simple and cheap, but the open flame and the cheaper components doesn't provide for a long-life. Finally, the heat is concentrated around the exhaust of the furnace, and may not disperse completely or efficiently to all areas of the shop.

Geothermal

Geothermal heat pumps can provide heating and cooling at significantly less cost compared to other systems (GEOEXCHANGE, 2003). The two types of heat pumps are ground source and air source heat pumps. Air source heat pumps use the air to create heat. Ground source heat pumps use the earth as a heat sink to extract or displace heat into. A heat pump takes existing heat and moves it from a low temperature location to a higher temperature location (GEOEXHANGE, 2003).

The process of elevating low-temperature heat to over 100° F and transferring it indoors involves a cycle of evaporation, compression, condensation and expansion (Water, 2004). A refrigerant is used as the heat-transfer medium which circulates within the heat pump. The cycle starts as the cold liquid refrigerant passes through a heat exchanger (evaporator) and absorbs heat from the low-temperature source (fluid from the ground loop). The refrigerant evaporates as heat is absorbed. The gaseous refrigerant then passes through a compressor where the refrigerant is pressurized, raising its temperature to more than 180° F. The hot gas then circulates through a refrigerant-to-air heat exchanger where heat is removed and pumped into the building at about 100° F. After it loses its heat, the refrigerant condenses back into liquid form. The liquid is cooled as it passes through an expansion valve and begins the process again (Water, 2004). To work as an air conditioner, the system's flow is reversed.

The ground loop is a loop of pipe that is buried in the ground and serves the purpose of being a stable low temp heat source. Ground loops can be open or closed loops, vertical or horizontal loops (PATH, 2005). An open loop system uses water from a well, whereas a closed loop system pumps the same fluid through it all the time. Vertical loops are usually 75 to 300 feet deep depending on location. Horizontal loops are generally 4 to 6 feet deep and about 400 feet long. Generally it takes 500 - 600 hundred feet of horizontal underground piping per ton (12,000 BTU) of system capacity (PATH, 2005). This much pipe is needed for thermal transfer of the ground heat into the pipe fluid or for the ground to absorb heat from the pipes during cooling.

The initial cost of a geothermal system is much greater than a conventional forced air or radiant hydronic fossil fueled system. Depending on the size, location, and terrain the underground loops will be the most expensive part. Some installation figures have been from $15,000 for average projects to $25,000 for larger projects (PATH, 2005).

The low operating cost of a geothermal system is what makes it so attractive. In terms of efficiency, they are 300% to 400% efficient (Econar, 2005). This means that for every unit of energy put in 3 to 4 units are returned. So, if 1 kWh has 3413 BTU's, (100% efficient for resistance heating) that means a geothermal system would put out 10,000 to 13,500 BTU's for every 1 kWh. But geothermal systems are not labeled according to efficiency; they are labeled by a coefficient of performance, or COP. COP is defined by the ratio of heating or cooling provided by a heat pump (or other refrigeration machine) to the energy consumed by the system under designated operating conditions (GEOEXHANGE, 2003). The higher the COP, the more efficient the system is. Most geothermal systems can lower average heating bills by as much as 60%, and cooling bills up to 30%.

Geothermal systems do not burn any fossil fuels directly, and emit no toxic or unwanted gases into the living or working space. The only energy requirement for a geothermal heat pump system is the electricity it takes to run the compressor and pump. This is a great safety feature of geothermal heating and cooling. Another advantage of geothermal systems is that they can produce domestic hot water. A geothermal heat pump, if properly equipped, can fulfill some or possibly all of a home's hot water needs during heating and cooling cycles. This may be very beneficial to people who have offices within their farm shops and want a bathroom with hot water for washing hands or showering.

This type of system can be used as a forced air system, radiant in floor heating system, or both. The comfort levels of geothermal systems are said to be of the very best in the industry (Econar, 2005). Some types of geothermal equipment or systems may even be eligible for rebates through the local utility companies or through government agencies.

Fuels

Liquid Propane (LP)

LP fuel (liquid propane) is a byproduct from the refineries which produce other heavy fuels or grease. But most of the LP used today comes from the purification of Natural Gas – which is a similar fuel (NPGA, 2006). Supplies of LP are directly related to the refining of other fuels, and therefore experience the same market fluctuations as other petroleum fuels. In the past few decades, especially the last few years, fossil or petroleum fuels have risen in cost significantly (Highland, 2004). They are however very reliable and contain great amounts of available energy. Thus, smaller quantities of fuel are capable of containing many BTUs and are capable of being stored in smaller containers, while containing more heat than an alternative fuel. LP systems, compared to alternative fuel sources, have relatively low maintenance (Highland, 2004). A lot of this is because of how clean and reliable LP is to burn. What makes these systems so attractive is also the fact that they can be started automatically, then set and forgot about for extended periods of time. Some people are willing to pay for features such as this.

