# Ground-Source Heat Pump System near Helena, Montana: Loop Temperature Analysis

Wayne Van Voast

Montana Bureau of Mines and Geology

Report of Investigation 1

1996

First Printing, 1996

Printed by University of Montana Printing Services, Missoula, September, 1996

Available from Montana Bureau of Mines and Geology, Main Hall, Montana Tech, Butte, Montana 59701

Report of Investigation 1

# Ground-Source Heat Pump System near Helena, Montana: Loop Temperature Analysis

Wayne Van Voast
Montana Bureau of Mines and Geology

1996

# Contents



# Figures



# Appendixes



## Disclaimer

# Introduction

Use of ground-source heat pump systems for domestic heating is increasing in Montana, particularly in rural settings where relatively inexpensive natural gas is unavailable. The systems also provide cooling, but in Montana's climate this capability is neither highly regarded nor used except in commercial installations such as office buildings. In these, it is reported that the cooling option of the systems sees far greater use than the heating.

Heat pumps utilizing ground or water energy have been in common use in temperate parts of the United States for many years. Only within the last decade has the technology of design and operation developed to provide adequate heat efficiently in northern states. In Montana, most ground-source heat pump systems have been installed in Flathead and Yellowstone counties. In these areas, the rural electric cooperatives provide various inducements to encourage use of the systems. The Northern Rockies Ground-Source Heat Pump Association estimates that 1,300 domestic systems and 50 commercial systems are now in operation in Montana (Maunder 1995). An additional 100 domestic systems and one commercial system are reported by the Montana Power Company (Moran 1995).

Along with the emergence of the ground-source heat pump as a viable provider of domestic and commercial heating, literature on the technology has evolved. Four publications consulted in this study, and thought to be particularly informative, are the *Water Source Heat Pump Handbook,* by Dexheimer (1985); *Earth-Coupled Heat Transfer,* by Hart and Couvillion (1986); *The Montana House Project,* by Jackson (1989); and *Geothermal Heat-Pump Systems: the ABC's of GHP's,* by Wright and Colvin (1993).

A ground-source heat pump system absorbs heat from the ground and transports it to a heat pump that extracts heat to warm the household air. Excess energy from the pump is used to augment the heat of the home's hot-water heater. The heat absorbed from the ground is presumed to be "stored solar heat" by many scientists and engineers and is considered "geothermal heat" by many others.

Ground-source systems are closed systems in which tubing charged with non-freezing fluids is buried near the homes, or in some cases submerged in surface-water bodies. The fluid is pumped through a system continuously during operation and through a heat pump that, using a small compressor and a refrigerant such as freon, extracts heat from the circulating fluid. The systems are "closed" because there is no physical interaction between the loop fluid or refrigerant and the outside environment, including air, ground, or water. The main advantage to using heat pumps is the exceptionally high efficiency (~200%–400%) afforded by the Carnot Cycle of refrigerant compression and expansion. These efficiencies are commonly expressed in terms of "coefficient of performance" (COP). A COP of four designates 400% efficiency for a system that provides four energy units for each energy unit consumed.

A special comment is made here about the non-freezing fluids commonly used in loop systems. In some places the industry standard is a 20% methanol solution, which is highly toxic. Some industry professionals respond to questions of toxicity by referring to "non-toxic methanol" in their systems; this does not exist. A fatal one-time dose of methanol may be as small as 25 mL (~3/4 oz), according to Kirk-Othmer (1981). Blindness is the typical result from less-than-fatal doses. A typical loop system contains about 60 gal of fluid that, having a 20% methanol content, would include about 12 gal of methanol. The concentration in the loop would be about 158,000 ppm. These comments are made partially to discourage use of methanol in loop systems but primarily to oppose advertising that a 20% methanol solution is *non-toxic.* Some states prohibit use of methanol in the loops, notably Minnesota, North Dakota, and Ohio. Propylene glycol, a non-toxic fluid, seems to be a reasonable substitute although somewhat more viscous and more expensive.

# Objectives

The objective of this study was to evaluate temperature changes in loop fluid in a system. A household near Helena, Montana, was examined during the 1992–1993 and 1993–1994 heating seasons. Specifically, the temperature drawdown of the earth-coupled system during heat extraction was monitored and evaluated. The temperature declines each season, and any residual decline overlapping from the first season to the second, were objects of monitoring. In interpreting the data, an objective was to examine a quantitative way to evaluate loop temperatures to characterize these systems during normal operating conditions.

# System Description

The house, heat pump, and ground-loop system are generalized below:

House: 5699 Rainbow Drive, Helena, Montana
4056 ft$^2$ floor area
Super Good Cents Construction

Heat Pump: Command Aire SWPR 411 GSS (3.5 ton)

Loop System: Vertical (drill holes) construction, three holes, 10-ft spacing, 235-ft-deep, fractured shale formation, water table at about 10 ft, 2 pipes 0.86-in. I.D./hole manifolded in parallel to one horizontal main 2-pipe leg 1.55-in. I.D., 90 ft to house. Charged with propylene glycol solution.

The system is generalized in figure 1, and detail on sizing and design is provided in appendixes A and B, which are the specifications and calculations developed for installation.

## Operating Costs, Owner Satisfaction, Problems

From initial operation on April 12, 1991, until March 23, 1995, the system drew 44,670 kilowatt-hours (kWh) of energy. Of these, 887 kWh were used by a resistance strip heater to augment the heat pump output and the remaining 43,783 kWh served the heat pump, providing household heat and supplemental heat for the hot-water heater. Activation of the strip heater was mostly accidental, performed in experimentation with various thermostat settings. Over nearly four years of operation, energy consumption averaged 11,310 kWh per year, about 20% greater than that predicted (9,518 kWh per year) by the installer's computer design program (appendix B). Likewise, the predicted annual heating and cooling cost of $598 was exceeded by 16% in the actual average of $692. The cause for the discrepancy is unknown and may be unique to this particular installation or may require a different application of general design criteria.

In spite of the less-than-predicted economy, the owner is generally satisfied with the system and particularly the concept. Lack of open-flame or resistance heating provides a clean heat, quietly distributed by the forced-air system.

## Instrumentation and Methods

Under agreement with the Montana Power Company, separate meters were installed at the residence to monitor energy consumption of the heat pump, the electric hot-water heater, and the auxiliary strip heater (figure 2). Only the records for the heat

