Greenhouse Heating with Geothermal Heat Pump Systems

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ABSTRACT

The objective of this study is to examine the feasibility of greenhouse heating with geothermal heat pump (GHP) systems. Both closed- and open-loop systems are examined at four locations across the U.S. and a net present value analysis is conducted for a 20-year life-cycle for various GHP base-load fractions.

Results show that it would only be under situations of relatively low ground loop installation costs and/or relatively high natural gas costs that some portion of a greenhouse could be economically heated with a closed-loop GHP system. At natural gas costs of about $0.60/therm ($0.21/m^3), no fraction of a closed-loop GHP system is economically feasible for the cases examined. At natural gas costs from $0.60/therm to $1.00/therm ($0.21/m^3 to $0.35m^3), closed-loop GHP systems begin to emerge as economically viable, but only at low loop installation costs, on the order of $5.50/ft ($18/m). At these rates, the feasible ground loop size would only be capable of handling 15-30% of the total annual heating demands of the greenhouse. At ground loop installation costs of $10/ft ($33/m), natural gas costs would have to exceed $1.50/therm ($0.53/m^3) for closed-loop GHP systems to be considered economically viable.

Open-loop GHP systems show considerably more favorable economics than closed-loop systems. At natural gas costs of about $0.60/therm ($0.21/m^3), an open-loop system could feasibly be installed to handle 25-30% of annual greenhouse heating demands. At $0.75/therm ($0.26/m^3) natural gas cost, the feasible annual base-load handled by an open-loop system would increase to 60% and then again to about 85% at $1.00/therm ($0.35m^3) natural gas cost. Of course, open-loop systems would need to be sited at locations with sufficient ground water supply.

INTRODUCTION

The success and economic benefits of heating greenhouses with low-temperature geothermal resources (i.e. groundwater temperatures >140°F (60°C)) has lead to the question of whether or not lower temperature resources could be exploited with the aid of geothermal heat pumps (GHPs). This study seeks to answer that question, and therefore the objective is to determine the feasibility of heating greenhouses with GHP systems. Both closed- and open-loop systems are examined at four locations across the United States: Boston, MA; Dallas, TX, Denver, CO; and Seattle, WA. A number of GHP base-load combinations are examined for the four locations to find the lowest 20-year life-cycle cost at various natural gas rates and GHP installation costs.

GREENHOUSE HEATING SYSTEMS

Of the many types of greenhouse heating systems, the two most common types are fan-coil systems and bare-tube systems. The particular system chosen by a grower depends on many factors such as economics, type of crop, and preference.

In a comparison study of this type, assumptions need to be made about the greenhouse heating system that is being displaced by the GHP system. GHPs are of two types: water-to-water and water-to-air. Water-to-water heat pumps would displace a low-temperature fossil-fuel fired boiler system. Water-to-air heat pumps would displace fan systems, where the conventional heat source could either be a boiler with unitary hot water fan coil system or a direct gas-fired air-handling type system. Therefore, for comparison purposes in this study, the greenhouse heating system considered is a simple bare-tube system where the base-load heat demand is supplied by a water-to water GHP system and the remaining heat demands are supplied by a natural gas-fired, low-temperature boiler.

GREENHOUSE HEATING LOADS

Hourly heating loads were calculated for a **1 acre** (4047 m^2**) greenhouse** using typical meteorological year (TMY) data for Boston, MA, Dallas, TX, Denver, CO, and Seattle, WA. Heat transfer processes included in the calculations were: *solar heat gain, conduction through the structure, convection, infiltration, and ground conduction*. Greenhouse construction was assumed to be fiberglass with a set-point temperature of 65°F (18.3°C) and infiltration losses of 1 air-change per hour. Greenhouse cooling was assumed to be accomplished by another means, such as natural ventilation or evaporative cooling.

Hourly heating loads for the year are shown in Figure 1. As might be expected, Denver and Boston show the most extreme heating loads. An interesting and important result is shown in Figure 2, which is a plot of the fraction of total annual heating demands versus the fraction of the peak load that a base-load system would be designed to handle. This is significant since a base-load system (the GHP system in this case) sized at 50% of the peak load could meet about 92% of the total annual heating requirements.

ECONOMIC ANALYSIS

Closed-Loop GHP System

The hourly loads shown in Figure 1 were converted to monthly total and peak loads, and using a software program, ground loops were sized for each city for several GHP part load cases (100%, 75%, 50%, 33%, 25%, 10%, and 0%). The loop-sizing software also computes heat pump power consumption.

