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**DESIGN AND CONSTRUCTION OF
THE NMSU GEOTHERMALLY HEATED
GREENHOUSE RESEARCH FACILITY**

FINAL TECHNICAL REPORT

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7. ABSTRACT <p>This report describes the design, construction, and performance of the New Mexico State University (NMSU) Geothermal Greenhouse Research Facility. Two 6,000-square-foot greenhouses were built on the NMSU campus and supplied with geothermal energy for heating. The geothermal water is pumped from one of three wells producing water at temperatures from 141°F to 148°F. Heat is delivered to the greenhouse space by means of overhead fan-coil unit heaters.</p> <p>The two greenhouses are double-glazed on roof and wall surfaces employing a total of four different film materials: Tedlar®, Melinex®, Softglass®, and Agrifilm®. One greenhouse is cooled using a traditional fan and pad cooling system. The second greenhouse is cooled with a high-pressure fog system and natural ventilation through roof and side vents. A 2,400-square-foot metal building next to the greenhouses provides office, work, and storage space for the facility.</p> <p>The greenhouse facility was leased to two commercial tenants who produced a variety of crops. The performance of the greenhouses was monitored and reported both qualitatively and quantitatively. Results from the tenant's pilot-scale studies in the NMSU greenhouse facility were transferred and applied to two commercial greenhouse ranges that were built in southern New Mexico during 1986/87.</p>		
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Modine Manufacturing

1.0 PROJECT BACKGROUND AND OVERVIEW

The New Mexico State University (NMSU) Geothermal Greenhouse Research Facility was funded jointly by the New Mexico Research and Development Institute (NMRDI) and New Mexico State University in order to stimulate geothermal greenhouse development in New Mexico. Under the initial contract, the New Mexico Solar Energy Institute designed the facility with features that would be of interest to the commercial greenhouse industry. The original design was published in 1985 in an interim report to NMRDI.

To proceed into the construction phase of the project, industry matching funds of at least \$50,000 were required. This requirement was to assure that interest truly existed in the commercial sector for the use and usefulness of the facility. In spring 1985, NMSEI had secured \$90,000 in total matching funds from industry sources, and procurement for the construction of the greenhouse facility was initiated.

All major equipment was ordered during the summer of 1985. This included the greenhouse structure and glazing, cooling fans, cooling pads, heaters, and controllers. Most of this equipment was received during summer/fall of 1985.

The greenhouse facility site was prepared in September 1985. This required the removal, leveling, grading, and compacting of approximately 6,000 cubic yards of soil. A 200 foot by 230 foot chain link fence was erected to enclose the site for security.

The metal building for the head house was ordered and delivered in December. A 40 foot by 60 foot concrete foundation

slab was prepared, and the head house was erected during January 1986.

Greenhouse foundation work started in December 1985. Following completion of the foundations, the greenhouse structure was erected during January and February 1986.

The greenhouse glazing panels were delivered in mid-March 1986. A consultant from SERAC Ltd. was present to oversee and assist in the mounting of all glazing materials. The entire task of glazing the greenhouse structure was carried out with student labor. In mid-April 1986 the greenhouses were covered and the interior/exterior finishing work was begun. All non-electrical work was accomplished with student labor. This included: installation of plumbing for fresh water and heating system, installation of fans, heaters, vents, vent motors and gears, installation of cooling pads, fog system lines and pump unit, and numerous other finishing tasks.

The electrical service line was extended to the greenhouse facility, and wiring of the greenhouses was completed in June 1986.

Benches were built for the south greenhouse; and the 6,000 ft² south greenhouse was leased to Flores de New Mexico, Inc. in mid-June 1986.

In August 1986 a contract was signed with Alex R. Masson, Inc. for the lease of the north greenhouse. The company started occupancy on September 1, 1986.

Following occupancy of the two greenhouses, NMSEI maintained and monitored the greenhouses for the two tenants. A telephone service was installed in both greenhouses. The telephone allows for the remote sensing of the greenhouses (temperature,

power) and for automatic warning when an emergency condition arises.