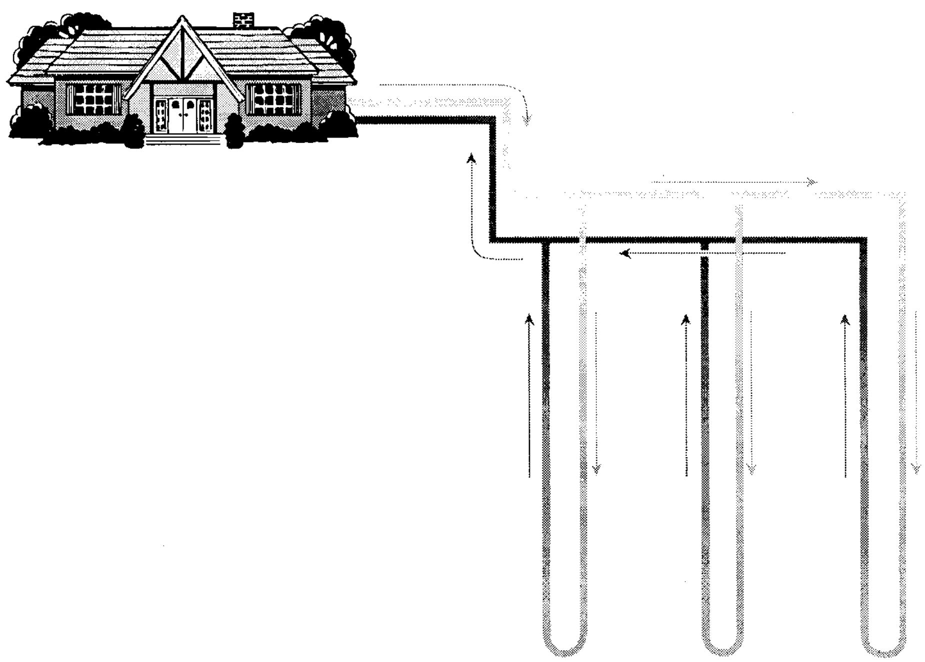

*Figure 1. The ground-source heat pump system consists of a heat pump with forced-air distribution within the house, and a vertical loop outside of the house. The loop is made from small-diameter polyethylene pipe inserted in three drill holes, each 235 ft deep. The vertical pipes are manifolded in parallel to a 90-ft horizontal pipe leading to the house.*

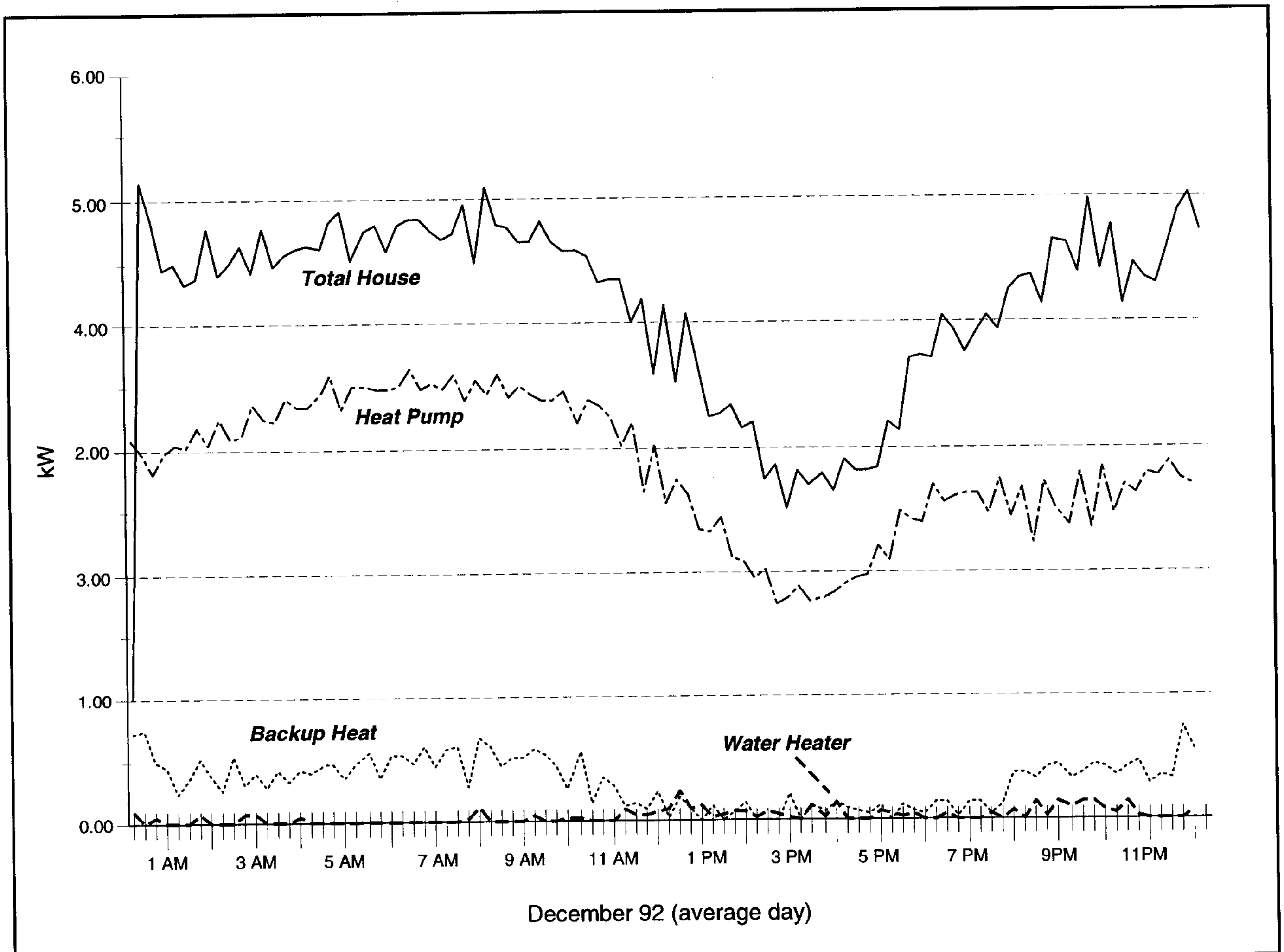


*Figure 2. Normally the heat pump operated almost cotinuously between midnight and about 9:00 A.M. Minimum daily loop temperatures for long-term evaluation were obtained from data recorded between 5:30 A.M. and 6:30 A.M. each day.*

pump are used in this report. The utilities meter recorded kWh of consumption at 15-min. intervals, accessed by data logger. The daily power consumption, as calculated from the 15-min. kWh readings, provided two levels of data for this report. First, the daily kWh usage multiplied by 3,413 gave the British Thermal Unit (Btu) consumption needed for estimating the system's COP. Btu production values for this report were obtained by multiplying Btu consumption by the COP. A COP of 3.10 was estimated using the loop flow rate and differences between entering and exiting loop temperatures, meaning that 3.10 Btu were produced for each Btu consumed. Precision of the estimated COP is not great, and the assumption that it is a constant is only for convenience. Second, the percent-time-of-operation was calculated by dividing the actual kWh usage by the energy draw for continuous operation (empirically determined).

To obtain minimum daily loop temperatures, the loop was originally monitored continously, creating a major problem of data handling. Examination of the energy consumption records (figure 2) showed that the coldest loop temperatures coincided with periods of longest heat pump operation, and that these were normally in the early morning hours. Therefore, the temperature recorder was set to record only during the one-hour interval between 5:30 A.M. and 6:30 A.M. each day. This generated a workable amount of data and seemed to meet the project objective. The recorded temperatures are considered to be daily minimum loop temperatures entering the heat pump system and to represent earth temperatures along the buried vertical and horizontal tubing.

## Data

Minimum daily outside air temperatures (figure 3) during the 1992–1993 heating season fell to about –20°F for brief periods and dropped below –30°F on one occasion during the 1993–1994 season. The first season was generally the colder, with most minimum daily temperatures in the range between –20°F and +20°F. In early 1993, the cold weather was interrupted by about six weeks of above-zero temperatures. In the second season minimum daily temperatures were below 0°F for only a few days.