A net present value (NPV) analysis of a 20-year life cycle was used to compare alternatives for the various part load cases. Equipment costs for natural gas-fired boiler systems were taken from R.S. Means Mechanical Cost Data and water-to-water heat pump material and installation costs were assumed at $1000/ton ($284/kW) of heat pump capacity. Ground loop installation costs are commonly reported per foot of vertical bore, and for this study, a range of $4/ft to $12/ft ($13/m to $39/m) was examined, which is representative of the widely varying values observed across the U.S.

Annual operating costs included fuel and maintenance costs. A range of natural gas costs from \$0.50 to \$2.00 per therm (\$0.18/m^3 to \$0.70/m^3) was examined. Electricity cost was fixed at $0.10/kW-hr. Annual boiler maintenance costs were assumed at 2% of capital cost. A discount rate of 6% was assumed.

Results of the closed-loop economic analysis are presented in Figure 3 in the form of a contour plot. Results were similar for all cities examined. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and ground loop installation costs. A review of Figure 3 reveals that at natural gas prices of about $0.80/therm (\$0.25/m^3), it would not be justifiable to heat any portion of a greenhouse with a closed-loop GHP system unless the ground loop could be installed at very low cost of about $5/ft ($16.40/m). At these rates, it would only be feasible to install a ground loop capable of handling 15-30% of the total annual heating requirements. At a loop installation cost of $10/ft ($33/m), natural gas prices would have to exceed \$1.50/therm (\$0.53/m^3) to justify installing a ground loop to handle 15-30% of the total annual heating requirements.

Open-Loop GHP System

The same overall approach was taken in the economic analysis of the open-loop systems as for the closed-loop systems with the following differences. The capital cost range of the open loop systems were taken from *Outside the Loop Newsletter* (Vol. 1, No.1, 1998). These costs, shown in Figure 4, are expressed per ton (and kW) of delivered capacity for various well configurations and include costs of production and injection wells, well tests, pumps, piping to the building, heat exchangers, controls, and 15% contingency. For the operating costs, additional electrical loads were included to account for a submersible pump operating under an assumed vertical head of 100 ft (30.48 m).

Results of the open-loop economic analysis are presented in Figure 5. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and open loop installation costs. A review of Figure 5 shows much greater feasibility of greenhouse heating with open-loop GHP systems over closed-loop systems. At natural gas prices of about \$0.80/therm (\$0.25/m^3), it would be economically feasible to install an open-loop GHP system up to a cost of about \$600/ton (\$170/kW). This open loop cost covers most of the well configurations shown in Figure 4. For this cost, an approximate 40% open-loop system (relative to the peak load) could feasibly be installed and would be capable of handling about 80% of the total annual heating demands (see Figure 2). Note also the relative "flatness" of the 0.1 to 0.4 curves in Figure 5 from about \$200/ton to \$600/ton (\$57/kW to \$170/kW). This reflects the economies of scale with open loop systems; only two to four wells are needed if enough ground water is present. Thus, a greenhouse would need to be sited at a location where there is sufficient ground water supply.

CONCLUDING SUMMARY

This study has examined the feasibility of greenhouse heating with closed- and open-loop GHP systems. Heating loads were computed for four climates across the U.S. The net present value of a 20-year life-cycle was determined for various GHP base-load fractions.

The results of this study show that the feasibility of heating greenhouses with closed-loop GHP systems is strongly dependent on the natural gas cost and the ground loop installation cost. It would not be economically justifiable to heat any portion of a greenhouse using a closed-loop GHP system unless loop installation costs were as low as \$4/ft to \$5/ft (\$13/m to \$16.40/m) and natural gas prices exceeded \$0.75/therm (\$0.26/m^3). This represents a very marginal situation at 2005 rates. On the contrary, for the cases examined, open loop systems appear to be quite economically feasible above natural gas rates of about \$0.60/therm (\$0.21/m^3).