The initial price for propane burning furnaces ranges from $500 to $5,000 installed (Highland, 2004). The average analyzed cost of LP being used is $1.30 per gallon. Liquid Petroleum contains 92,000 BTU/gallon and burns at an efficiency of 80% (NPGA, 2006). This results in a total cost of $17.88 per million BTU.

Corn

Corn furnaces that use shelled corn as a fuel source are the second cheapest form of heat on the market today (Carolus, 2005). The initial price for corn furnaces varies greatly on the size of the furnace desired and the system in which the corn furnace will be utilized. The basic free-standing corn furnace with a forced air system that produces 70,000 BTU/hr will typically cost around $1,500 installed. Whereas a corn furnace used to heat water and pump that water through a system of floor heat or radiant heaters will generally cost more; upwards of around $5,000 installed (McLean, 2005).

The problem with corn furnaces, like many of the other fossil fuel based furnaces, is that the price for the fuel is going to vary from year to year. All the figures for corn furnaces are going to be analyzed at a price of $2 per bushel. This is roughly the average price of corn over the past twenty years. The price per BTU, which is estimated at $5.65 per million BTU, is going to change from year to year based on the price of corn. This figure is based on the fact that there is 420,000 BTUs in one bushel of corn, and it burns at an efficiency of 85% (Carolus, 2005). Overall, unless there is a sudden spike in the market for corn, corn furnaces are a very practical consideration when deciding what kind of furnace to install in a farm shop.

Another thing about corn furnaces that makes them appealing is that they are relatively safe to use compared to fossil fuel burning furnaces. The fuel form of corn is not nearly as flammable as natural gas or liquid propane is if they are not handled and stored correctly. Corn furnaces can be considered safer than electric furnaces also, because electric furnaces require a large amount of current and voltage that can be detrimental to someone if he or she comes into contact with the power supply lines. It is possible though that corn furnaces can be unsafe as well, it is just not as likely as the other types.

The main advantage to corn burning furnaces is the low cost of the fuel source (McLean, 2005). One of the disadvantages is that the corn furnaces can require regular cleaning of ashes that conventional furnaces would not have a problem with. This depends greatly on the type of corn furnace being used and the procedure that some models of corn furnaces take to discard the ashes after burning. Another disadvantage of the corn furnace is that the bulk fuel form of corn takes up a lot of space. This probably really is not an issue with farm shops because people are used to seeing large bins on farms. It could be a problem in larger urban areas where it might be an eyesore to see a large storage container outside a residence with the bulk form of corn being stored in it to be used throughout the winter.

Waste Oil

Oil burning furnaces that use waste oil as their fuel source can be the cheapest form of heat on the market today. This all depends on the amount it costs, if anything, to get access to waste oil. Most of the time waste oil is considered something that just needs to be discarded and of very little value. A lot of maintenance shops accumulate several hundred gallons of waste oil every year that needs to be discarded in some way. The best way to discard this oil is by burning it in a waste oil furnace (Clean Burn, 2006). Using an average price of $.05 per gallon, it costs approximately $.45 to produce one million BTUs. This cost reflects the heat value of used oil which is 140,000 BTU per gallon being burned at an efficiency of 80% (HECO, 2006). Prices greatly differ on waste oil furnaces, but the most generic type using the forced air system can be installed for approximately $500. A more extensive system using a boiler can be installed for $5,000 (HECO, 2006).

The main advantage of using a waste oil furnace is the cheap and often free price of the waste oil. This drastically helps reduce the amount of money spent on heating a farm shop in the winter. Another advantage of using a waste oil furnace is that it provides a way to discard any used oil that may be found in farm shops. This is a convenient and cost effective method of utilizing waste oil that is created in a farm operation.

The main disadvantage of using a waste oil furnace is that you don't know what kind of quality the waste oil is in. A lot of times, people put all kinds of foreign liquids with their waste oil just to discard it. So there needs to be an extensive filtering system installed to make sure that the only thing being burned is waste oil. Otherwise there could be some problems with the oil burners plugging and not creating a clean burn in the process. Another disadvantage of using an oil burner is that there usually has to be a large storage tank to hold the waste oil before it is burned. This can take up valuable shop space and be in the way of some operations that take place within a farm shop.