Minimum daily loop temperatures (figure 3) corresponded well to outside air temperatures. Lowest loop temperatures occurred during the periods of coldest weather, reflecting greater heat pump usage. The correlation between loop temperatures and outdoor temperatures is surprisingly good, considering the human factors of thermostat adjustments and other domestic variables. Most important for this report are the periods of more-or-less progressive loop temperature declines at the beginning of each heating season. These are the periods: November 17, 1992, through March 16, 1993, including the warmer interlude, and October 16, 1993, through February 12, 1994. These were times of increasing thermal demands on the loop system, separated by a period of temperature recovery in the summer of 1993. Maximum loop temperature decline for the first season was 8.3°F and for the second season was 8.8°F in spite of the latter's warmer weather. Heat production during the first heating season (120 days) was over 76 million Btu (figure 4) as calculated from metered energy consumption and a COP of 3.10. In the second heating season (also 120 days) heat production was about 71 million Btu. So far as can be seen from the data, loop temperature recovery following each heating season was complete. Following only two cycles, however, precise data would likely be necessary to detect any long-term trend of decline.

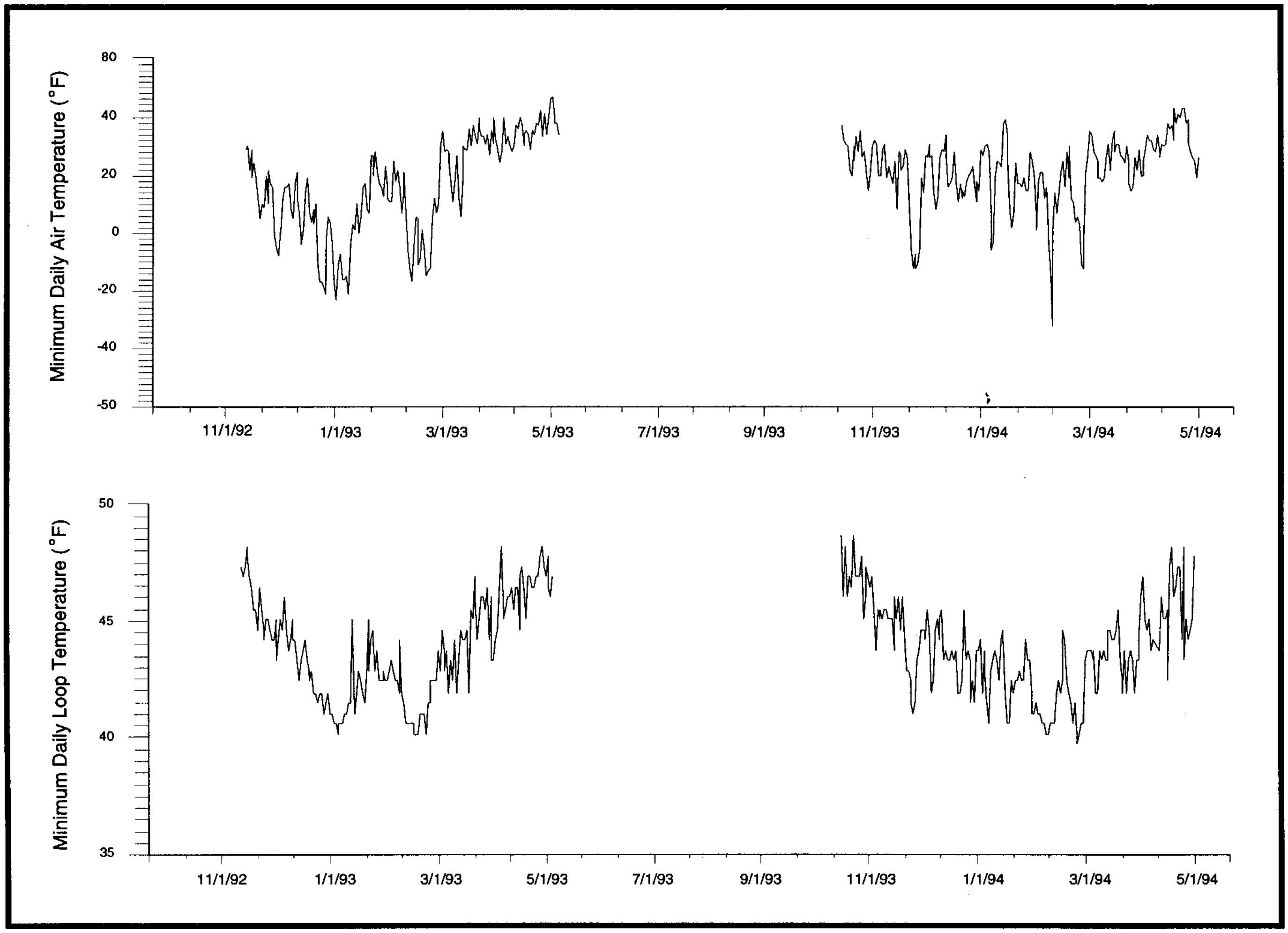


*Figure 3. The 1992–1993 heating season was generally colder than the 1993–1994 season. Loop temperature correspond to outside air temperatures.*