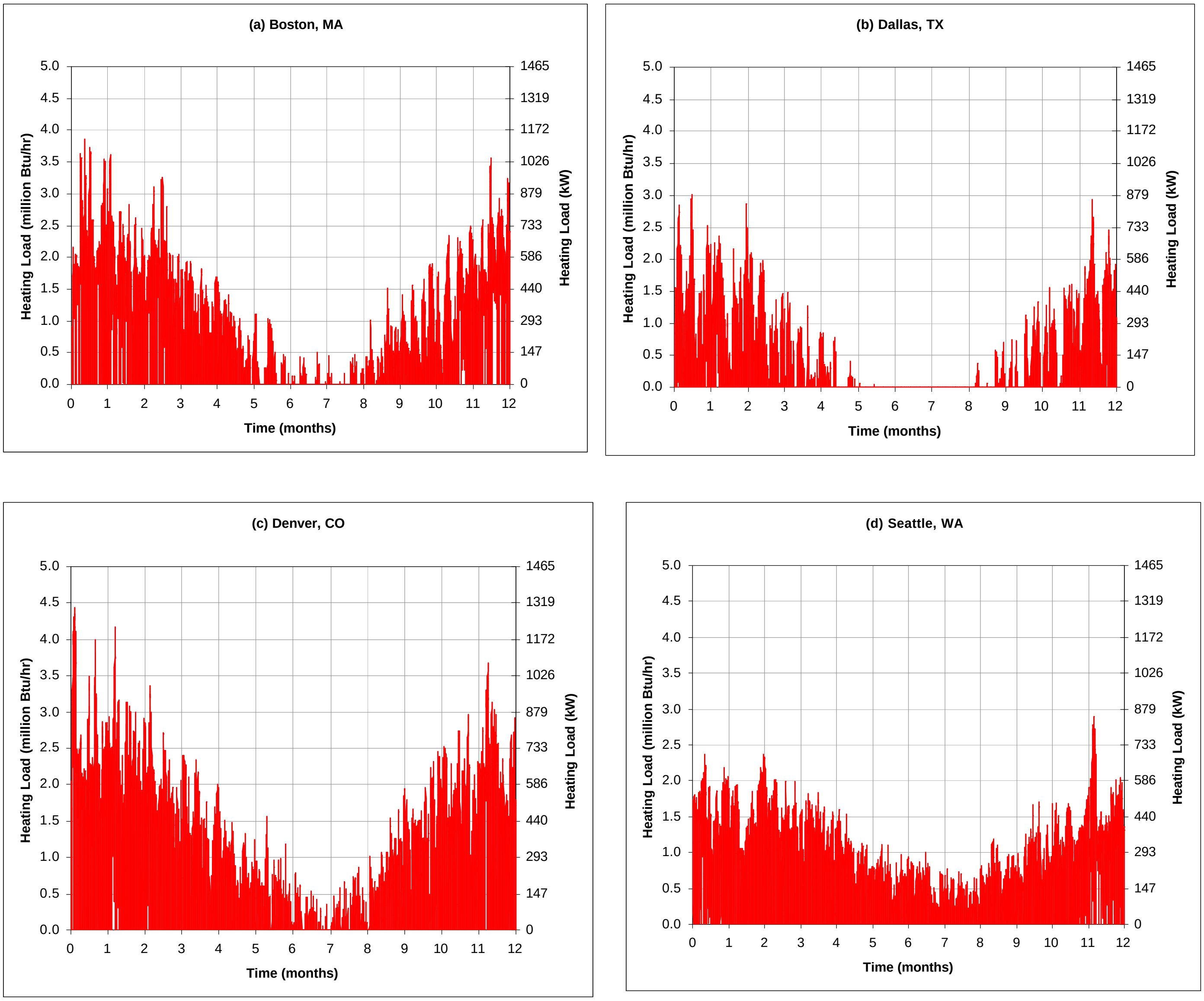

Figure 1*. Hourly heating loads on an annual basis.*

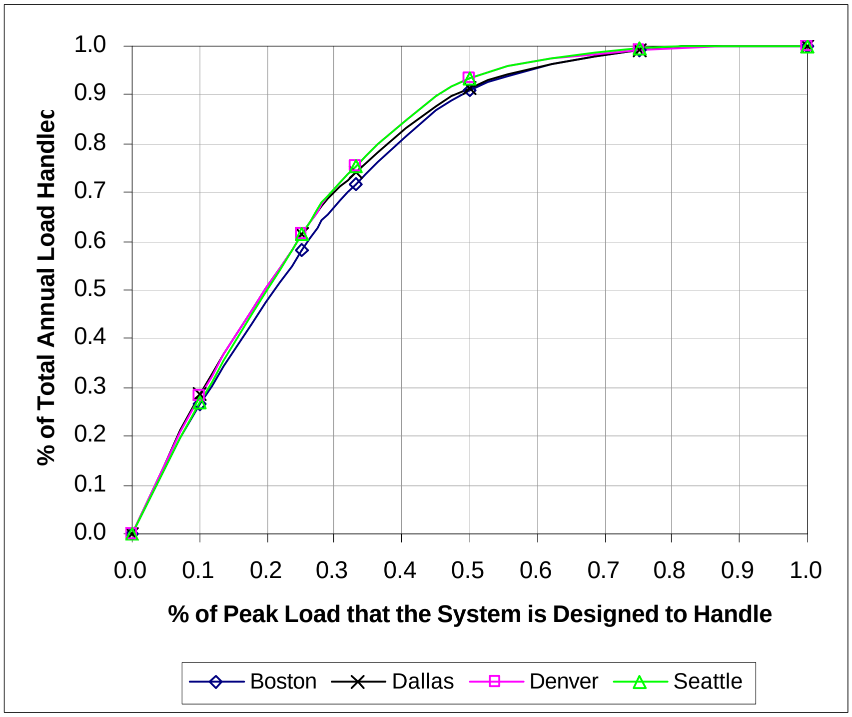

***Figure 2**. Fraction of total annual heating load actually handled versus design fraction of peak load for a base-load system.*

