FOSSIL FUEL-FIRED PEAK HEATING FOR GEOTHERMAL GREENHOUSES

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DISCLAIMER STATEMENT

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ABSTRACT

This report examines the capital and operating costs for fossil fuel-fired peak heating systems in geothermally (direct use) heated greenhouses. Issues covered include equipment capital costs, fuel requirements, maintenance and operating costs, system control and integration into conventional hot water greenhouse heating systems. Annual costs per square foot of greenhouse floor area are developed for three climates: Helena, MT; Klamath Falls, OR and San Bernardino, CA, for both boiler and individual unit heater peaking systems. In most applications, peaking systems sized for 60% of the peak load are able to satisfy over 95% of the annual heating requirements and cost less than $0.15 per square foot per year to operate. The propane-fired boiler system has the least cost of operation in all but Helena, MT climate.

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EXECUTIVE SUMMARY

Heating of greenhouses is one of the largest uses of low-temperature geothermal resources. In most cases, the existing projects use the geothermal heat in systems which supply 100% of the peak and annual heating requirements. As these facilities expand, some operators may encounter limitations in either the production or disposal of the geothermal fluids. Such flow restrictions can result in the necessity of operating new facilities (at lower temperatures) using effluent from the existing developments.

From an engineering standpoint, the obvious strategy is to select heating equipment (fan coil units or unit heaters) which perform well under low-temperature conditions. Unfortunately, this type of equipment is not acceptable to many growers, particularly cut flower and bedding plant operators. These operators prefer the so-called bare tube system in which the hot water is circulated through small diameter plastic tubes located under or adjacent to the plants. These systems are low cost, easy to install and unencumbered by the necessity for fans to circulate the air. On the negative side, however, they require substantial quantities of tubing to provide 100% of the heating needs at low outside temperatures.

This report explores the cost of installing and operating a fossil fuel-fired (propane or fuel oil) peak heating system designed for 20 to 50% of a greenhouse peak heating load.

Due to climate related temperature occurrences, it is possible to design a geothermal system for only 50% to 60% of the peak heat loss of a greenhouse and still meet well over 90% of the annual heat energy needs of the structure. This is a result of the fact that the coldest outside temperatures (for which heating systems are normally designed) occur only a few hours per year. The bulk of the hours in a typical heating season occur at roughly halfway between the minimum temperature and the temperature maintained inside the greenhouse. As a result, a down-sized geothermal system is able to satisfy most of the annual heating requirements.

Two broad approaches to installing a peaking system are individual unit heaters or a central boiler. The unit heaters, because of the large number of individual pieces of equipment, tend to result in a higher capital cost for a given heat output than the boiler approach.

The boiler design, on the other hand, results in higher fuel cost in a given application than the unit heater system. This is a result of its incorporation into the heating loop and its negative impact on the capacity of the geothermal heat exchanger during peaking. The unit heaters, since they are a separate system, do not influence the capacity of the geothermal system during peaking.

Figures A, B and C provide information on the costs (ownership, maintenance and fuel) associated with the operation of a fossil fuel (propane and fuel oil) fired peaking system in three different climates assuming a 60° temperature in the greenhouse. In general, the propane fired boiler system is the least total cost system for most applications due to its low installation cost. Only in the coldest climate (Helena, MT) where fuel consumption (rather than equipment cost) is the dominant cost factor does another system (oil boiler) provide for least cost.

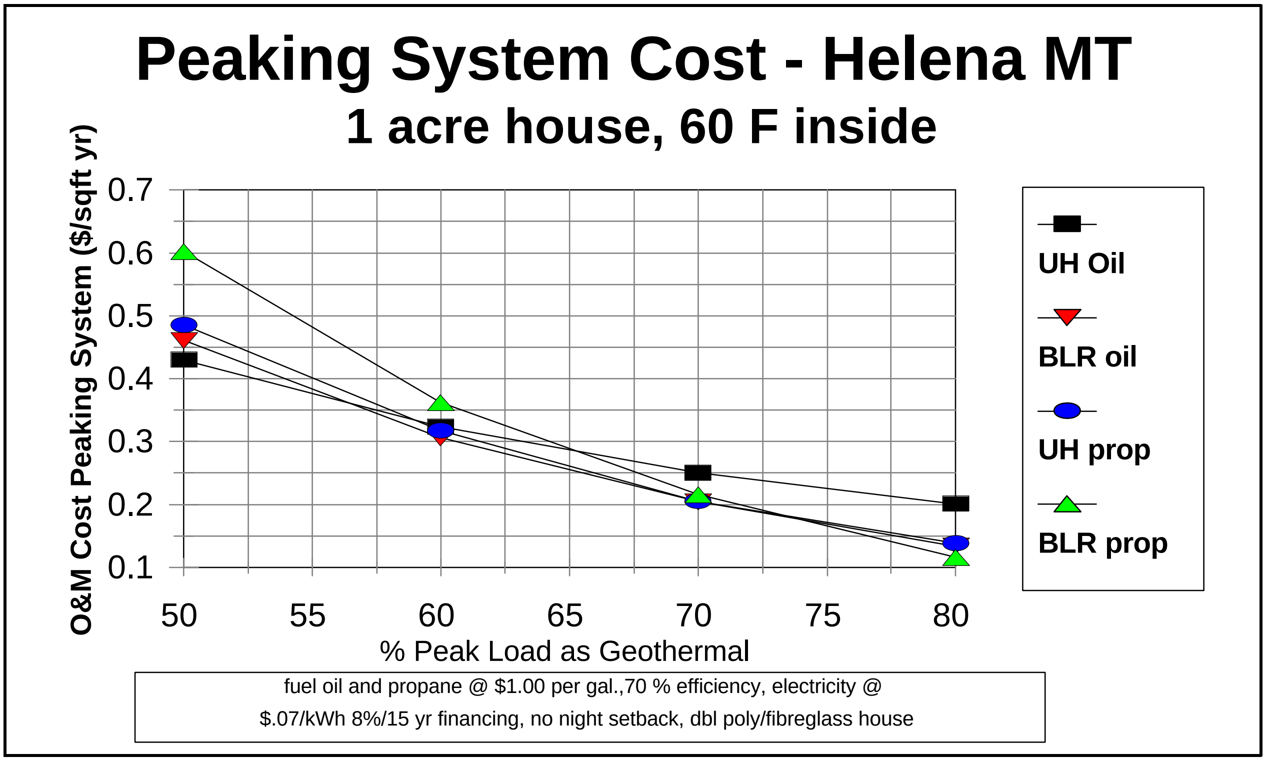
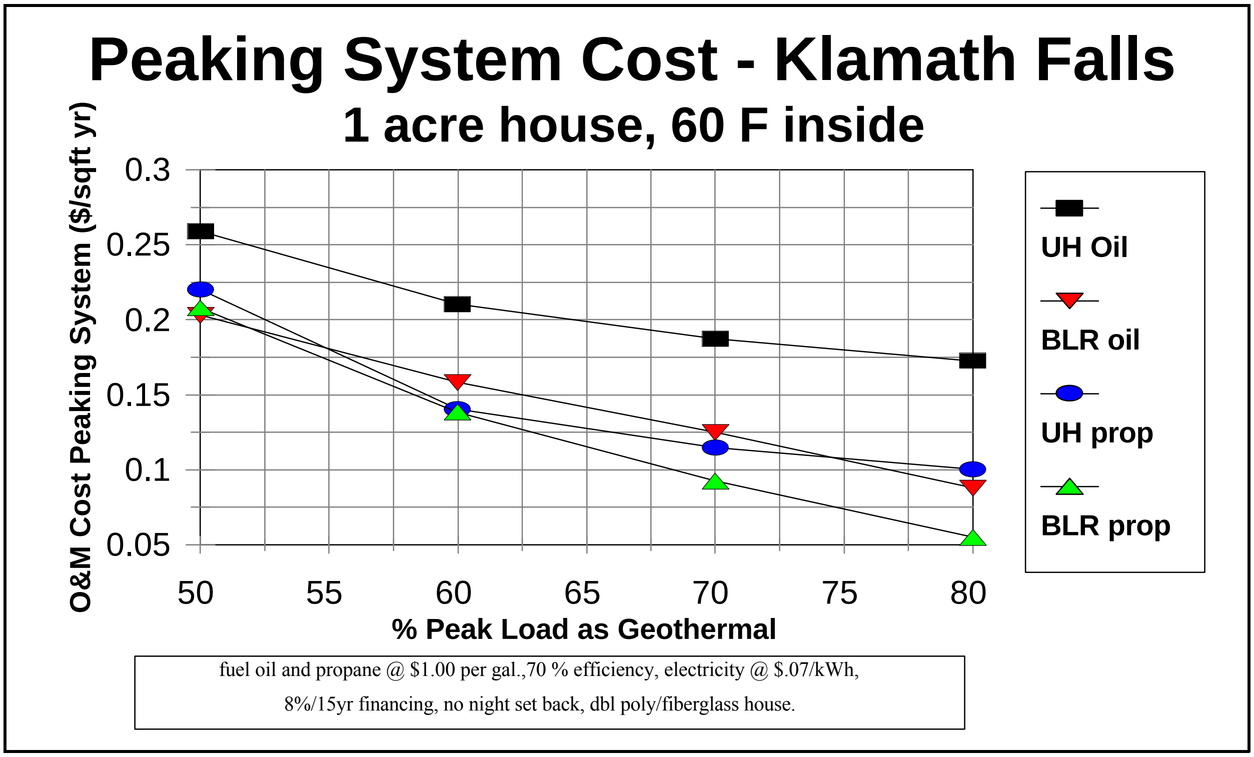