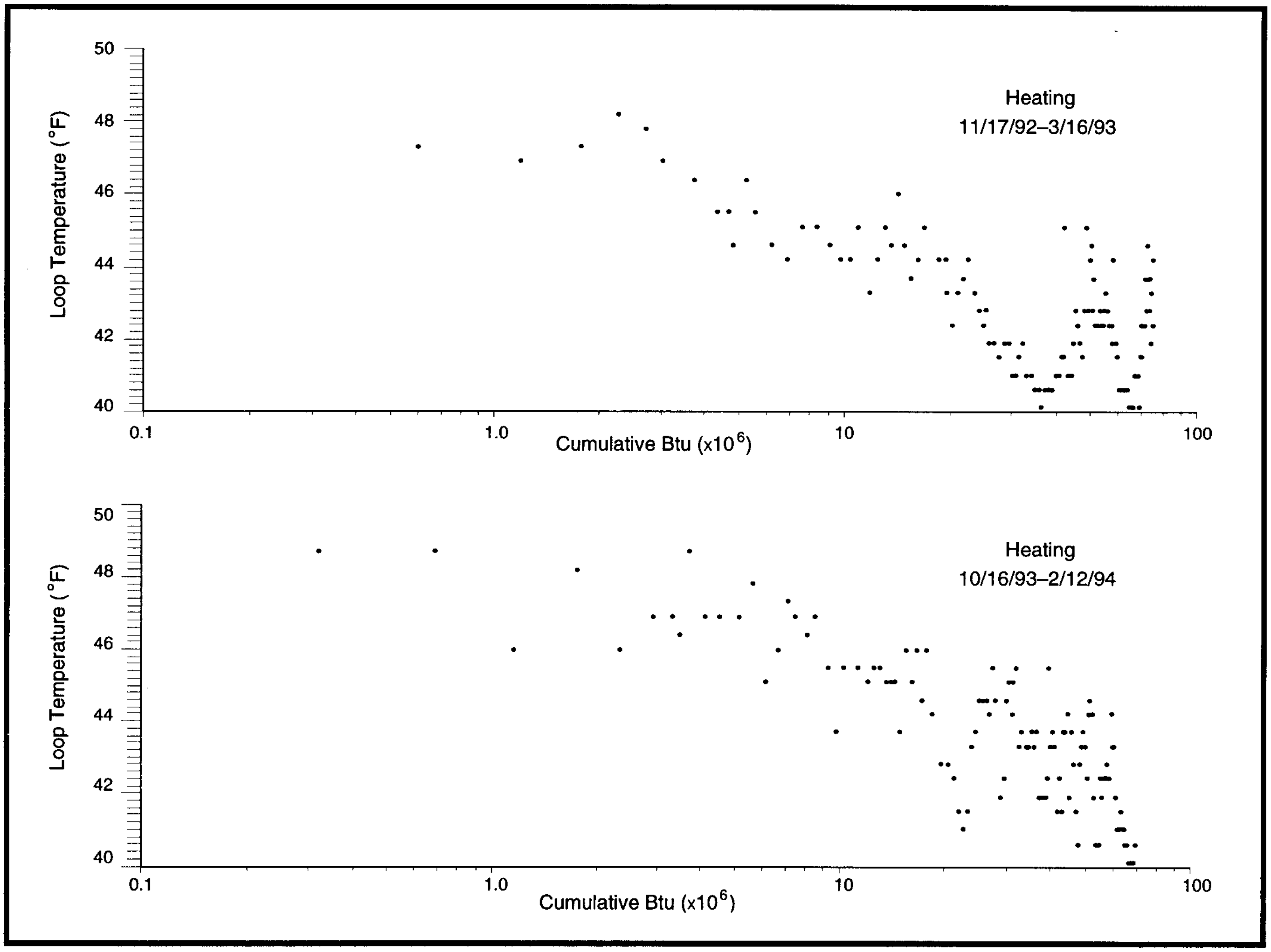


*Figure 4. During the 120-day, 1992–1993 heating season, 76 million Btu were produced by the system. During the 120-day, 1993–1994 heating season, 71 million Btu were produced.*

## Discussion

One objective of the loop-system monitoring was to try to establish a quantitative way to evaluate and compare these systems in situ, after installation and during normal operating conditions. A technique developed for evaluating aquifers and groundwater discharge was examined for this because of the analogy between heat and groundwater flow. Historically, the basic equations employed in hydrologic studies were, in fact, developed from thermodynamic equations. The hydrogeologic technique applied to the loop-temperature data is the Jacob (1950) semilogarithmic method of solution for transmissivity of an aquifer from which water is pumped under certain specific conditions.

The equation for Jacob's approximation:

$$K = \frac{2.3Q}{4\pi m(s/\log \text{ cycle } t)}$$

contains the terms:

- K = hydraulic conductivity
- Q = pumping rate (quantity/time)
- m = aquifer thickness
- s = drawdown (pressure or water-level decline)
- t = time

The following heat flow terms and units were substituted into Jacob's approximation:

- C = thermal conductivity (Btu/hr–ft–°F)
- Q = heat withdrawal rate (Btu/hr)
- d = length of loop boreholes and trenches (ft)
- $\Delta T$ = temperature decline (°F)
- t = time

This gives the following approximation for estimating thermal conductivity:

$$C = \frac{2.3Q}{4\pi d(\Delta T/\log \text{cycle } t)}$$

There is no precedent for developing heat-flow solutions using hydrodynamic equations. The analogies are clear, however, between heat flow, electricity, and hydrodynamics. Most important, the equations for groundwater flow were originally developed from thermodynamics; solutions found in this study suggest that a reverse application should be valid. Jacob's approximation is a field simulation of the laboratory method of measuring thermal conductivity, described by Hart and Couvillion (1986), and can be derived from their equation.

Temperature declines for the initial parts of the two heating seasons were plotted against time (days) on semi-logarithmic graph paper (figure 5). A key condition for Jacob's approximation (constant rate of heat withdrawal) could not rigorously be met with the heat-pump operation, however. Average daily rates of heat production resulting from the outside temperature extremes (figure 3) and the human factors of thermostat adjustments (hopefully kept to a minimum) ranged from about 7,000 Btu/hr to about 40,000 Btu/hr during the first season, and about 5,900 Btu/hr to 41,000 Btu/hr during the second season. Average production rates were 26,450 Btu/hr and 24,670 Btu/hr, respectively. The extreme variations of loop temperature caused by variations of heat production gave a scatter to the points on figure 5 that makes an analysis somewhat subjective.

Visual best-fit straight lines on the two semi-log plots give temperature declines of 3.60°F and 3.35°F per log cycle, respectively. Combined into Jacob's approximation with the average 120-day heat-production rates of 26,450 Btu/hr and 24,670 Btu/hr, the temperature declines indicate a thermal conductivity of 1.7 Btu/hr–ft–°F. The duplicative result for two seasons in spite of broad spreads of data suggests that the approximation technique may have merit. The implied thermal conductivity of 1.7 Btu/hr–ft–°F is somewhat higher than the values of 0.75 and 0.266 Btu/hr–ft–°F for the soil and the polyethylene pipes, respectively, used in designing the loop system (appendix B). The 1.7 Btu/hr–ft–°F value is well within the range (0.59 to 3.33 Btu/hr–ft–°F) given by Hart and Couvillion (1986) for a shallow water-table condition in sandstone and shale. The 1.7 Btu/hr–ft–°F value also is within the range of 0.75–2.00 Btu/hr–ft–°F given by Dexheimer (1985) for