The last thing to consider about waste oil furnaces is the comfort and suitability from the heat that is generated. Waste oil furnaces do not typically burn as clean as other furnaces used to heat a farm shop. This becomes a problem when the furnace is not ventilated properly and allows some of the emissions to be present within the farm shop. There can be cases with high carbon monoxide readings within a shop that can be detrimental if not taken care of properly.

Wood

Average price for an outdoor wood burning unit sized large enough to heat a shop with a 70,000 BTU/hr requirement is about $7,750 installed, but without an insulating and protective shed structure (Northland, 2006). With the shed included, the price increases to about $9,500. The shed enclosure is an option that should be seriously considered due to the added efficiency for the combustion unit, and because it will also extend the life of the combustion chamber by sheltering it from the weather.

Fuel costs for a wood burning system are hard to calculate due to the many variables associated with collecting firewood. Wood is sold by the cord, which is defined as wood that is split and tightly stacked, in a row that is 4 feet tall, 4 feet deep, and 8 feet long (Goddard, 2006). If a wood furnace owner has trees on their property, the only costs associated with collecting firewood are transporting, cutting, splitting, and labor. If the wood furnace owner does not have trees on their property, they must get the wood from somewhere else. The average price for a cord of firewood that is cut, split, delivered, and stacked is $120 per cord. An average cord of firewood contains 16.5 million BTU of energy burning at an efficiency of 75% (Goddard, 2006). This results in a fuel cost of approximately $9.71 per million BTU.

Electricity

Electricity is a heat source that is not as common in settings such as a shop. Many electrical systems are radiant heaters, but most of the electrical radiant heaters being used today are not big enough to handle our 70,000 BTU/hr requirement. One of the cheapest, simplest and most space saving electrical furnace designs is a unit that combines a heating unit and cooling unit, and is mounted from the ceiling (BN, 2006). Air is pulled through the unit and conditioned, and the exhausted out the front through a vent.

The average price for a high heat capacity ceiling mounted system is $725 for a 36,000 BTU/hr 10 kW heating system (BN, 2006). One kW is approximately equal to 3413 BTU, so with one unit, total heat output would be about 34,000 BTU/hr. Two units is about 68,000 BTU/hr, which is close to the target of a 70,000 BTU/hr system. This brings the total initial price cost to $1450. There is no ductwork, so the only other cost would be if the shop owner would want to hire someone to install the units, or if wiring needed to be done due to either a 220 volt system or a 208 volt three-phase system.

The price of electricity varies depending on location and time of year, but with an average rate of $.07 per kWh, and 3413 BTU per kWh, the average price of electrical heat is $20.51 per million BTU.

The advantages of using electricity as a heat source are numerous. With an electrical system, there is no need to have fuel stored on location. All of the fuel needed is wired to the system. This also eliminates the need for pipe and plumbing. With the system described above, there is also no need for ductwork. All of these things help keep costs down. Since there is no combustion taking place, there is also no need for any sort of exhaust system, and there is no danger of hazardous byproducts from faulty combustion. Another benefit of this system is that an air conditioner unit is built right into the system, so cooling is also an option. All of these things add together to make a system that is really simple to have. And although there is a need for two units, this can be viewed as a positive because if one unit fails, there is still heat available from the other unit.

The disadvantages of an electrical system are also numbered. One of the main negative points is that radiant in-floor system powered by electricity is not strong enough to support a shop environment. Another negative is that electrical systems are expensive to operate. The fuel costs are much higher than some of the alternatives. The last negative point is the fact that no single unit is big enough to heat a 70,000 BTU/hr requirement, which creates the need to operate more than one unit, resulting in more possibilities of breakdown and also raises the amount of maintenance needed.

Results

After researching all the heating fuels, waste oil is the least expensive heating fuel. When the waste oil is matched with a forced air system it has an approximate life of 25 years, which results in an owning and operating cost of slightly less than $5,000. Corn was the next cheapest at $14,000, wood was third at $16,000, geothermal was fourth at $18,000, LP was fifth at $36,000, and electric was sixth at $38,000. This is a huge range for the fuels being compared. These results can also be viewed in Figure 1.

The three different systems were analyzed based on efficiency. The geothermal system had the best efficiency of 320%. The hydronic system was next best at 96%. The forced air system came in last with an efficiency of 73%. These efficiencies are very important when selecting which system to implement.