Figure A. Peaking System Cost - Helena, MT

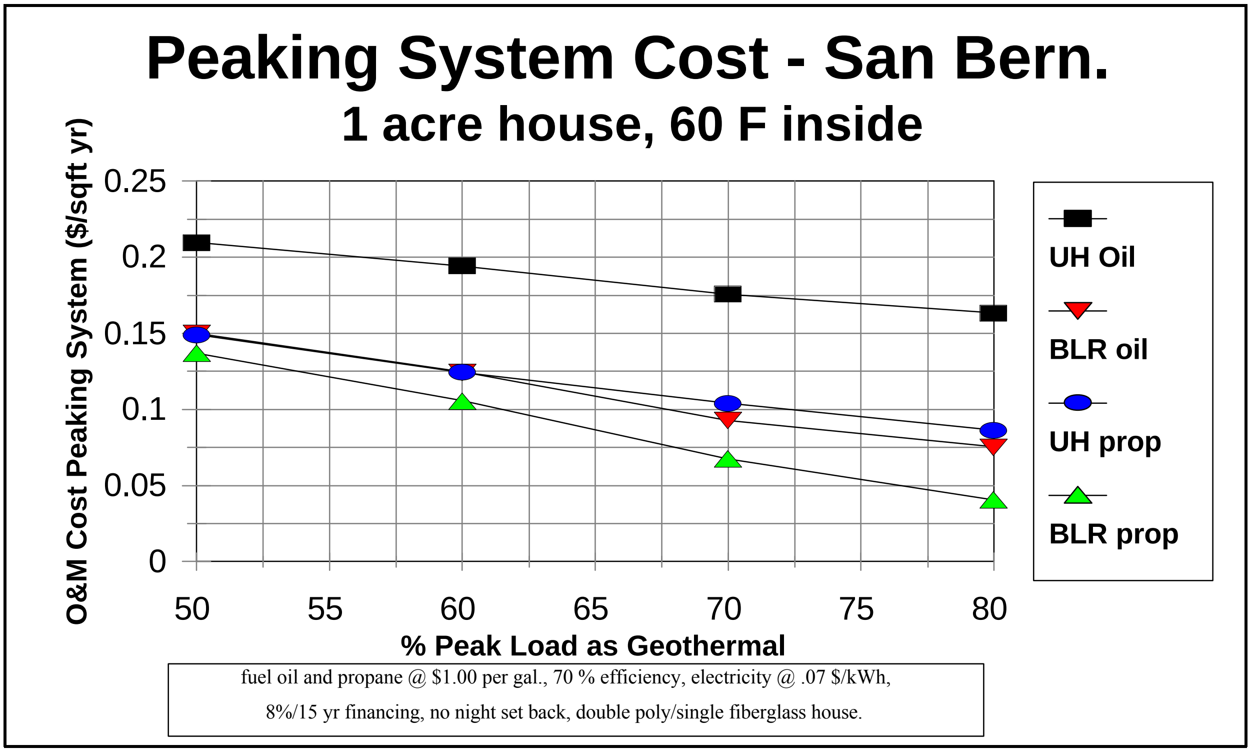


Peaking System Cost - Klamath Falls

1 acre house, 60 F inside

fuel oil and propane @ $1.00 per gal.,70 % efficiency, electricity @ $.07/kWh,
8%/15yr financing, no night set back, dbl poly/fiberglass house.

Figure B. Peaking System Cost - Klamath Falls



Peaking System Cost - San Bern.

1 acre house, 60 F inside

fuel oil and propane @ $1.00 per gal., 70 % efficiency, electricity @ .07 $/kWh,
8%/15 yr financing, no night set back, double poly/single fiberglass house.

Figure C. Peaking System Cost - San Bernardino

Fossil fuel-fired peaking is unlikely to be used in applications where an acceptable geothermal system can economically meet the peak heating load. In applications where the geothermal resource flow is limited, this approach permits the grower to use the heating system of choice for a reasonable increment in operating cost.

INTRODUCTION

Greenhouses are a major application of low-temperature geothermal resources. In virtually all operating systems, the geothermal fluid is used in a hot water heating system to meet 100% of both the **peak** and **annual heating requirements** of the structure. This strategy is a result of the relatively low costs associated with the development of most U.S. geothermal direct-use resources and past tax credit programs which penalized systems using any conventional fuel sources.

Greenhouse operators tend to have unequivocal preferences regarding heating system equipment. Many growers, particularly cut flower and bedding plant operators, prefer the "bare tube" type heating system. This system places small diameter plastic tubes under the benches or adjacent to the plants. Hot water is circulated through the tubes providing heat to the plants and the air in the greenhouse. Advantages include the ability to provide the heat directly to the plants, low cost, simple installation and the lack of a requirement for fans to circulate air. The major disadvantage of the system is poor performance at low (<140^{o}F) water temperatures, particularly in cold climates. Under these conditions, the quantity of tubing required to meet the peak heating load is substantial. In fact, under some conditions, it is simply impractical to install sufficient tubing in the greenhouse to meet the peak heating load.

As a result of these considerations, it is common practice, when expanding an operation, to pump additional water from the production well (or a new well) to serve the system in the added greenhouse area. This simplifies the design process for the developer since the same heating equipment (spacing, size, diameter, etc.) can be used as in the existing structure. In cases where available geothermal fluid is not limited, this is the obvious strategy. In many cases, however, limitations in either production or disposal restrict the available flow rate. Under these circumstances, either the design of the heating system must be modified to use the lower temperature fluid available as effluent from the existing operation.

Forced-air heating equipment (unit heaters, fan coil units, etc.) is very effective at low temperature operation. Unfortunately, many growers strongly resist using it. In these cases, the use of cascaded geothermal fluid to provide a portion of the heating requirements (base load) along with a conventionally-fueled **peak heating system** may be an effective strategy.

For a system operating from a 180^{o}F resource, exit water (at say, 140^{o}F) from the existing facility would be supplied to the new addition. In the new facility, the lower water temperature would reduce tubing system output to only about 60% of the required peak output (assuming tube length, spacing and diameter is the same). The difference could be made up from a conventionally-fueled heating system.

Due to temperature occurrences in most western geothermal locations, a base load system (geothermal) designed for approximately 60% of the peak load can actually meet 95+% of the annual heating requirements. As a result, a facility with limited geothermal flow can expand, use the heating system of choice and still achieve substantial energy savings with a **base load**/peak load heating system design. In addition, the fossil-fueled peak load system offers a no-cost emergency backup in the event of a failure in the geothermal system.

The text of this report includes a number of terms common to heating load calculations, but unfamiliar to some readers. A glossary including these terms appears at the end of the report. Terms included in the glossary appear in bold at their first appearance in the text.

CONVENTIONAL GREENHOUSE HEATING SYSTEM

Conventional greenhouse heating systems can take a wide variety of configurations (unit heater, fan coil unit, bare tube, finned pipe, etc.). Two system types, however, are most common: fan coil and bare tube. The fan coil heating units, as the name implies, include a fan for moving the air and a coil or heat exchanger for transferring heat from the water to the air. Several designs are available with some off-the-shelf units optimized for performance at low (<120°F) temperatures. Custom designed units are also sometimes used.

Bare tube systems consist of a large quantity of bare tubing, usually of polyethylene, polybutylene or EPDM, distributed throughout the greenhouse. Bare tube systems, in comparison to fan coil systems, are characterized by low equipment cost and zero fan energy consumption and simple installation practices. This makes the bare tube system especially attractive to greenhouse growers. The tubing system permits do-it-yourself installation, another feature attractive to developers. At low water temperature, bare tube systems require substantial quantities of tubing to meet 100% of the peak heating requirement in cold climates.

All hot-water heating equipment suffers from reduced capacity as the temperature of the water supplied to it is reduced. The nature of this capacity reduction is a function of the equipment type. Characteristic curves for bare tubing and fan coil units are shown in Figure 1. As indicated, the capacity of the equipment at 120°F is approximately 47% of its capacity at 180°F. This translates into the need for more and larger equipment to meet the heating load at low temperature.

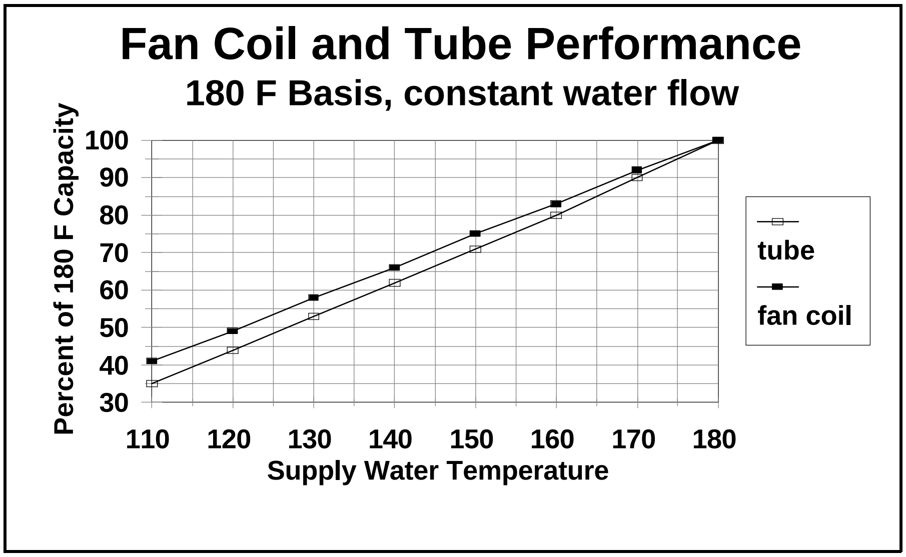


Figure 1. Fan Coil and Tube Performance

Figure 2 presents some data on the cost impact of various supply water temperatures for three types of heating equipment. The costs shown on the vertical axis are the system (terminal equipment, distribution piping, central heat exchanger and circulating pump) costs in $/ft^2 of greenhouse floor area for a system supplying a 1-acre greenhouse (60° **inside**, 0° **outside**) using conventional design practices (100% of the peak). The systems shown include bare tube (BT), low-temperature unit heater (GLW) and standard unit heater (UH).