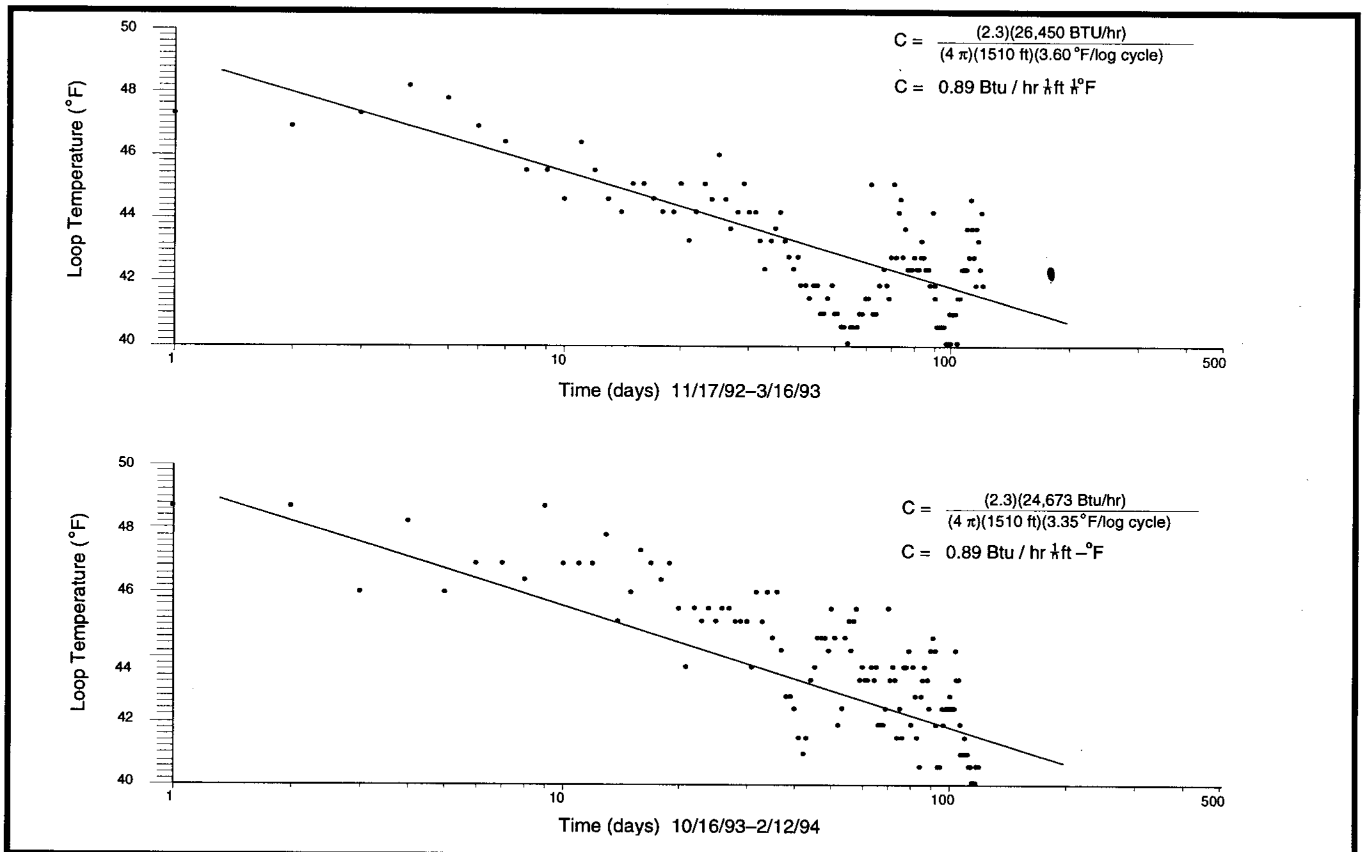


*Figure 5. Semi-log plots of loop temperature versus time can be used to estimate thermal conductivity at ground-source heat pump installations.*

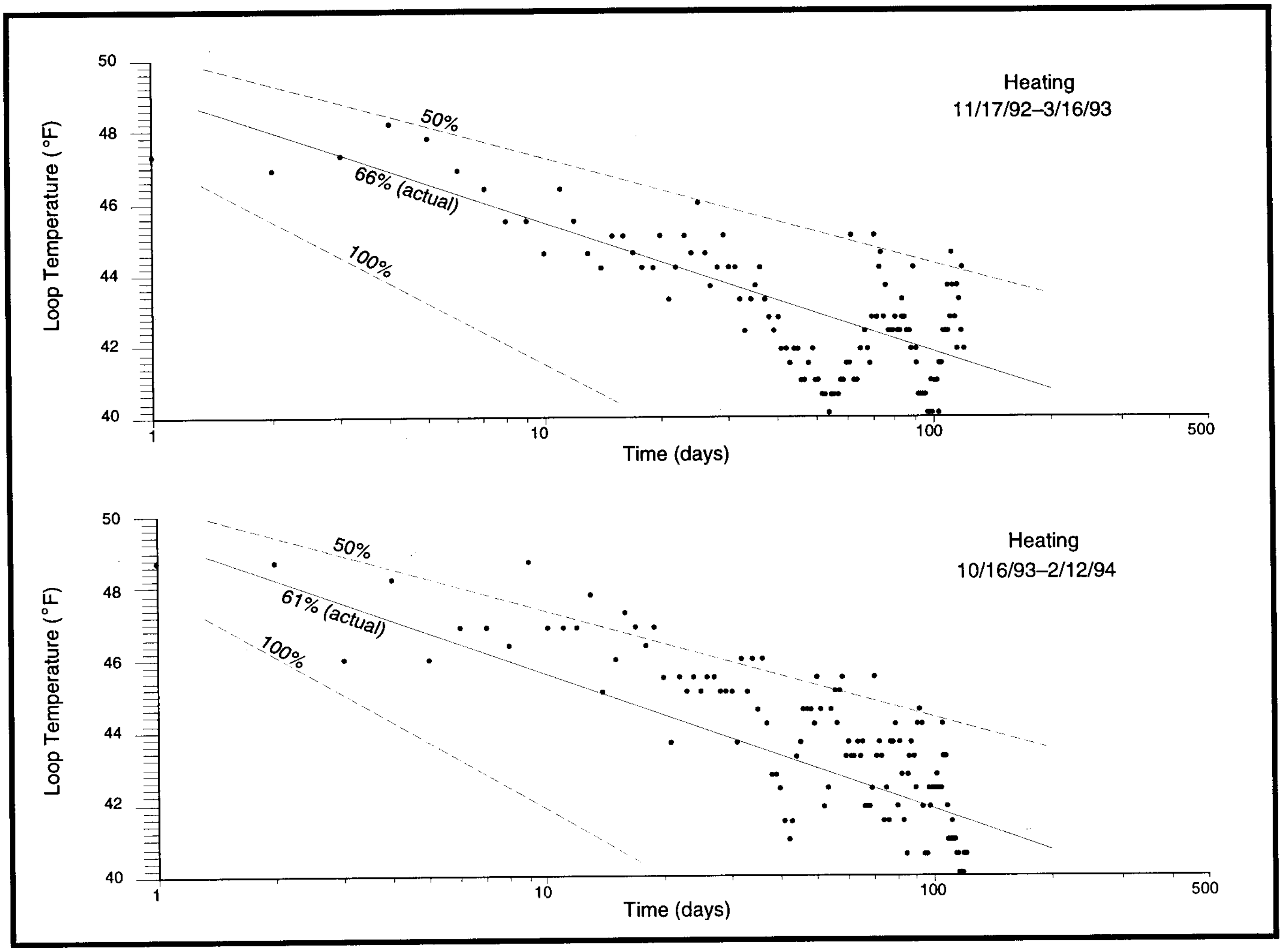


*Figure 6. The percent of time that a system operates determines the loop-temperature decline. In these tests, actual performances were 66% and 61% of the time. Hypothetical temperatures are shown (dashed) for 50% and 100% operating conditions.*

bedrock materials. The combination of vertical and horizontal, with pipes of two diameters, and with variations of soil moisture probably preclude any more precise calculation for thermal conductivity at any site. The advantage hoped for in this in-situ approximation has been to avoid these specifics to estimate actual operational values. It appears that the approximation method applied here may be useful but could be greatly improved with more uniform patterns of system operation.

Semilog plots of temperature decline also may predict declines for other heat-production rates (figure 6). For any selected thermal conductivity value, the temperature decline (°F/log cycle t) in Jacob's approximation, varies directly with the rate (Btu/hr) of heat produced. In 1992–1993, the system operated 66% of the time and in 1993–1994, the system operated 61% of the time. By simple ratios, the hypothetical temperatures for 100% and 50% operation are shown in figure 6; they are identical for each year. Similarly, any other percent-operating time can be projected and will not vary yearly unless changes occur in the earth heat source or in system efficiency.

## Conclusions

A vertical-loop, ground-source heat pump system near Helena, Montana, was instrumented and monitored during the 1992–1993 and 1993–1994 heating seasons. Continuous records of operating time and energy use, daily minimum loop temperatures, and spot measurements of entering and leaving loop temperatures over a wide operating range were obtained. The latter were used to estimate a COP of 3.10, close to the manufacturer's specification of 3.11, which was used for sizing design. Minimum daily loop temperatures were found to occur between about 4:00 A.M. and 6:00 A.M., when temperatures outside were coldest and heat pump operation was greatest.