In August/September 1986, the geothermal heat exchanger was installed in the head house and the plumbing for the hot water circulating system was completed. The backup boiler was installed and tested. The heating system for the greenhouses was turned on (for nighttime heating) on September 12, 1986.

Following the decision by NMSU to not connect geothermal well PG-4 to the campus system within the near future, a well pump of sufficient size to heat the greenhouse research facility was ordered for the project. A 10 HP submersible pump with a stripper well motor was selected. The pump was scheduled for delivery in November 1986, but delivery was delayed due to manufacturing problems until March 1987. The pump was set in the well on March 4, 1987.

In December 1986 NMSU installed a reconditioned pump in geothermal well PG-1 and started to run the NMSU campus geothermal system. Approximately 60 gallons per minute of geothermal fluid from PG-1 was pumped to the greenhouse complex for heating purposes through a 2-inch pipeline installed by NMSEI. The greenhouse facility has been heated exclusively from geothermal fluid since December 18, 1986.

2.0 LOCATION

The NMSU geothermal greenhouse is located on the east side of the NMSU campus near Tortugas Mountain. The greenhouse is accessible via the NMSU rodeo arena road. The site was chosen

because it is located next to geothermal production well PG-4, has utility power and water nearby, and is wide open for future expansion.

3.0 GREENHOUSE STRUCTURE AND LAYOUT

The greenhouse structure is of Dutch design and was fabricated by Dalsem Kassebouw of Den Hoorn, Holland. The house design is double span and gutter connected. The span is 31.5 feet and the section length is 12.3 feet. Each of the two greenhouses consist of two spans and seven sections plus two gable ends. The overall greenhouse dimensions are 63 feet by 97.7 feet, or 6,155 square feet. Gutter height of the greenhouses is 8.5 feet. Height to the roof peak is 16.2 feet. All structural members, braces, and purlins are made of galvanized, rolled steel.

The foundation consists of 10-inch diameter reinforced concrete piers that are set 24 inches deep into the ground. Upright support beams are bolted to the piers. All support piers along the perimeter of the greenhouse are tied together at ground level by a reinforced concrete stem wall that is 8 inches wide and 12 inches tall. The stemwall has a slight slope from one end to the other to allow for adequate drainage of the gutters. Four foot wide concrete sidewalks were poured in the center of each bay of the two greenhouses.

The long dimension of the greenhouses was oriented on the east-west axis to minimize shading effect of structural members on the plant crop.

The two greenhouses were spaced precisely 31.5 feet apart. This design allows for the future expansion of the greenhouse facility by adding a truss span between the two separate houses and opening up the facility into one larger greenhouse with five bays.

The two greenhouses have a 7 foot 7 inch by 8 foot sliding door for personnel and equipment access at the east end of one sidewall.

4.0 VENTILATION AND COOLING

The two greenhouses employ two different ventilation and cooling systems. The south greenhouse has a traditional fan and pad ventilation and cooling system, whereas the north greenhouse is cooled by a high-pressure fog system. A description of the two systems follows.

4.1 Fan and Pad Cooling

The south greenhouse has a 6 foot by 60 foot cooling pad installed at the west gable end. Outside air enters the greenhouse through a 4 foot by 60 foot motorized vent. As the air passes through the cooling pad, it picks up moisture (relative humidity increases) and the temperature drops to approach the wet bulb temperature. The air then passes through the greenhouse and exits on the east gable end through four fan openings. This air movement is accomplished by four 48-inch diameter 3/4 HP fans. The four fans are installed at bench height (about 4 feet off the ground) and are spaced evenly in the gable end. The fans were manufactured by ACME Engineering Company, and are each rated at 19,000 cubic feet

per minute air flow. The four fans achieve one complete air exchange per minute.

The cooling pad is made of a 1 1/2 inch thick bat of synthetic fibers that are bonded together and coated with a cellular absorbent foam for water absorption. The fiber pad is attached to a rigid welded wire grid for physical stability. The synthetic fibers are chemically resistant and can be cleaned from mineral buildup and algae growth with high pressure water spray.