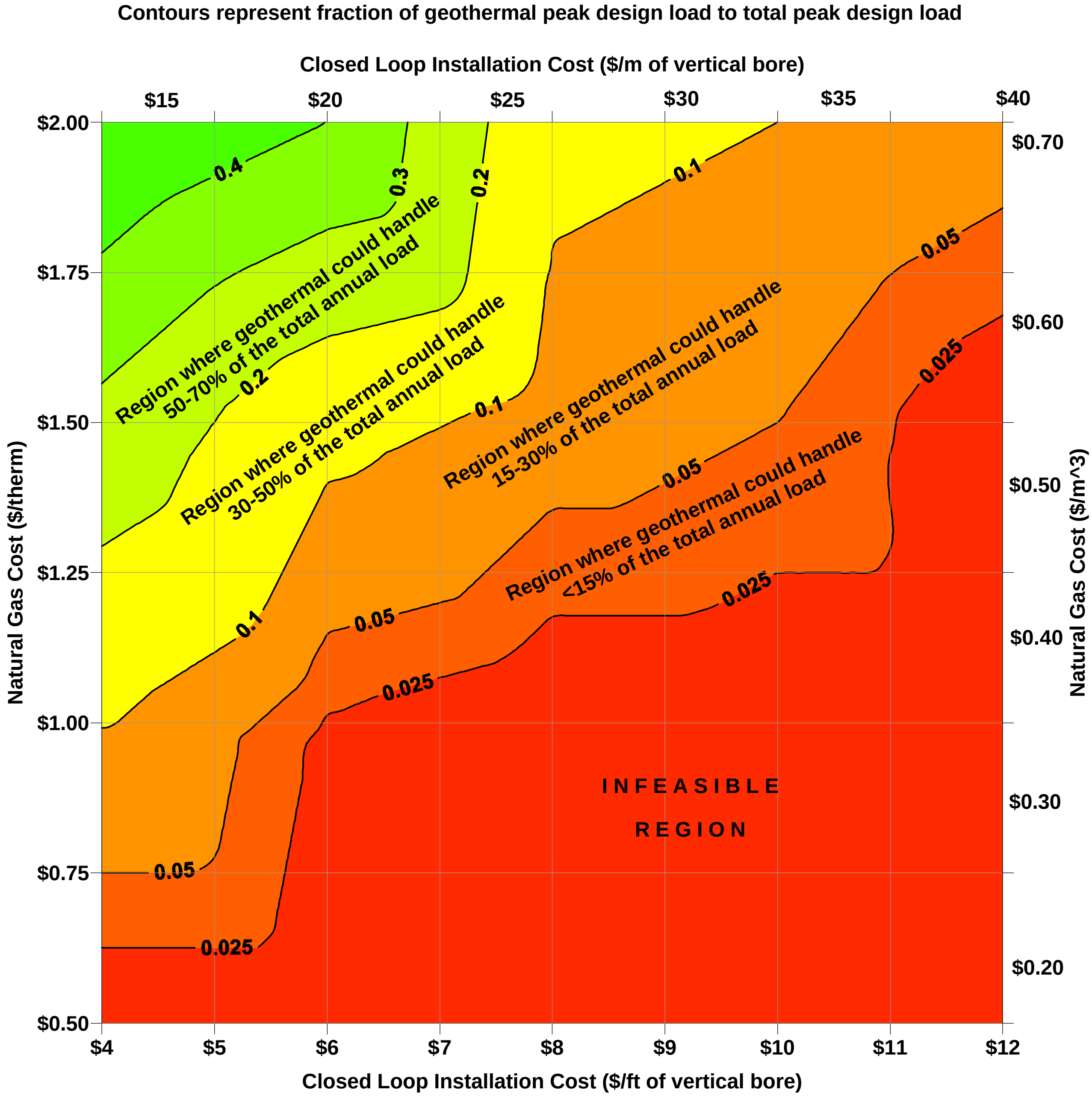

***Figure 3**. Closed-loop GHP system fraction providing lowest net present value of a 20-year life cycle at various natural gas costs and closed-loop installation costs. (Results derived from Boston, Dallas, Denver, and Seattle climate data.)*