Outdoor minimum daily temperatures during the first heating season commonly ranged between −20°F and +20°F; during the second season they were below 0°F for only a few days. Loop-fluid temperatures fluctuated similarly to those of outdoor air, ranging from about 49°F to 40°F each season.

In addition to measuring loop-fluid temperature decline, an objective of this work was to try to use time, energy production, and loop temperatures in a simple relationship to estimate thermal conductivity of the earth and piping system. Using a semilogarithmic equation borrowed from hydrogeologic technology, thermal conductivity was calculated by using the analogy between heat flow and groundwater flow. The data points are heavily scattered in the plots, making a solution somewhat subjective. Best-fit lines gave a thermal conductivity of 1.7 Btu/hr–ft–°F. Design thermal conductivities in loop construction were 0.77 and 0.22 Btu/hr–ft–°F for the earth source and the polyethylene piping, respectively. Other values from the literature range between 0.59 and 3.33 Btu/hr–ft–°F. The test results are valid and well within the ranges typical for similar bedrock materials, in spite of the widely scattered data. Though not definitive, the results are promising enough that semi-log analyses of other systems, both vertical and horizontal, may lead to a reasonably simple and dependable technique for in-situ system evaluations.

## Acknowledgements

Monitoring and other activities described in this report were funded in part by the U.S. Department of Energy's Low-Temperature Geothermal Resources and Technology Transfer Program, administered through the University of Utah Research Institute, Salt Lake City, and through the Geo-Heat Center at the Oregon Institute of Technology, Klamath Falls. Additional funding and power-consumption data were provided by the Montana Power Company, Butte. Support by colleagues, John Metesh, Sharon Miller, and Pat Tamarin of the Montana Bureau of Mines and Geology, Butte, is gratefully acknowledged.

## References

Dexheimer, R. D. 1985. *Water Source Heat Pump Handbook*. National Water Well Association. Dublin, Ohio. 241 p.

Hart, D. P., and Couvillion, R. 1986. *Earth-Coupled Heat Transfer.* National Water Well Association. Dublin, Ohio. 192 p.

Jackson, M. A., 1989, *Montana House Project.* Montana Department of Natural Resources and Conservation. Helena, Montana. 30 p.

Jacob, C. E. 1950. Flow of ground water. *In Engineering Hydraulics*. John Wiley and Sons. New York, New York. p. 321–386.

Kirk-Othmer 1981. *Encyclopedia of Chemical Terminology*. John Wiley and Sons. New York, New York. Third ed., v. 15, p. 411–412.

Maunder, J. 1995. Personal communication, May 4. Secretary, Northern Rockies Gound Source Heat Pump Association and member-services representative, Missoula, Electric Co-op. Missoula, Montana.

Moran, C. 1995. Personal communication, May 8. Energy Services representative, Montana Power Company. Butte, Montana.

Wright, P. M. and Colvin, S. L. 1993. *Geothermal Heat-Pump Systems: The ABC's of GHP's in Utilities and Geothermal.* An Emerging Partnership. Geothermal Resources Council Transactions. Davis, California. v. 17, p. 303–314.

# Appendix A

# House Thermal Specifications

# and

# Design Heat Load

01/01/80 WATTSUN version 4.2 - SUMMARY REPORT FILE : C:\WS4\VANVOAST.HSE

## HOUSE IDENTIFICATION

| | | | |
|---|---|---|---|
| House ID | : VAN VOAST | Utility | : MPC |
| Address | : MERCURY ST. BUTTE | Analyst | : KG |
| Builder | : ENERGY RE/CON | Location | : HELENA3 |
| Owner | : WAYNE VAN VOAST | Floor Area | : 4056 $ft^2$ |

===================QUALIFICATION CRITERIA===================

| SUPER GOOD CENTS/ NORTHWEST ENERGY CODE | REFERENCE | CURRENT | PROPOSED |
|---|---|---|---|
| Thermal Performance (Btu/hr-F) | 628 | 457 | 457 |
| Energy Budget (kWh / ft2-yr) | 4.44 | 0.99 | 2.58 |

*QUALIFIED *

| HEATING AND VENTILATING SYSTEMS | CURRENT | PROPOSED |
|---|---|---|
| Heating System Type | Heat Pump | Furnace |
| Heat Pump heating Season Performance Factor | 10.20 | N/A |
| Heat Load at 91°F design temp different (Btu/hr) | 44043.7 | 44043.7 |
| System Size at 150% Design Load (kW (kBtu/hr)) | 19.5(66.0) | 19.5(66.0) |
| Average Annual Space Heat Requirement (kWh/yr) | 5096 | 13250 |
| Ventilation System Type | NHRV: Integrated Spot & Whole House | |

| ECONOMICS | CURRENT | PROPOSED |
|---|---|---|
| Incremental Construction Cost | $ ______ | $ 0.00 |
| Projected Yearly Heating Cost | 0.00 | 0.00 |
| First Year Monthly PITI ($/month) | $ 0.00 | $ 0.00 |
| Average Monthly heating Costs | $ 0.00 | $ 0.00 |
| TOTAL FIRST YEAR MONTHLY PAYMENT | $ 0.00 | $ 0.00 |
| 30 year Life Cycle Cost | $ 0.00 | $ 0.00 |

Actual energy use will vary with climate, lifestyle, and construction. Economic and energy use estimates should be used for comparative purposes only.

01/01/80

WATTSUN version 4.2 - COMPONENTS REPORT
FILE : C:\WS4\VANVOAST.HSE

BUILDING COMPONENT SUMMARY

| Component | Entries | Curr Area | Prop UA | UA | Cost | $/UA |
|---|---|---|---|---|---|---|
| Below-Grade Walls | 1 | 124 | 55.6 | 55.6 | | |
| Slab Perimeters | 1 | 95 | 43.2 | 43.2 | | |
| Floors Over Crawl Spaces | 0 | 0 | 0.0 | 0.0 | | |
| Walls | 1 | 2295 | 91.8 | 91.8 | | |
| Windows | 1 | 413 | 132.2 | 132.2 | | |
| Doors | 2 | 70 | 23.1 | 23.1 | | |
| Skylights | 0 | 0 | 0.0 | 0.0 | | |
| Ceilings | 1 | 2028 | 35.3 | 35.3 | | |
| Air Leakage Control | 1 | 25350 | 79.6 | 79.6 | | |
| Mass | 2 | 4056 | 18252.0 | 18252.0 | | |
| TOTALS | | | 460.7 | 460.7 | | |

GLAZING ORIENTATION

| Area Eff. Area | CURRENT Eff. Area | % Floor Area | Orientation | PROPOSED Area | | % Floor Area |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | South | 0.0 | 0.0 | 0.0 |
| 31.0 | 25.9 | 0.8 | Southeast | 31.0 | 25.9 | 0.8 |
| 0.0 | 0.0 | 0.0 | East | 0.0 | 0.0 | 0.0 |
| 83.0 | 25.0 | 2.0 | Northeast | 83.0 | 25.0 | 2.0 |
| 0.0 | 0.0 | 0.0 | North | 0.0 | 0.0 | 0.0 |
| 22.0 | 6.6 | 0.5 | Northwest | 22.0 | 6.6 | 0.5 |
| 0.0 | 0.0 | 0.0 | West | 0.0 | 0.0 | 0.0 |
| 277.0 | 231.3 | 6.8 | Southwest | 277.0 | 231.3 | 6.8 |
| 413.0 | 288.7 | 10.2 | TOTALS | 413.0 | 288.7 | 10.2 |