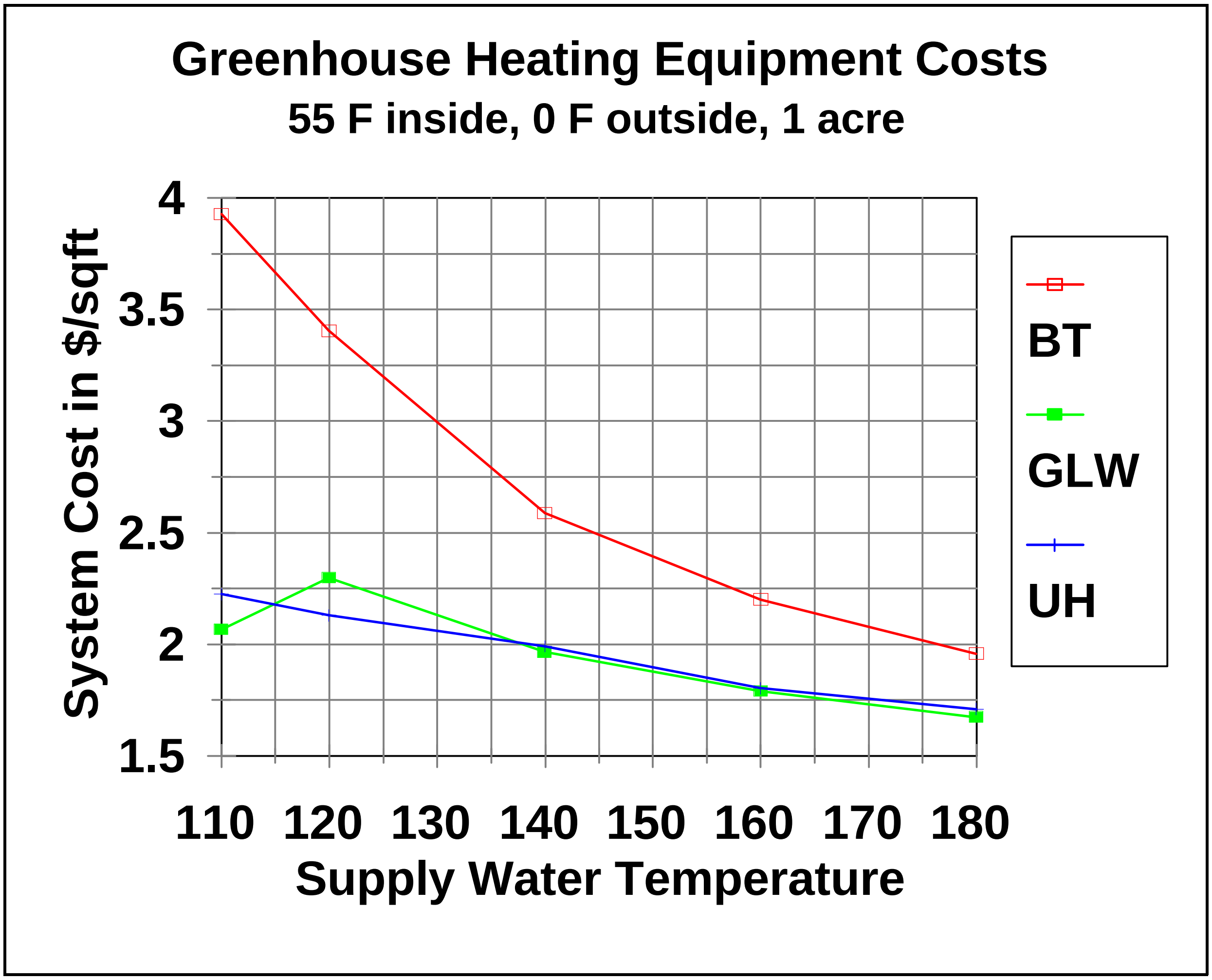


Figure 2. Greenhouse Heating Equipment Costs

It is apparent that the fan coil and unit heater systems are more capable of economically dealing with low supply water temperatures than the bare tube system. The reason for the high costs of the bare tube system at low temperatures is illustrated in Figure 3. As indicated, the tubing length requirement at 110°F is approximately 397,000 feet compared to 106,000 feet at 180°F. This means that for the example greenhouse, tubes would have to be spaced at intervals of less than 1 1/2 inches (over the entire floor area) to meet the load.

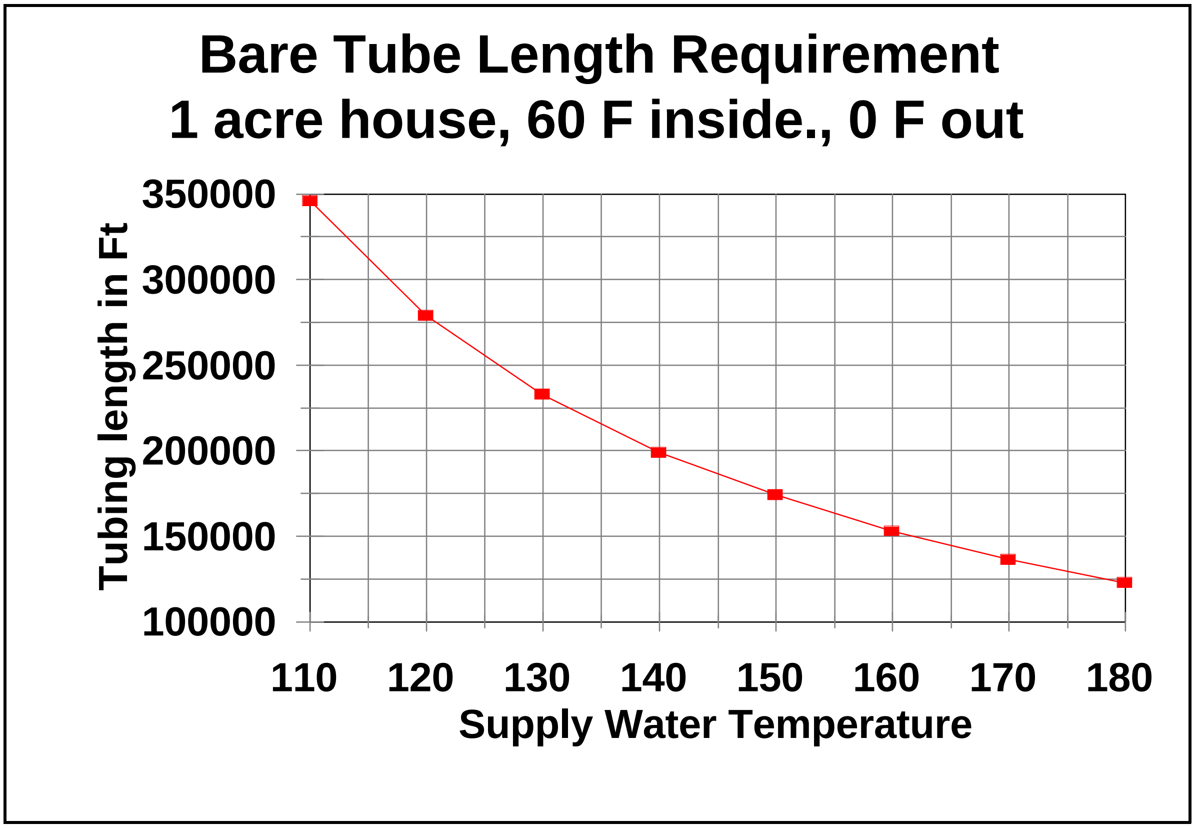


Figure 3. Bare Tube Length Requirement

To maintain the tube length at reasonable values with a low-temperature resource, the tubing system must be augmented with other hot water equipment (fan coil units) or a conventional fuel-fired system.

CLIMATE CONSIDERATIONS

The rationale behind using different base load and peak load heating systems lies in the annual temperature profile. Table 1 presents weather data for a typical western U.S. high-desert location. It is apparent that the annual number of hours at very low outside temperatures is quite low compared to the number of hours at more moderate temperatures. The same data is portrayed graphically in Figure 4.

Table 1.
Annual Temperature Occurrences (Bin Data)
Klamath Falls, OR

Outside Temperature (°F)	Hours/Year
95 - 99	1
90 - 94	39
85 - 89	124
80 - 84	235
75 - 79	313
70 - 74	373
65 - 69	468
60 - 64	551
55 - 59	658
50 - 54	783
45 - 49	826
40 - 44	931
35 - 39	1044
30 - 34	1132
25 - 29	675
20 - 24	352
15 - 19	150
10 - 14	82
5 - 9	39
0 - 4	17
-5 - -1	6
-10 - -6	2

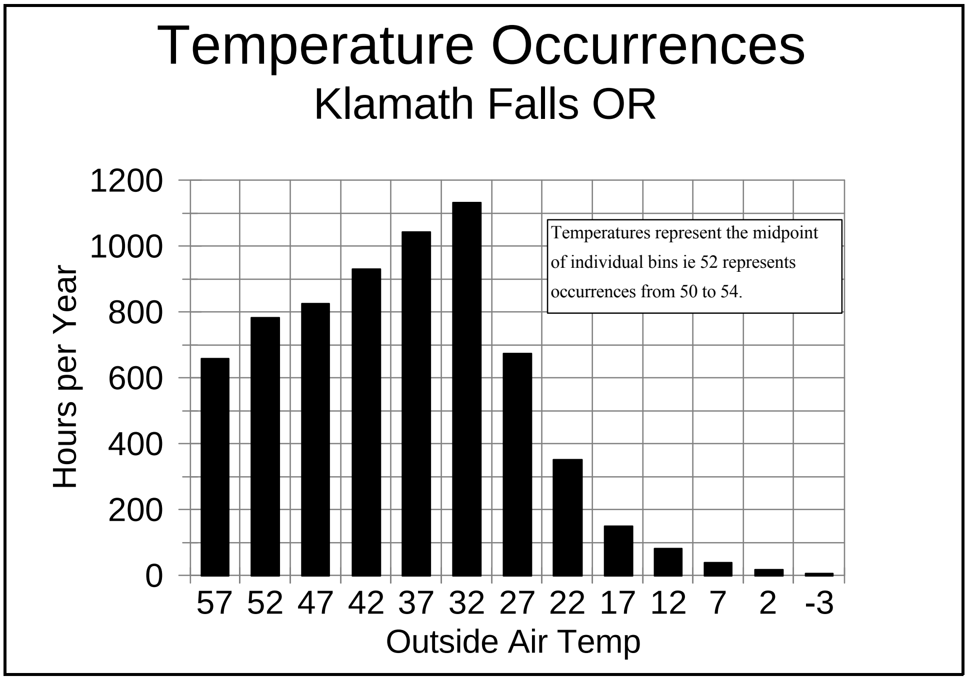


Figure 4. Temperature Occurrences

This data is arranged in 5° increments (i.e., 70°F to 74°F). These 5° increments are known as temperature "**bins**" and the data from which it comes is referred to as bin data. Bin data for many locations in the U.S. is published by the Defense Department in Engineering Weather Data, AFM 88-29, 1978.

The rate at which heat must be supplied to a structure (Btu/hr) to offset heat loss is directly related to the temperature difference between the outside air and the temperature inside the structure. The so-called peak load is calculated at an outside temperature referred to as the design outside temperature. This is a value below which only 1% of the hours in a typical winter occur. Conventional practice in the U.S. for geothermal systems is to design the system for 100% of the peak load.

It is apparent from Table 1 that a system designed for 100% of the peak load actually operates at those conditions for only a very few hours per year. In fact, the bulk of system operation occurs at loads of 50% or less. As a result, a system designed for 100% of the peak load is grossly under utilized.

The amount of energy required to heat a building (on annual basis) is determined by the number of hours occurring at outside temperatures less than the temperature maintained in the structure. The quantity of annual energy required at a particular temperature bin is determined by the number of hours at that bin and the temperature difference between it and the inside temperature of the structure. Summing the number of hours at various outside temperatures permits the development of a cumulative heating requirement curve similar to that in Figure 5. This particular plot was developed for an inside temperature of 60°F using the weather data from Table 1. The plot indicates the percentage of annual heating requirements occurring above (or below) a particular outside air temperature. For example, reading vertically from 30°F to the intersection with the curve and then horizontally to the axis, yields a figure of approximately 71%. That is, 71% of the annual heating requirement occurs above this temperature.