Discussion

An assumption used throughout the report was the size of the shop. It was based upon a typically common size with respect to square floor area and ceiling height. Another assumption was what the shop was used for, how often it was used, the interior temperature the thermostat was to be kept at 60 degrees Fahrenheit, and also how long and often an overhead door was to be opened. To determine the amount of heat loss in the shop a psychrometric analysis was completed. Also, it was assumed that when the large overhead door is opened that 50% of the outside air would replace the inside air and would need 38,000 BTU/hr to heat the shop back to 60 degrees Fahrenheit from 20 degrees Fahrenheit. It was also researched that the coldest temperature in Iowa is approximately -20 degrees Fahrenheit (World Climate, 2005). At this temperature the 70,000 BTU/hr furnace will run without stopping. Basically, the heating system was sized for the absolute coldest winter day in Iowa. Finally, this project was based on a newly built farm shop, and the prices do not take into account remodeling an existing farm shop and implementing one of the heating systems. As a result, the building's weighted R value of insulation was calculated to be 17.1. To determine the total heating needs for the season, the Heating Degree Days for central Iowa were used along with the average winter temperature and the heat loss of the building. To calculate the heating degree days for a particular day, find the day's average temperature by adding the day's high and low temperatures and dividing by two. If the number is above 65, there are no heating degree days that day. If the number is less than 65, subtract it from 65 to find the number of heating degree days (World Climate, 2005).

Conclusion

It is very difficult to say which system is best for a farm shop. There are many variables that may determine which choice is best for a particular owner. Overall the systems and fuels presented in this paper all have good features and bad features. Geothermal may be the safest, easiest to use and manage, and provide an excellent heat source, but the high initial cost of the ground loops is a major disadvantage. Waste oil heaters are very cheap to operate but the hazardous waste oil needs to be stored somewhere during the summer months. A simple wood stove may by very cheap to buy, but there is a lot of work to be done in collecting the wood and cleaning the ash out of the stove. LP is easy to use and easy to get, but it is also getting more and more expensive to purchase. Electricity can be used efficiently and cheaply in small areas, but it is not as economical in larger areas. These are some of the concerns when deciding on a system. Many of these concerns depend on the shop use and the amount of time that one is willing to spend making sure the system is running. Also initial cost is a major concern, but one should be more concerned with the life cycle cost of the system.

Nomenclature

BTU – British thermal unit. Amount of energy needed to raise the temperature of one pound of water one degree Fahrenheit.

Hydronic – Pertaining to water or an aqueous solution.

R-Value – Ability of insulation to resist heat flow. As the R-Value of the insulation increases, the resistance to heat exchange increases also.

Ton – A unit of heating or cooling is equal to 12,000 BTU.

References

Alpine Home Air Products. 2006. Available at: http://www.alpinehomeair.com. Accessed 17 March 2006.

BN thermic. 2006. Available at: http://www.bnthermic.co.uk/products/dff.php. Accessed 5 March 2006.

Carolus, Doug. 2005. Corn as a Non-Ethanol Heating Fuel Source. Available at: http://www.farmdoc.uiuc.edu/manage/newsletters/html/112901.html. Accessed 3 March 2006.

Clean Burn . 2006. Engineered Like No Other Used-Oil Heating Equipment. Available at: http://www.cleanburn.com. Accessed 21 April 2006.

Econar. 2005. Geothermal Heat Pumps for Residential and Commercial Applications. Available at: http://www.econar.com/index.htm. Accessed 23 March 2006.

GEOEXCHANGE. 2003. Geothermal Heat Pump Consortium. Available at: http://www.geoexchange.org/about/how.htm#TOP. Accessed 23 February 2006.

Goddard, Neil. 2006. Why Heat with Wood? Available at: http://www.blountweb.com/goddards/fire_wood.htm. Accessed 26 February 2006.

Heat Transfer Products. 2006. Available at: http://www.htproducts.com/products/munchkin/index.html. Accessed 5 April 2006.

HECO Waste Oil Heat. 2006. Slash Your Heating Bills. Available at: http://www.heco.net/wasteoil.htm. Accessed 26 February 2006.

Highland Propane. 2004. Propane Furnaces. Available at: http://www.highlandpropane.com. Accessed 3 March 2006.

McLean, Terri. 2005. Cold Temperatures, Rising Energy Prices Renew Interest in Heating With Corn. Available at: http://www.ca.uky.edu/agc/news/2005/Dec/corn.htm. Accessed 12 April 2006.