01/01/80 WATTSUN version 4.2 - COMPONENTS REPORT (Continued)
FILE : C:\WS4\VANVOAST.HSE

## BELOW-GRADE WALLS

| Description | F-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> 4' depth/2x4 24" o.c. /interior R-11 + R-19 | 0.450 | 123.5 | 55.6 | | |
| P> 4' depth/2x4 24" o.c. /interior R-11 + R-19 | 0.450 | 123.5 | 55.6 | | |

## SLAB PERIMETERS

| Description | F-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> Slab/R-10 insulation, /2' horizontal | 0.455 | 95.0 | 43.2 | | |
| P> Slab/R-10 insulation, /2' horizontal | 0.455 | 95.0 | 43.2 | | |

## WALLS

| Description | U-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> 2 x 6 R-19 advanced + R-7.2 sheath | 0.040 | 2295.0 | 91.8 | | |
| P> 2 x 6 R-19 advanced + R-7.2 sheath | 0.040 | 2295.0 | 91.8 | | |

## WINDOWS

| Description | U-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> 2-glaze, ½", wood or vinyl w/storm | 0.320 | 413.0 | 132.2 | | |
| P> 2-glaze, ½", wood or vinyl w/storm | 0.320 | 413.0 | 132.2 | | |

## DOORS

| Description | U-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> Wood solid core, flush | 0.330 | 70.0 | 23.1 | | |
| P> Wood solid core, flush | 0.330 | 70.0 | 23.1 | | |

1/01/80 WATTSUN version 4.2 - COMPONENTS REPORT (Continued)
FILE : C:\WS4\VANVOAST.HSE

## CEILINGS

| Description | U-value | Pmtr | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> R-60 advanced | 0.017 | 2028.0 | 35.3 | | |
| P> R-60 advanced | 0.017 | 2028.0 | 35.3 | | |

## AIR LEAKAGE CONTROL

| Description | ACH | Volume | UA | $/sf | Cost |
|---|---|---|---|---|---|
| C> Advanced Air Sealing - above grade volume | 0.200 | 25350.00 | 79.6 | | |
| P> Advanced Air Sealing - above grade volume | 0.200 | 25350.00 | 79.6 | | |

## MASS

| Description | M-value | Area | Btu/F | $/sf | Cost |
|---|---|---|---|---|---|
| C> Light frame construction Btu/F-ft$^2$ flr | 3.000 | 2028.0 | 6084.0 | | |
| Slab-carpet, rubber pad Btu/F-ft$^2$ flr | 6.000 | 2028.0 | 12168.0 | | |
| TOTALS> | | | 4056.0 | 18252.0 | |
| P> Light frame construction Btu/F-ft$^2$ flr | 3.000 | 2028.0 | 6084.0 | | |
| Slab-carpet, rubber pad Btu/F-ft$^2$ flr | 6.000 | 2028.0 | 12168.0 | | |
| TOTALS> | | | 4056.0 | 18252.0 | |

1/01/80

WATTSUN version 4.2 - HEATING SYSTEM REPORT
FILE : C:\WS4\VANVOAST.HSE

| SYSTEM | CURRENT | | | PROPOSED | | |
|---|---|---|---|---|---|---|
| Heating system type | Heat Pump | | | Furnace | | |
| Heat Pump HSPF | 10.20 | | | | | |
| Ducts | Size | Length | Rval | Size | Length | Rval |
| | 10" x 20" | 5 ft | R-11 | 10" x 20" | 5 ft | R-11 |
| | 10" | 40 ft | R-11 | 10" | 40 ft | R-11 |
| | 8" | 60 ft | R-11 | 8" | 60 ft | R-11 |

| BUILDING HEAT LOSS | CURRENT | PROPOSED |
|---|---|---|
| Envelope | 460.7 Btu/hr-°F | 460.7 Btu/hr-°F |
| Ducts | 23.3 | 23.3 |
| TOTALS> | 484.0 | 484.0 |

| DESIGN RESULTS | CURRENT | PROPOSED |
|---|---|---|
| Design heat load | 44043.7 Btu/hr | 44043.7 Btu/hr |
| | 12.9 kW | 12.9 kW |
| System size (150%) | 66.0 kBtu/hr | 66.0 kBtu/hr |
| | 19.5 kW | 19.5 kW |
| Total Space Heat | 5096.0 kWh/yr | 13250.0 kWh/hr |

| BASED ON THE FOLLOWING DESIGN CONDITIONS | |
|---|---|
| Winter design wind speed | 15 mph |
| Thermostat set point | 70° F. |
| Winter design temperature | -21° F. |
| Design temperature difference | 91° F. |

Actual energy use will vary with climate, lifestyle, and construction. Economic and energy use estimates should be used for comparative purposes only.

# Appendix B

## Heat Pump

## Design Program

*******************************************************************************

Closed-Loop/Ground-Source Heat Pump Design Program
Vertical and Horizontal Systems
James E. Bose Ph.D., P.E.

(405)624-2554
4618 William Court
Stillwater, OK 74075

*******************************************************************************

Software Licensee
John Dibble - Earth Energy
(208)263-7358
Sandpoint, ID 83864

*******************************************************************************

PROJECT DESCRIPTION - - - - -VAN VOAST VERTICAL 3½ TON

TEMPERATURE BIN DATA LOCATION - - - - - - - HELENA, MONTANA
HEAT PUMP MODEL NUMBER - - - - - - - - - - - - 411E
MANUFACTURER - - - - - - - - - - - - - - - - - - - - - - CA

| | | | | |
|---|---|---|---|---|
| Annual Cooling Cost ($) | 79 @ 0.05 | $/kWh. | 26425 | Btu/hr |
| Annual Heating Cost ($) | 518 @ 0.064 | $/kWh. | 44043 | Btu/hr |

Total Heating and Cooling Costs - - - - - - - - - 598

Domestic Hot Water Costs ($) for 100 gallons/day at a water temperature of 130°F.

| | |
|---|---|
| Electric resistance | 441 |
| With desuperheater | 291 |
| with 100% heat pump | 145 |

| | |
|---|---|
| Heating capacity @ EWTmin = 25°F is 32000 Btu/hr | COP - 3.11 |
| Cooling capacity @ EWTmax =75°F is 45500 Btu/hr | EER - 12.69 |

| | |
|---|---|
| Supplemental heat Required (kW) | 5.32 @ -38°F Outdoor Air Temperature |
| Heat Pump Power (kW) | 3.06 @ -38°F Outdoor Air Temperature |

| | |
|---|---|
| Heat Pump Power (kW) | 3.58 @ 75°F Entering Water Temperature |

BUILDING HEAT LOAD (Btu/HR) - - - - - - - - - - - - - - - - - - - - - - - - - - - 44043
WINTER DESIGN TEMPERATURE - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -16
HEAT PUMP HEATING CAPACITY (Btu/HR) - - - - - - - - - - - - - - - - - - - 32000
    MINIMUM EWT (F) - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 25
    COP @ MIN EWT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 3.115
    RUN FRACTION (Fh) - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 0.62
    SUPPLEMENTAL HEAT REQUIRED (KW) - - - - - - - - - - - - - - - - - - - - - 5.3
    STRIP HEAT REQUIRED (KWH IN JANUARY) - - - - - - - - - - - - - - - - 204