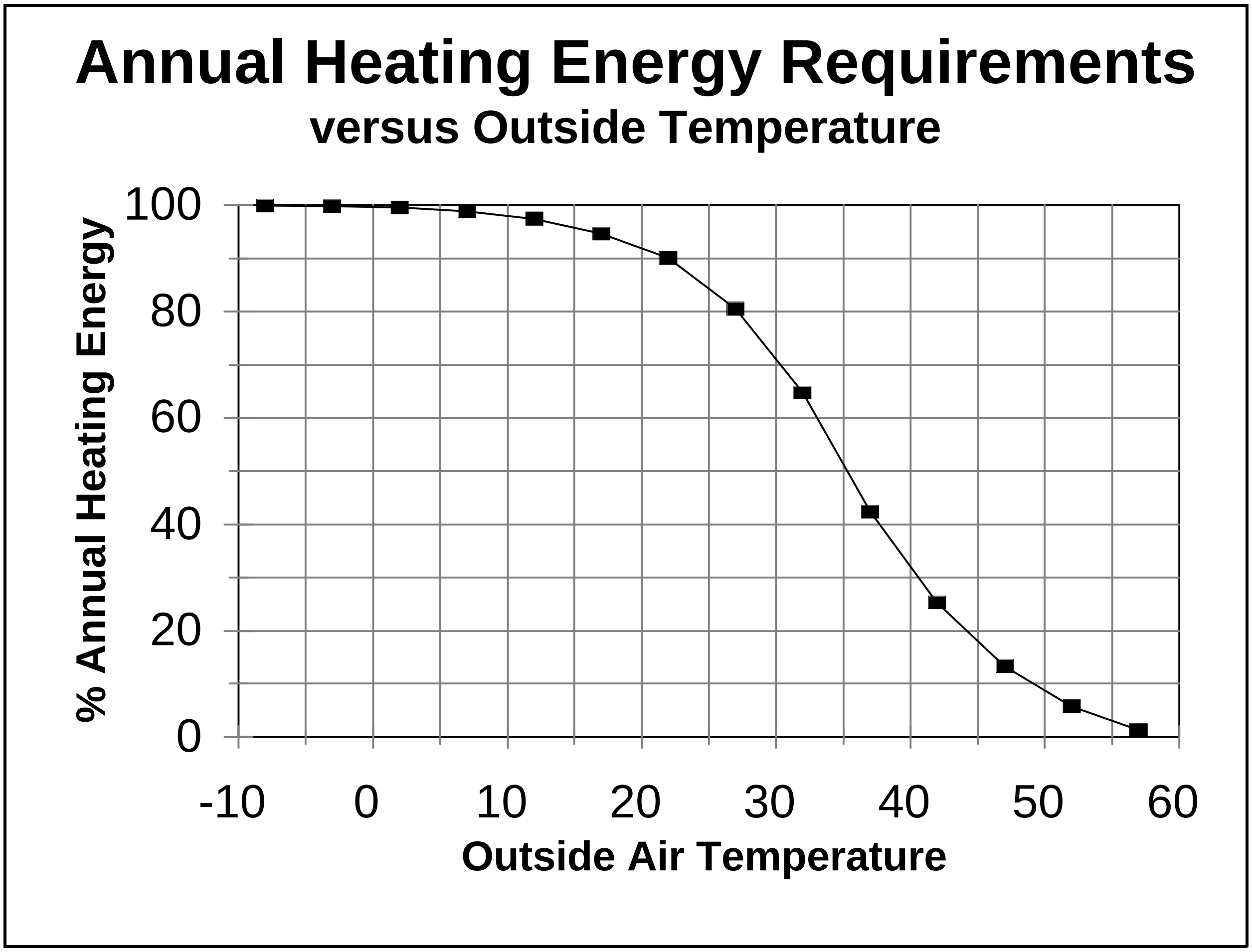


Figure 5. Annual Heating Energy Requirement

This is significant since the normal design temperature in the Klamath Falls area is 0^{o}F. A system designed for 30^{o}F would be only 50% the size of a normal system designed for 100% of the load (assuming an inside design temperature of 60^{o}F). Despite this, it could capture 71% of the annual heating requirements. In addition to this, the down-sized system would capture most of the remaining 29% of heating energy requirement by operating in parallel with a peaking system.

Figure 6 presents a plot of the annual energy requirements which could be met by a base load system designed for various percentages of the peak load. This plot assumes that the base load system continues to operate (at its maximum capacity) in parallel with the peak load system below the **balance point**. The 50% (of peak load) system described above would capture approximately 93% of the annual heating requirements of the structure (assuming a 60^{o}F inside temperature, 0^{o}F design outside temperature and Table 1 weather data).

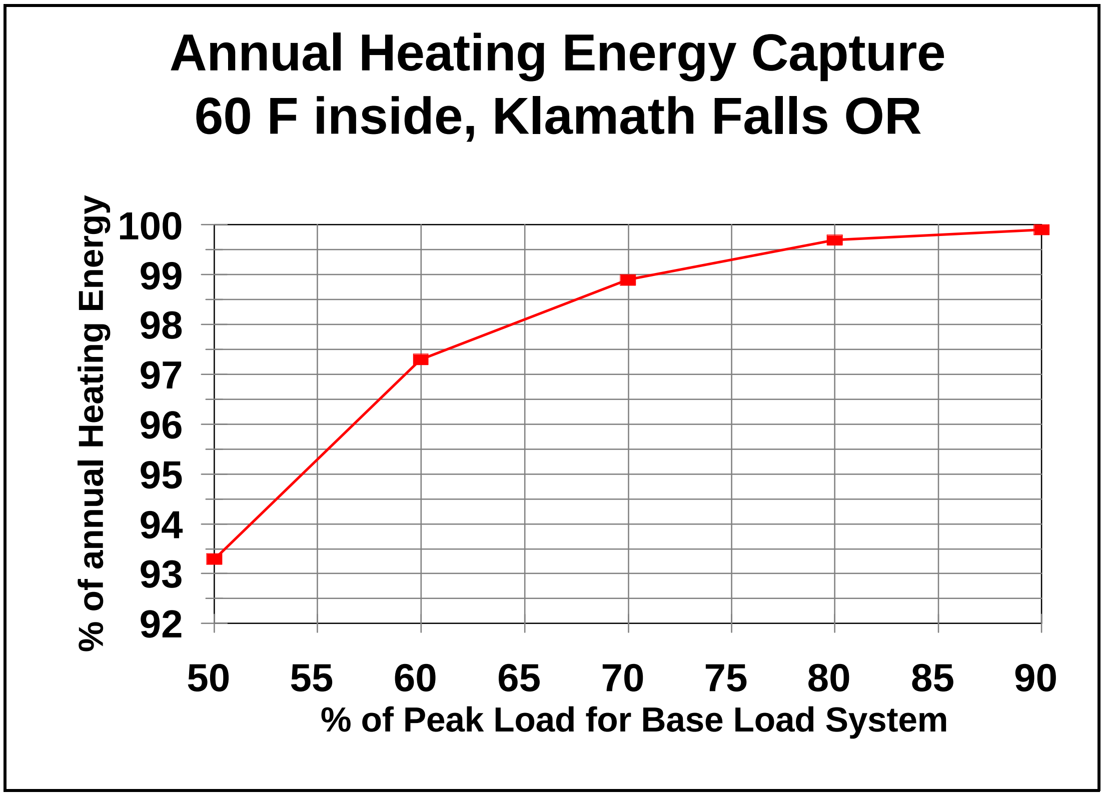


Figure 6. Annual Heating Energy Capture

It is clear that due to the nature of temperature occurrences, the base load heating system capable of meeting only half the peak heating requirement and still meets more than 90% of the annual heating energy needs of a structure.

PEAKING EQUIPMENT CAPITAL COSTS

Two broad approaches are available for the use of conventionally-fired peak heating equipment in a hot water greenhouse heating system: individual unit heaters and central peaking boiler.

Individual unit heaters offer the advantage of zero floor space requirements (since they can be hung from the ceiling). Because each unit requires accessory equipment (flue pipe, thermostat, distribution "poly tube", fuel line, electrical connection, etc.), the cost of a given amount of heating capacity is relatively high in comparison to the boiler approach. This affect is compounded by the need to use a large number of units to assure adequate air distribution in a large greenhouse. For example, consider a 1-acre greenhouse for which a peaking system capacity of 1,300,000 Btu.hr is required. Although it is possible to supply this capacity with just three or four large units, to assure adequate air distribution, a minimum of 8 or 10 units should be employed. Costs for unit heater capacity assuming 10 units per acre appears in Figure 7.

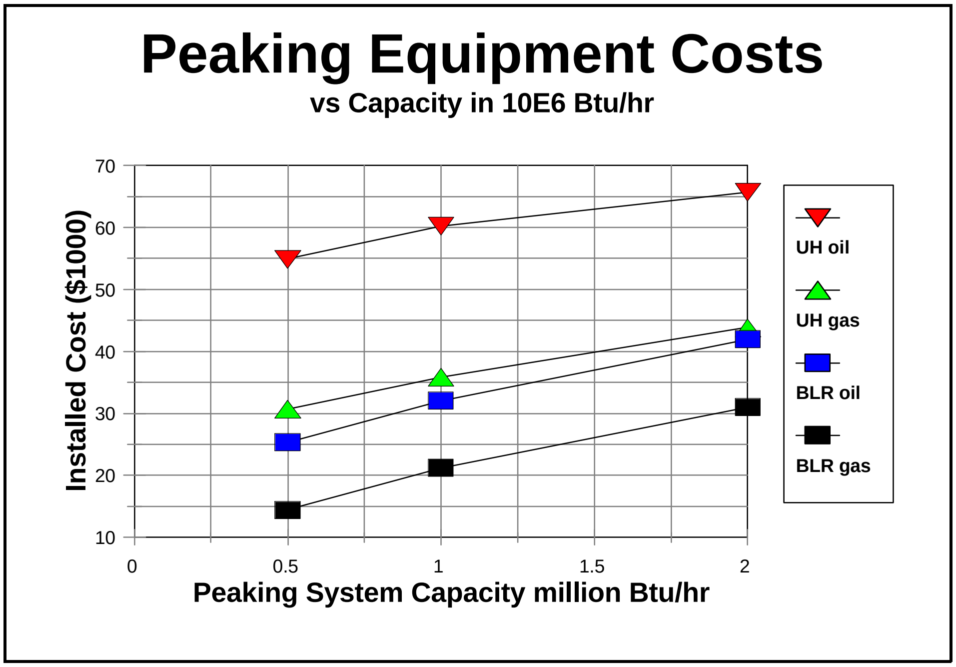


Figure 7. Peaking Equipment Costs

The costs shown include, for the propane (or natural gas), fired unit heaters: unit heater (blower type), installation, flue pipe and cap, thermostat and wire, fuel distribution pipe (inside greenhouse), and electrical connection (120 v). Costs for the oil unit heater equipment reflects the much higher cost for this type of unit and includes the cost of a double-wall oil storage tank (2500 gal). Oil-fired unit heaters are much more expensive (50 - 80% depending upon size) than equivalent capacity gas-fired units. This fact along with the cost of the oil tank tends to push the cost of the oil-fired unit heater system far above the other alternatives. Less expensive propeller fan type gas-fired unit heating equipment is available. This equipment, 18 to 25% less than the blower units, is not suitable for extensive air distribution through "poly tube" ducts. As a result, it has not been considered in the costs shown in Figure 7.