Northland Outdoor Wood Furnace. 2006. Available at: http://www.northlandoutdoorwoodfurnace.com. Accessed 21 March 2006.

NPGA. 2006. National Propane Gas Association. Available at: http://www.npga.org. Accessed 27 February 2006.

PATH. 2005. Partnership for Advancing Technology in Housing. Available at: http://www.toolbase.org/techinv/techDetails.aspx?technologyID=130. Accessed 27 February 2006.

Shelter Technology. 2006. A New Day for Boilers. Available at: http://www.sheltertech.com/new_day_for_boilers.htm. Accessed 18 April 2006.

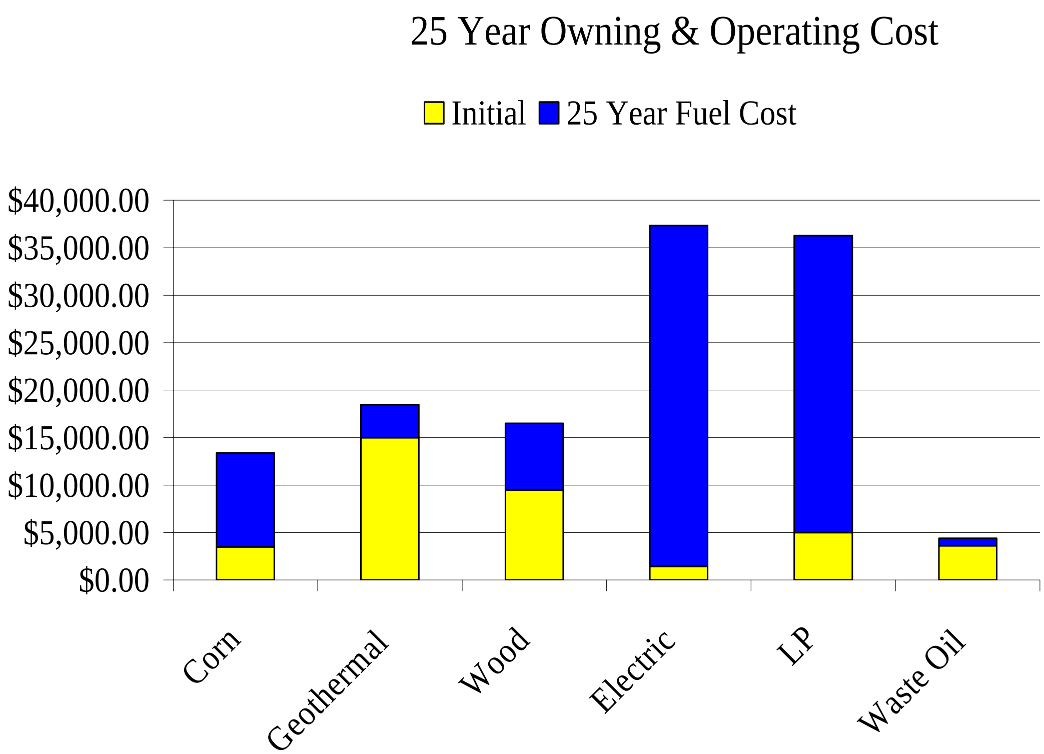
Water Furnace. 2004. Smarter From the Ground Up. Available at: http://www.waterfurnace.com. Accessed 16 February 2006.

World Climate. 2005. Available at: http://www.worldclimate.com. Accessed 13 February 2006.

Table 1

	BTU VALUE PER UNIT (UNITS/1,000,000 BTU's)	FUEL PRICE PER UNIT subject to local values	EFFECTIVE COST TO PRODUCE 1,000,000 BTU's	EFFICIENCY (%)
DRY SHELLED CORN	420,000/bu (2.4 bu)	$2.00/bu	$5.65	85
ELECTRICITY	3,413/kWh (293 kWh)	$.07/kWh	$20.51	100
LP GAS	92,000/gallon (11 gallons)	$1.30/gal	$17.88	80
WOOD	16,464,000/cord (.0607 cords)	$50/cord	$4.05	75
GEOTHERMAL	3,413 BTU/kWh (90.9 kWh)	$.07/kWh	$1.99	320
WASTE OIL	140,000/gallon (7.1 gallons)	$.05/gal	$0.45	80

Figure 1



25 Year Owning & Operating Cost
Initial
25 Year Fuel Cost
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$0.00
Corn
Geothermal
Wood
Electric
LP
Waste Oil