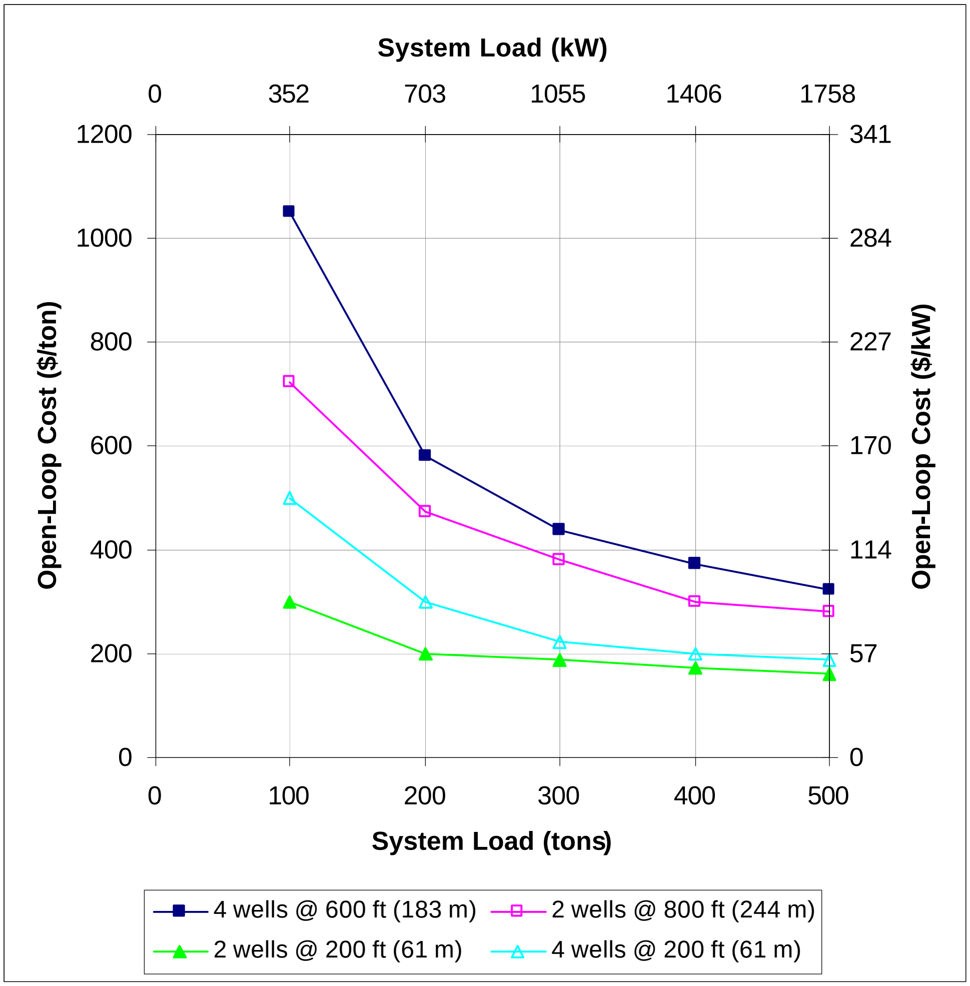

***Figure 4**. Open-loop system costs for 60°F groundwater (Source: Outside the Loop Newsletter, Vol. 1, No. 1, 1998).*

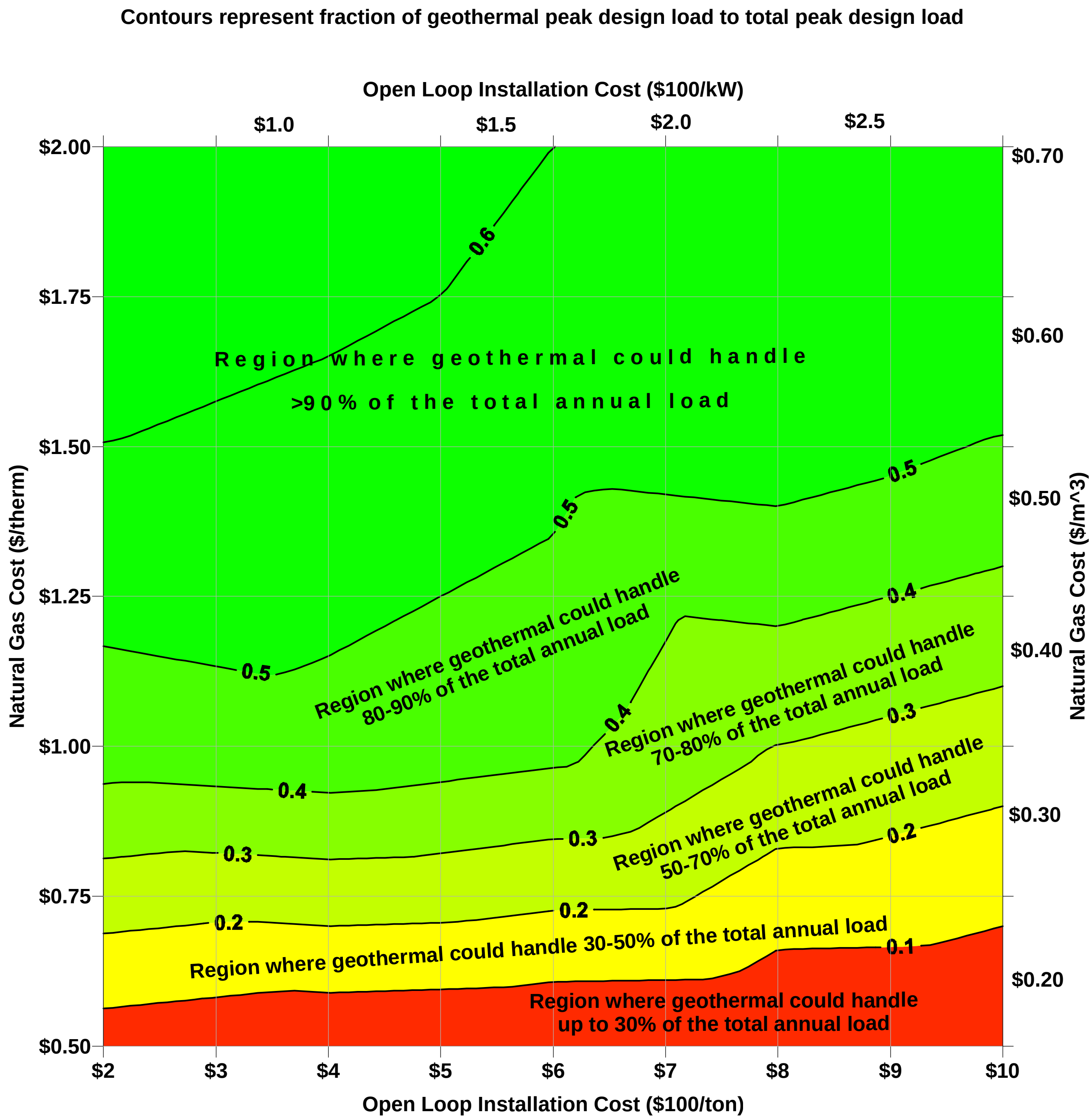

***Figure 5**. Open-loop GHP system fraction providing lowest net present value of a 20-year life cycle at various natural gas costs and open-loop installation costs. (Results derived from Boston, Dallas, Denver, and Seattle climate data.)*