The central boiler approach involves the installation of a peaking boiler downstream of the geothermal heat exchanger. The boiler's function is to boost the supply water temperature to the heating equipment during the peak load period. The higher water temperature allows a down-sized tubing system to provide the required capacity to meet the space heating requirement. Because only a single piece of equipment (along with its accessory equipment) is required, the cost of a given heat output is much lower than for the unit heater equipment cited above. Figure 7 presents costs for both propane- and oil-fired cast iron boiler equipment. These costs include boiler, stack, electrical connection, fuel lines, controls, 3-way valve, circulating pump, installation, and for the oil system, a double-wall storage tank of 2500 gal.

It is clear from Figure 7, that in the system capacity range of 500,000 Btu/hr to 2,000,000 Btu/hr, the unit heater system (UH) is always more expensive to install than the boiler design (BLR).

Again due to the cost of the oil storage facilities, the oil boiler system is higher than the gas (or propane) system by a substantial margin (-66%).

CONTROLS AND OPERATIONAL CONSIDERATIONS

The object of the peaking equipment is to provide the capacity difference between the structure's requirement and the capacity of the base load (geothermal) system. This task must be accomplished in such a way as to produce even heat output and without compromising the performance of the base load system.

Peaking with individual unit heaters is a simple process with regard to controls. Each individual unit is equipped with a thermostat which initiates operation of the unit when additional capacity is required in the zone that it serves. To eliminate unnecessary operation, it is useful to incorporate an outside temperature driven lockout to prevent use of the peaking unit above the balance point temperature.

For the boiler design, the situation is somewhat more complex. This results from the boiler being incorporated into the heating loop. Because the boiler changes the temperature of the supply water, it not only influences the output of the terminal equipment but also the capacity of the geothermal heat exchanger.

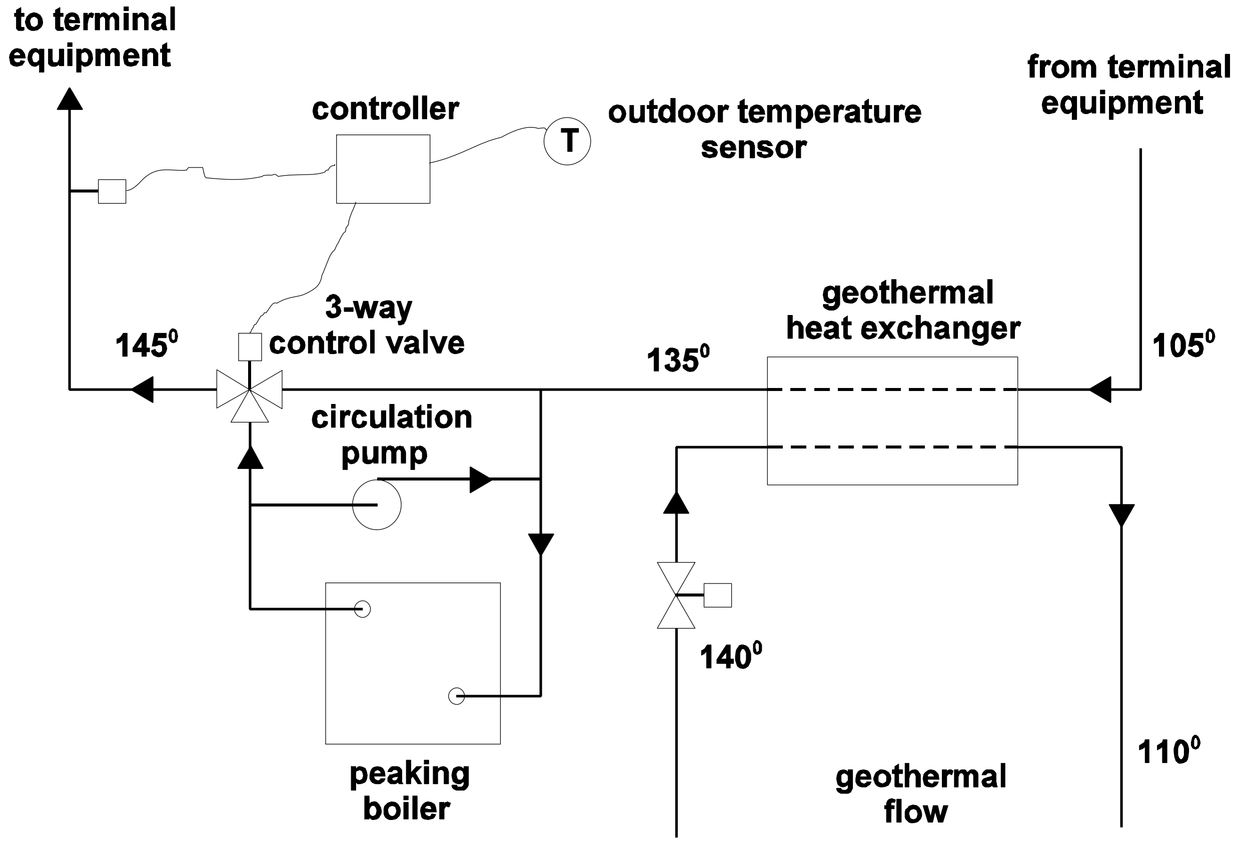


Figure 8. Heating System Flow Diagram

Figure 8 presents a common design for installing a boiler on a circulating water loop. Located downstream of the heat exchanger, the boiler's function is to raise the supply water temperature to the terminal equipment during the peak heat load period. This is accomplished by resetting the supply water upward as the outside air temperature decreases. Table 2 presents a typical temperature reset schedule. In this case, the boiler begins operation between 30 and 25°F outside air temperature. Actual temperatures will vary with system design.

Table 2
Typical Supply Water Temperature Reset Schedule and System Performance

Outside Air Temp	Supply Water Temp	Return Temp	Geothermal Heat Exchanger Capacity	Greenhouse Load	Required Boiler Output	% Geothermal
25	140	105.0	2,116,000	2,116,000	0	100
20	149	109.6	1,866,000	2,418,000	552,000	77
15	159	114.1	1,627,000	2,721,000	1,092,000	60
10	168	118.3	1,407,000	3,023,000	1,616,000	47
5	177	122.3	1,197,000	3,325,000	2,128,000	36
0	186	126.3	989,000	3,627,000	2,638,000	27

As the supply water temperature rises, the output of the terminal equipment rises. At the same time, the temperature of the return water rises as well.

The rise in return temperature occurs at a rate less than the supply water increase due to the higher output of the terminal equipment (which results in an increasing system ΔT). However, the rising return water temperature erodes the capacity of the geothermal heat exchanger to the extent that its capacity at the peak condition (0°F outside) is approximately 50% of its capacity prior to the initiation of boiler operation.

The impact of this decreased geothermal heat exchanger capacity is illustrated in Table 3 which compares the performance of unit heaters and boiler peaking strategies for the same example case.

Table 3
Comparison of Boiler and Unit Heater Peaking Strategies

Outside Air Temp	Hrs/Yr	Boiler Fuel (gal Propane)	% Geothermal	Unit Heater Fuel (gal Propane)	% Geothermal
20	352	3107	77	1687	88
15	150	2591	66	1440	78
10	82	2085	47	1180	70
5	39	1317	36	748	64
0	17	617	27	407	58
		9717 gal		5462 gal	

As indicated for this example, the boiler design requires approximately 78% more fuel than the unit heater design. At the peak condition (0°F), the unit heater supplies 58% of the heating energy needs of the structure compared to the boiler's 27%.

This means that the required capacity of the peaking boiler is larger than that of the unit heater equipment for the same application. This disparity in required capacity at the peak load becomes more pronounced as the percentage of peak load carried by the base load system decreases. For example, a system in which the base load capacity is 40% of the peak would suggest a peaking boiler sized for 60% of the load. In fact, due to issues discussed above, the boiler would have to be sized for 93% of the peak. Table 4 provides a summary of the peaking boiler and unit heater sizing requirements for selected base load system capacities.

Table 4
Peaking System Sizing Requirements
(60°F Inside, 0°F Outside)

Base Load System Capacity (% of Peak)	Unit Heater System Peaking Capacity (% of Peak)	Boiler Peaking Capacity (% of Peak)
40	60	93
60	40	73
80	20	27

Figures 9, 10 and 11 present heating energy displaced for unit heater type peaking systems in three different climates for a variety of inside temperatures set points. Figures 12, 13 and 14 present the same information for boiler peaking system. Although the percentages of displaced energy appear to be quite similar to the unit heater values for boiler system, because the heating energy requirement for greenhouses are so high, small percentage differences translate into substantial fuel cost differences.