BUILDING HEAT GAIN (Btu/HR) - - - - - - - - - - - - - - - - - - - - - - - - - - - 26425
SUMMER DESIGN TEMPERATURE (F) - - - - - - - - - - - - - - - - - - - - - - - - - 88
SUMMER INDOOR TEMPERATURE (F) - - - - - - - - - - - - - - - - - - - - - - - - - 78
SUMMER BALANCE TEMPERATURE (F) - - - - - - - - - - - - - - - - - - - - - - - - 70
HEAT PUMP COOLING CAPACITY (Btu/HR) - - - - - - - - - - - - - - - - - - - 45500
    MAXIMUM EWT (F) - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 75
    EER @ MAX EWT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 12.7
    RUN FRACTION (Fc) - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 0.23

SOIL THERMAL PROPERTIES

SOIL DESCRIPTION : HEAVY SOIL DAMP
THERMAL DIFFUSIVITY (FT' 2/HR) ---------------------------- 0.025
THERMAL CONDUCTIVITY (Btu/HR-FT-F) ----------------------- 0.75

PIPE PROPERTIES

PIPE IDENTIFICATION : ¾ INCH PE SDR-11
THERMAL CONDUCTIVITY (Btu/HR-FT-F) ---------------------- 0.226
PIPE INSIDE DIAMETER (INCHES) ----------------------------- 0.86
PIPE OUTSIDE DIAMETER (INCHES) --------------------------- 1.05

PIPE AND SOIL RESISTANCE VALUES

PIPE RESISTANCE (HR-FT-F/Btu) ---------------------- 9.641665E-02
SOIL RESISTANCE (HR-FT-F/Btu) ------------------------ 0.9361914 @ 463 HRS

SOIL TEMPERATURES

MEAN EARTH TEMPERATURE (F) - 50, ANNUAL SWING (F) = 20 , PHASE SHIFT (DAYS) = 40

SOIL MINIMUM TEMPERATURE AT DEPTH = 100 (FT) ------------- 49.9
SOIL MAXIMUM TEMPERATURE AT DEPTH = 100 (FT) ------------- 50.0

* * * * * * * * * * * * * * * * * * GROUND HEAT EXCHANGER DESIGN * * * * * * * * * * * * * * *

PIPES IN LOOP BUNDLE ---------------------------------- 2
BORE LENGTH REQUIRED FOR HEATING REQUIREMENTS (FEET) --- 590
BORE LENGTH REQUIRED FOR COOLING REQUIREMENTS (FEET) -- 731

Closed-Loop/Ground-Source Heat Pump Design Program (Continued)

| (FT) BRANCH | LENGTH | (IN'S) DIAMETER | (GPM) FLOW | REYN NUMBER |
|---|---|---|---|---|
| 1 | 350 | 0.86 | 3 | 2135 |
| 2 | 350 | 0.86 | 3 | 2135 |
| 3 | 350 | 0.86 | 3 | 2135 |
| 4 | 350 | 0.86 | 3 | 2135 |

HEAD=(FEET) = 6.505 12

FLUID – 20% PG ** TEMPERATURE – 23° F ** VISCOSITY (LB/FT-HR) – 12.94

C – CONTINUE ESC – ESCAPE BACK TO MAIN MENU

| PIPE BRANCH | 1 PIPE DESC— 4 | 1½ UBCG OE SDR-11 |
|---|---|---|
| | 2 PIPE DESC— 0 | |
| | 3 PIPE DESC— 0 | |

| Pipe Branch Number SB 1 | SB 2 | SB 3 | HP | PAR BRCH | |
|---|---|---|---|---|---|
| Pipe Inside Diameter (inches) ----------- 1.554 | 0 | 0 | | | |
| Flow Rate (gpm) -------------------- 12 | 0 | 0 | 0 | | 12 |
| Fluid Velocity (ft/sec) 2 -------------------- 0 | 0 | | | | |
| Reynolds Number ----------------- 4719 | 0 | 0 | | | |
| Fluid --------------- 20% PG | | | | | |
| Fluid Temperature (F) ------------------ 23.0 | 0.0 | 0.0 | 0.0 | | |
| Fluid Density (lb/ft^3) -------------------- 64 | 0 | 0 | | | |
| Fluid Viscosity (lb/ft-hr) ----------------- 12.9 | 0.0 | 0.0 | | | |
| Pipe Length (feet) ----------------- 180 | 0 | 0 | | | |
| Pressure Drop (feet of head) -------------- 3.4 | 0.0 | 0.0 | 0.0 | | 6.5 |
| (psi) ------------------- 1.4 | 0.0 | 0.0 | 0.0 | | 2.8 |
| Volume (gallons) ----------------- 17.7 | 0 | 0 | | | 42 |

Total PD (FT) = Parallel + Series + Heat Pump = 9.9 Volume (Gallons) = 59.9

P – SB Press Drop A – Add Loops C – Clear ESC – Return to Design Menu

Closed-Loop/Ground-Source Heat Pump Design Program (Continued)

| (FT) BRANCH | (IN'S) LENGTH | (GPM) DIAMETER | REYN FLOW | NUMBER |
|---|---|---|---|---|
| 1 | 466 | 0.86 | 4 | 2846 |
| 2 | 466 | 0.86 | 4 | 2846 |
| 3 | 466 | 0.86 | 4 | 2846 |

HEAD (FEET) = 15.391 12

FLUID – 20% PG ** TEMPERATURE – 23° F ** VISCOSITY (LB/FT-HR) – 12.94

C – CONTINUE ESC – ESCAPE BACK TO MAIN MENU

PIPE BRANCH 1 PIPE DESC— 4 1½ INCH PE SDR-11
2 PIPE DESC— 0
3 PIPE DESC— 0

| Pipe Branch Number | SB 1 | SB 2 | SB 3 | HP | PAR BRCH |
|---|---|---|---|---|---|
| Pipe Inside Diameter (inches) -------- | 1.554 | 0 | 0 | | |
| Flow Rate (gpm) ---------------- | 12 | 0 | 0 | 0 | 12 |
| Fluid Velocity (ft/sec) 2 ---------------- | 0 | 0 | | | |
| Reynolds Number -------------- | 4719 | 0 | 0 | | |
| Fluid ------------ | 20% PG | | | | |
| Fluid Temperature (F) 23.0 ------------ | 0.0 | 0.0 | 0.0 | | |
| Fluid Density (lb/ft^3) 64 --------------- | 0 | 0 | | | |
| Fluid Viscosity (lb/ft-hr) -------------- | 12.9 | 0.0 | 0.0 | | |
| Pipe Length (feet) --------------- | 180 | 0 | 0 | | |
| Pressure Drop (feet of head) ----------- | 3.4 | 0.0 | 0.0 | 0.0 | 15.4 |
| (psi) ---------------- | 1.4 | 0.0 | 0.0 | 0.0 | 6.7 |
| Volume (gallons) -------------- | 17.7 | 0 | 0 | | 42 |

Total PD (FT) = Parallel + Series + Heat Pump = 18.8 Volume (Gallons) = 59.9

P– SB Press Drop A– Add Loops C– Clear ESC - Return to Design Menu