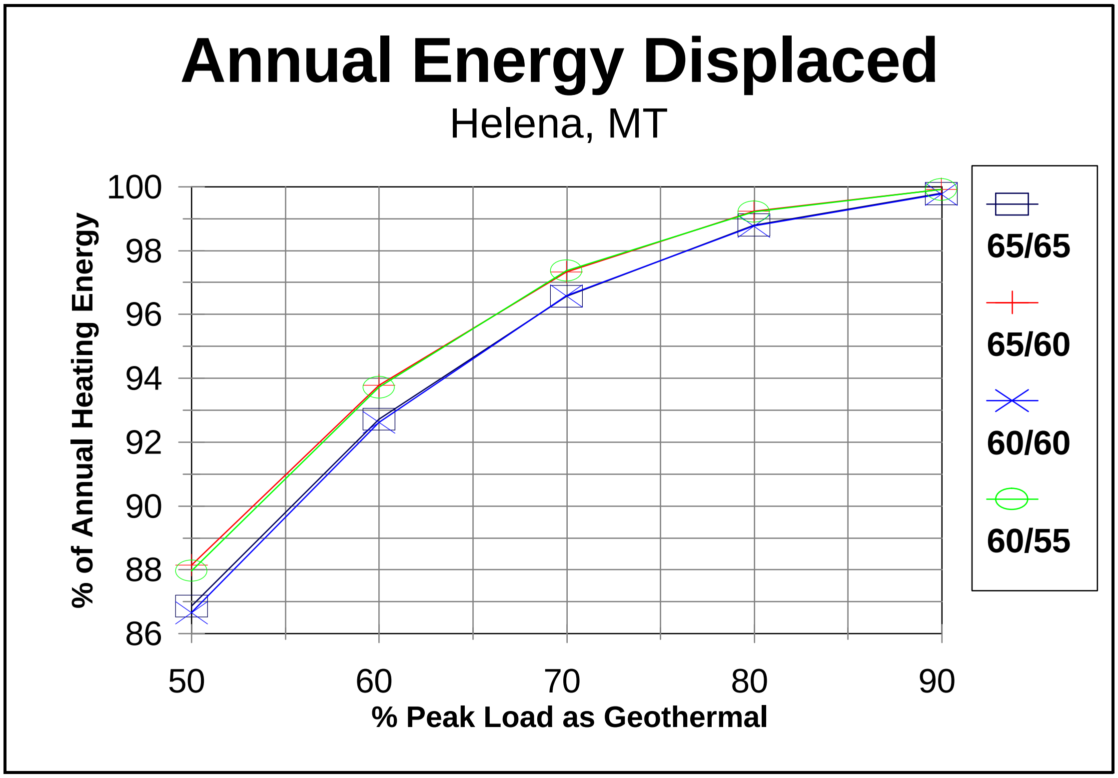


Figure 9. Unit Heater Annual Energy Diplaced, Helena, MT

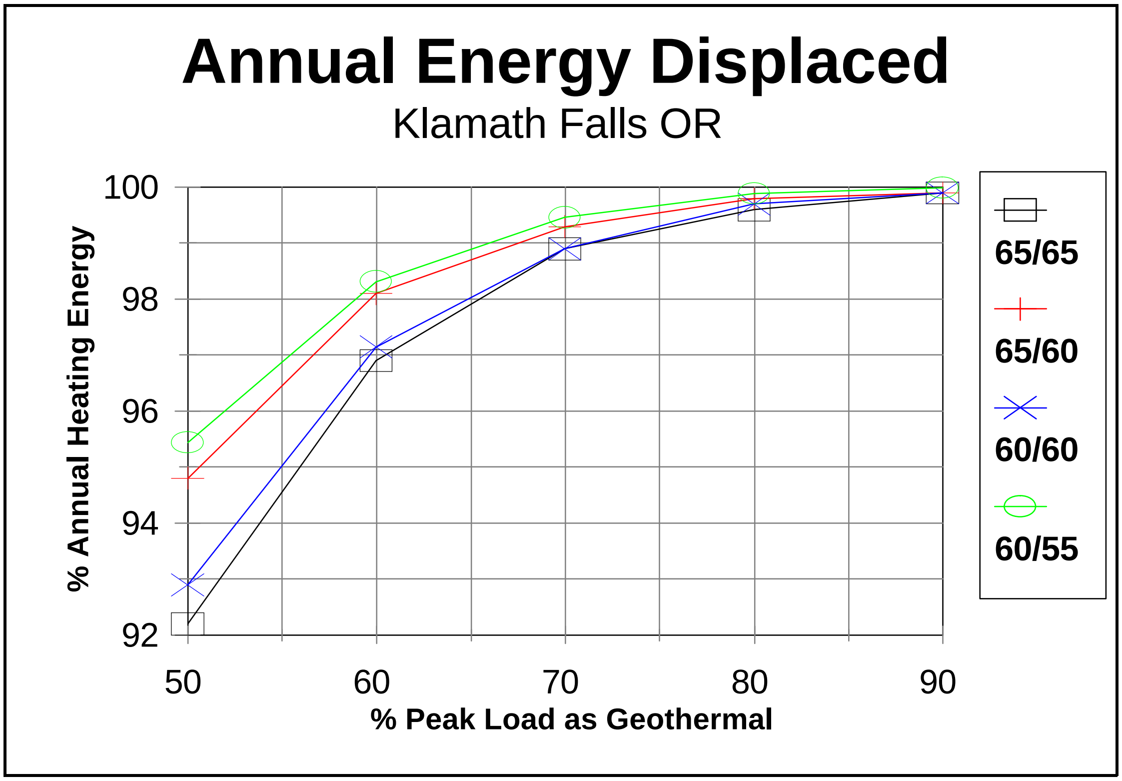


Figure 10. Unit heater Annual Energy Displaced, Klamath Falls, OR

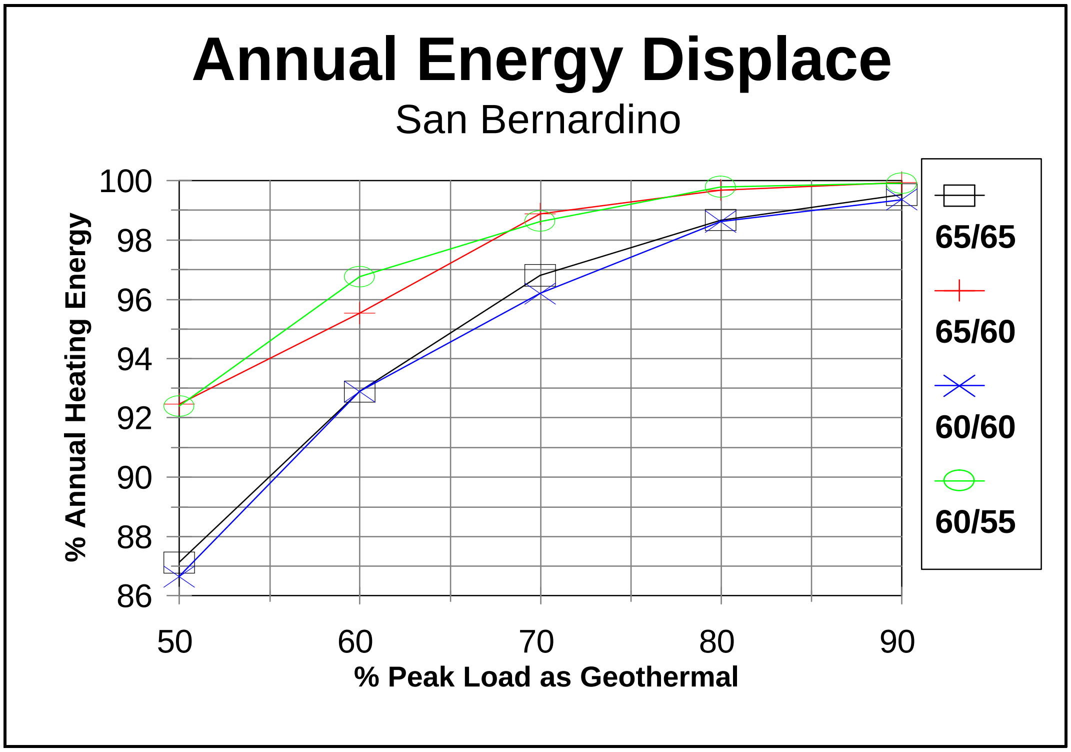


Figure 11. Unit Heater Annual Energy Displaced, San Bernardino, CA

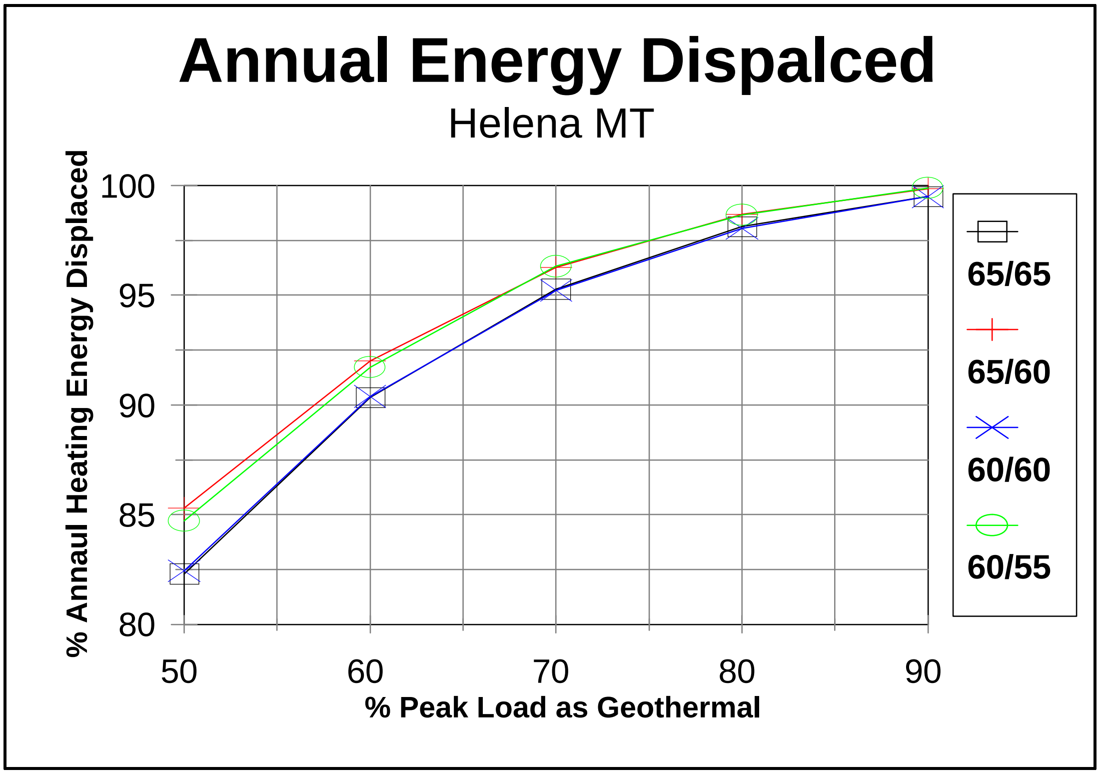


Figure 12. Boiler Annual Energy Displaced, Helena, MT

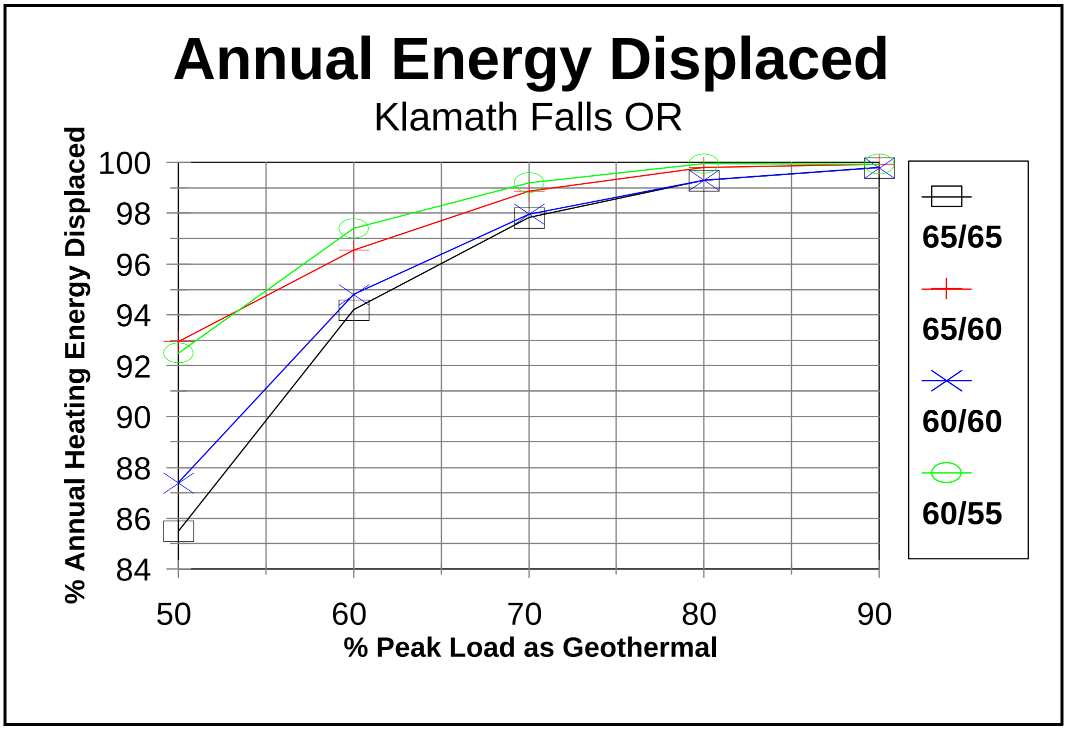


Figure 13. Boiler Annual Energy Displaced, Klamath Falls, OR

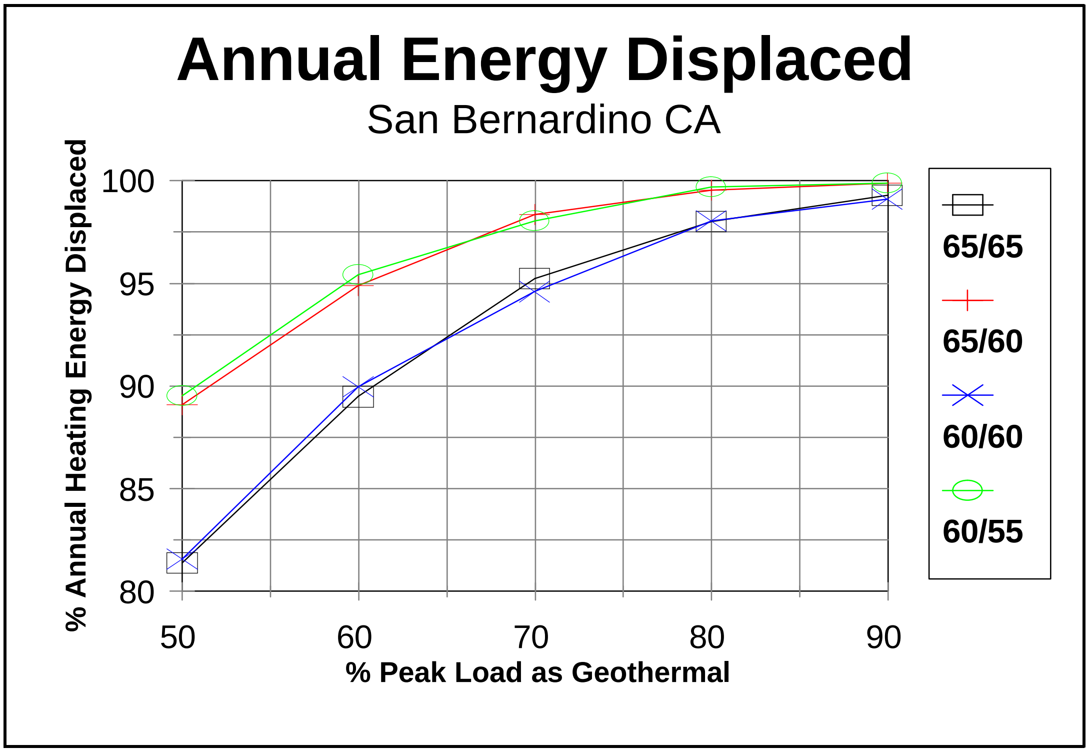


Figure 14. Boiler Annual Energy Displaced, San Bernardino, CA

Table 5 presents the fuel consumption for 1-acre greenhouse in the three climates for the same temperature set points as in Figures 9 through 14. Using the Klamath Falls climate data as an example, for a system with a base load capacity of 60% of the peak and a 60^{o} day/60^{o} night set point, the boiler system would displace 94.8% of the annual heating requirements compared to 97.2% for the unit heater design.

Although these figures seem comparable, attaching fuel consumption values to them clearly indicates the difference. Using data from Table 5, assuming the use of propane as the fuel, the boiler would require 4,613 gal/yr and the unit heater system 2,484 gal/yr.

Table 5
Fuel Consumption for 1-Acre Greenhouse - Btu x 10^9

	Helena, MT	Klamath Falls, OR	San Bernardino, CA
$60^{o}/60^{o}$	7.36	5.59	1.78
$60^{o}/55^{o}$	6.37	4.52	1.09
$65^{o}/60^{o}$	7.59	5.81	1.88
$65^{o}/65^{o}$	8.69	6.96	2.77

Notes: Double poly roof, single fiberglass sides, 1 ACH.
To convert to gallons of propane per year, divide by 63,000.
To convert to gallon of fuel oil per year, divide by 93,000.
To convert to therms of natural gas, divide by 70,000.
Conversions assume 70% efficiency.
At $1.00/gal and 70% efficiency, fuel oil cost $10.20/$10^9$ Btu and propane $15.87/$10^9$ Btu. At the same efficiency at $0.50 per therm, gas cost $7.14/$10^9$ Btu.

COST OF IMPLEMENTATION

Using Figures 9 through 14 along with Table 5, the capital cost for equipment and the annual fuel cost can be calculated for any application (based on the three climates used in this report). As discussed above, the boiler approach is characterized by lower equipment cost than the unit heater approach, but higher fuel consumption in a given application. As a result of this, for a given set of conditions, there will be an optimum system from a total cost standpoint.

Calculation of the lowest cost system for a particular application involves consideration of equipment ownership cost (capital cost and financing), fuel costs, equipment maintenance and fan energy (unit heater system).

This is best illustrated with an example. Consider a 1-acre greenhouse to be built in a moderate climate (Klamath Falls) in which effluent from an existing facility will be used as the supply for the new construction. Using the effluent will permit the heating system to meet 55% of the peak load. Propane will be employed for the peaking fuel and inside temperature set point will be 60^{o}F day and night.

Assuming a double poly roof/single fiberglass construction, the peak heating load for the structure would be 2.77 x 10^{6} Btu/hr. As a result, the unit heater peaking equipment would be sized for .45 x 2,780,000 - 1,247,000 Btu/hr. The boiler would be sized (interpolating from Table 4) for .75 x 2,770,000 = 2.16 x 10^{6} Btu/hr. From Figure 6 the capital cost for the peaking system would be $37,000 for the unit heaters and $42,500 for the boiler. Based on 15 years/8% financing, the annual cost of the unit heater equipment would be $4,322 and $4,694 for the boiler system.

Using Figure 10 and Table 5, the annual propane consumption for the unit heater system would be 4,436 gallons ((1 - .95) x 5.59 x 10^{9} ÷ 63,000) and 7,892 gallons ((1 -.911) x 5.59 ÷ 63,000) for the boiler system.

Assuming a value of 2% of capital cost for equipment maintenance, the cost for the boiler system would be $850/yr and for the unit heater system $740/yr. Fan energy consumption is a function of the size and number of unit heaters installed. Assuming 10 units at 125,000 Btu/hr each, the fan motor in each unit would be 1/3 hp. For 10 units, 3.3 hp or approximately 2.9 kW. For 1325 hours per year operation, the electric consumption would amount to 1590 kWh or about $111 at $0.07/kWh.

Table 6 presents a summary of the costs for the two peaking systems in both $ and $/ft^{2} of greenhouse.

Table 6
Summary of Peaking System Costs - Propane Example

	Unit Heaters		Boiler	
	$	$/ft^2	$	$/ft^2
Equipment (15 yrs/8%)	4,322	.099	4,969	0.114
Maintenance (2% of capital)	740	.017	850	0.019
Electricity ($0.07/kWh)	111	.003	0	0
Fuel ($1.00/gal)	4,436	.102	7,897	0.18
Total	9,609	.221	13,716	0.313

In this case, the unit heater design is the clear choice due to its lower equipment and fuel costs. If fuel oil was to be the peaking fuel in the same situation, the results are quite different. Table 7 presents the results for the oil case.

Table 7
Summary of Peaking System Costs - Fuel Oil Example

	Unit Heaters		Boiler	
	$	$/ft^2	$	$/ft^2
Equipment (15 yrs/8%)	7,241	0.166	3,738	0.086
Maintenance (2% of capital)	1,240	0.028	640	0.015
Electricity ($0.07/kWh)	111	0.003	0	0.0
Fuel ($1.00/gal)	2,851	0.065	5,076	0.117
Total	11,443	0.262	9,454	0.218

In the case of fuel oil, the much higher cost of oil-fired unit heater equipment tends to be the pivotal cost item. Despite the lower fuel costs for the unit heater system, the boiler design is the clear choice.

CONCLUSIONS

It is unlikely that a base load/peak load system would be used in place of a 100% geothermal system if the decision was based solely on costs. In most, if not all, cases, the base load/peak load system will have both higher operating cost and capital cost than a geothermal system designed to meet 100% of the peak. In cases where there is limited geothermal flow available and the grower wishes to use a system which is difficult to apply at low water temperatures, the use of fossil fuel peaking permits the use of the growers preferred system for a reasonable increment in operating costs.

Figures 15, 16 and 17 summarize the cost data discussed in the previous section and present the total costs associated with the peaking system for the three climates discussed in this report. In each case, the costs are presented in \$/ft^2 of greenhouse, a value commonly used in the greenhouse industry.

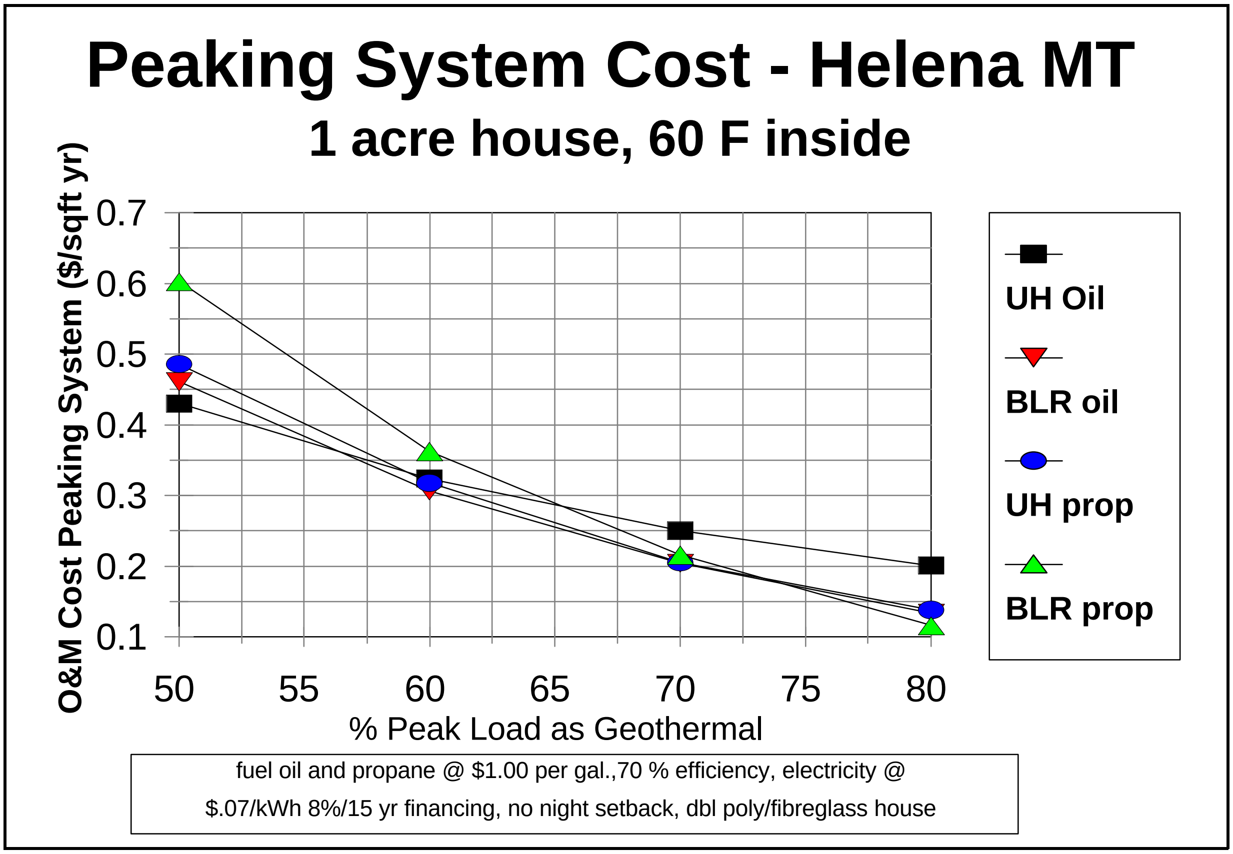
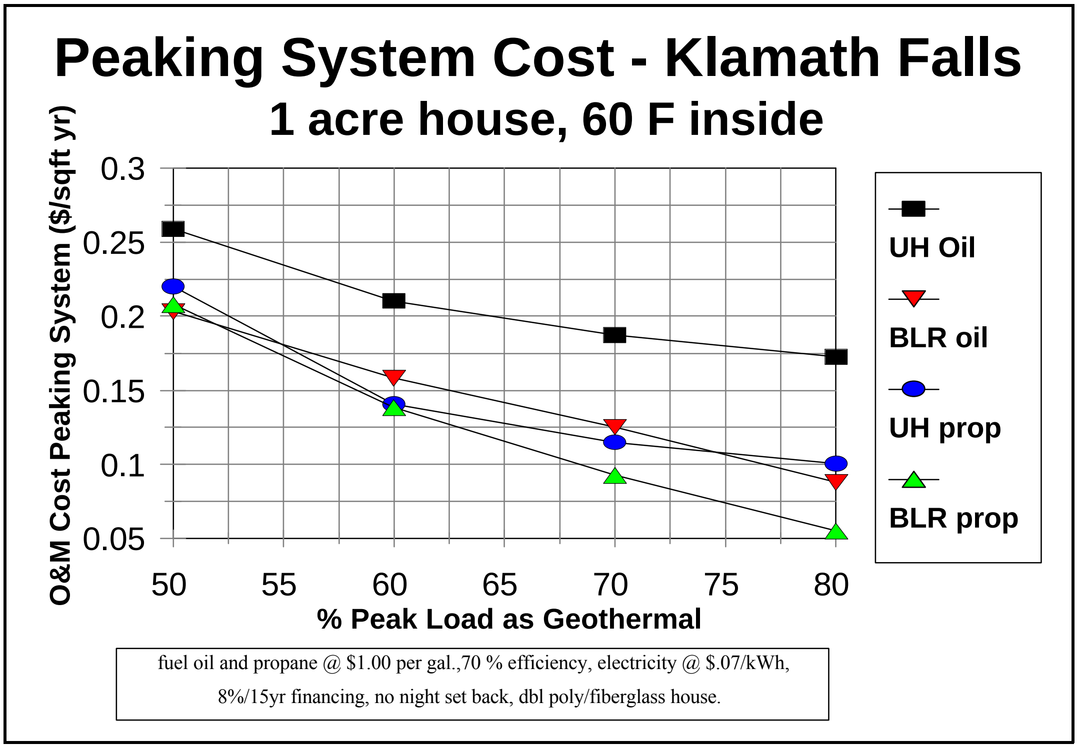
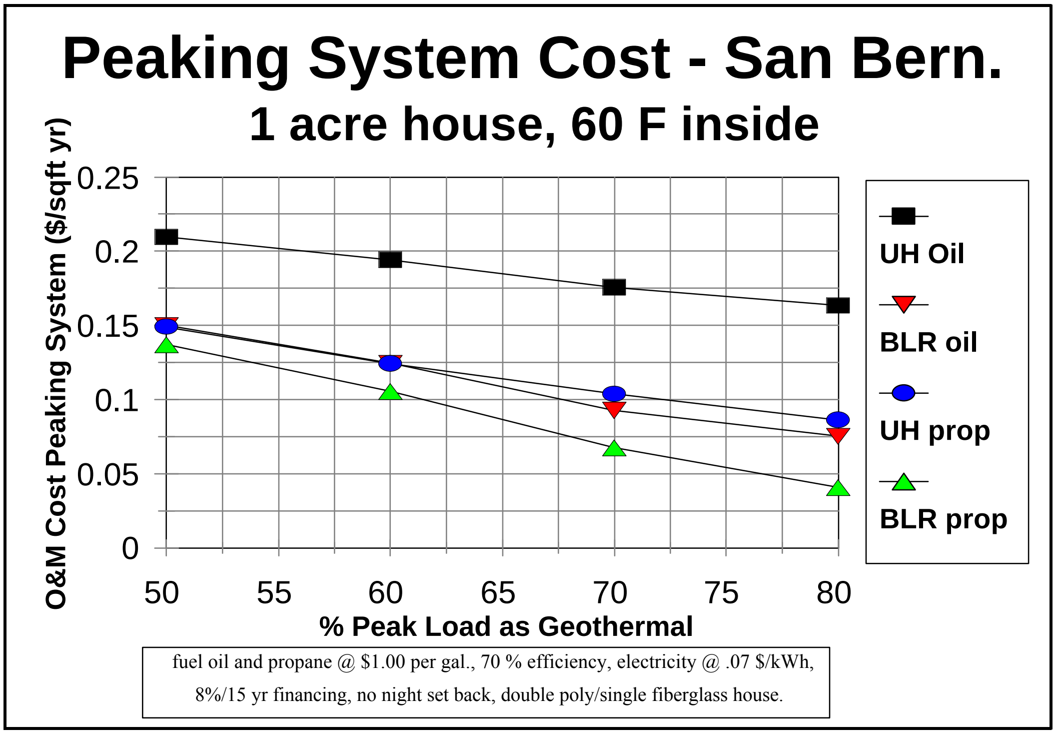


Figure 15. Peaking System Cost, Helena, MT



fuel oil and propane @ $1.00 per gal.,70 % efficiency, electricity @ $.07/kWh, 8%/15yr financing, no night set back, dbl poly/fiberglass house.

Figure 16. Peaking System Cost, Klamath Falls, OR



fuel oil and propane @ $1.00 per gal., 70 % efficiency, electricity @ .07 $/kWh, 8%/15 yr financing, no night set back, double poly/single fiberglass house.

Figure 17. Peaking System Cost, San Bernardino, CA

For the coldest climate, the impact of heating fuel consumption is clear. For base load system capacities of less than 60%, the oil-fired unit heater design, despite its substantial capital cost, is the least expensive system to operate. This is due to the large fuel requirements under these conditions. For base load system capacities of greater than 60%, this system steadily loses competitiveness, and above 65% it is the highest cost system.

The propane unit heater and propane boiler approaches are very close to each other and are the least cost choice in the 55% to 75% base load capacity range. The propane boiler design is not competitive except above 75% base load capacity.

In the moderate Klamath Falls climate, the lower heating energy requirement (compared to Helena) results in the oil-fired unit heater system being cost prohibitive under all conditions. For base load system capacities under 55%, the oil boiler is the least cost design, but only marginally. The propane boiler is the least cost above 55%. In the 60% to 70% range, both the oil boiler and propane unit heater systems are within 20% of the cost of the propane boiler system.

In the mildest climate, the results are similar with the oil unit heater system uncompetitive and the propane boiler system offering least cost. Again, the oil boiler and propane unit heater systems are close to each other and at base load capacities of less than 60% are within 10 - 20% of the cost of the propane boiler system.

Figures 15, 16 and 17 are based on a constant 60° set point (night and day) in the greenhouse. Because the set point temperature, and whether or not set back is used, have a substantial impact upon energy usage. The above conclusions are valid for the 60° set point only. For other temperatures calculations, using Figures 9 through 14 and Table 6 should be done.

GLOSSARY

Inside design temperature - The temperature to be maintained in the heated structure (for greenhouses typical values are 50 - 65°F).

Outside design temperature - The outdoor temperature for which heating systems are designed, varies with location. For greenhouses, the 99% ASHRAE figure is normally used. This is the outside temperature below which only 1% of the hours in a normal winter occur.

Design D**T** - Inside design temperature minus outside design temperature.

Peak (or Design) heating load - The product of the design ΔT times the building heat loss characteristic in Btu/hr°F. Peak heating load has units of Btu/hr. It is the rate at which heat must be supplied to the structure to offset the heat loss at the design condition.

Annual heat load - The total heating energy (in Btu) which must be supplied to the structure over a 1-year period to offset the heat losses.

Temperature bin - A 5° increment (i.e., 30 to 35°) in temperature for which annual hours of occurrence are published.

Bin data - Information published by the Department of Defense and others which indicates the number of hours in a typical year which occur at each 5° temperature bin.

°F-hour - The product of the hours in a particular temperature bin times the temperature difference between that bin and the inside temperature of the structure.

Base load heating system - A heating system designed to supply only a portion of the peak heating load usually in the range of 50% to 70%. Operates most the heating season.

Peaking system - A heating system designed to supply only the difference between the base load capacity and the peak heating load requirement. Operates only a few hours per year.

Balance point - The temperature at which the capacity of the base load system is equal to the structure heat loss. Above the balance point, the base load system supplies all heating requirements. Below the balance point, the peaking system supplements the base load system.