The pads are wetted from a header pipe with evenly spaced holes. As the water runs down through the pads, it is absorbed by the pad. Excess water is collected in a trough in which the bottom of the pads are mounted. The trough system also serves as the sump tank. The water flows through the trough to the centrally located sump pump. The sump pump lifts the water back into the header pipe for distribution to the pads. Makeup water to account for the evaporative losses continuously enters the trough/sump tank and is regulated by a simple float valve.

The fan and pad cooling system can achieve approximately 75 percent wet bulb depression. This efficiency was confirmed by occasional spot measurements during the cooling season. On a typical day with the 90°F dry bulb temperature and 40 percent relative humidity,¹ the air entering the greenhouse through the cooling pad would be measured at 75°F.

A distinct disadvantage of the traditional fan and pad cooling system is the air temperature gradient between the pad end and the

¹Wet bulb temperature under these conditions is 70°F.

fan or discharge, end. As the air travels the 98 foot distance from the pad to the fan, its temperature increases. Gradients in the range of 10°F - 12°F were observed on warm sunny days during mid-day. The fog system, by contrast, does not have these temperature gradients.

4.2 Fog Cooling System

The north greenhouse employs a fog cooling system. The fog system operates by creating a very fine mist (10 micron droplet size) that is discharged into the air. The mist droplets evaporate, thereby creating the evaporative cooling effect.

The fog system consists of six lines of fog nozzles. The six lines run parallel to the greenhouse long axis and are spaced evenly through the greenhouse. The nozzles in each line are spaced six feet apart. There are a total of 90 nozzles in the greenhouse. The fog lines/nozzles are installed at gutter height, or 8.5 feet above ground level, and the mist is ejected upwards to minimize wetting of the plant material.

A control module supplies the fog lines with pressurized water. The control module filters the water (30 micron filter cartridge) and boosts the pressure to 1,000 pounds per square inch. This filtered, high pressure water enters the fog lines and is discharged into the air through the nozzles. Opposite the extremely small nozzle opening is an impact pin. As the water leaving the nozzle strikes the impact pin, it is atomized into droplets of approximately 10 micron average diameter. These droplets are light enough to float in the air, where they evaporate, thereby increasing humidity and decreasing

temperature. The fog created by the system is so fine that generally no wetting occurs at the plant level below the nozzles.

The fog system relies on natural ventilation to accomplish the required air exchanges. Hot and humid air rises and leaves the greenhouse through roof vents. The roof vents are 4 feet wide by 94 feet long and are installed on the north facing slope of the two bays. The vent is hinged along the roof peak and opened by a rack and pinon mechanism from the inside. The vent system is motorized and wired to the Wadsworth greenhouse temperature controller for automatic operation. Side vents replace the hot humid air that is leaving through the roof vents with dry outside air. As this dry outside air picks up moisture from the fog, it cools down and descends to the plant level. The natural convection loop described above continues throughout the day as long as cooling and humidification are required. The side vents are 4 feet by 94 feet and are operated similar to the roof vents.

The fog cooling system has several advantages over the fan and pad cooling system. First, since humidity is added to the air throughout the entire greenhouse, there is no horizontal temperature gradient, and environmental conditions are the same throughout the greenhouse. Secondly, more moisture can be added to the air as compared to a fan and pad system. This results in higher cooling efficiency. Thirdly, the fog system allows the greenhouse operator to accurately control and adjust humidity. For example, when the greenhouse is closed up and heated at night, the fog system can be run to maintain the desired relative humidity, resulting in a better crop quality.

The fog system, however has a disadvantage that should be addressed. As the water droplets evaporate, they leave behind minute solid particles of the minerals contained in the water. A fraction of these particles leave the greenhouse along with the hot air exiting the roof vents. A substantial fraction, however, falls down and coats the leaves of the crop with a white residue film that, depending on the chemical composition of the water, will not wash off. This residue film renders the plant foliage unattractive for sale in the retail market. As long as plants are grown in the fog house for propagation purposes only, the accumulating white deposit does no harm. For foliage production destined for sale, however, the water for the fog system should be treated to adjust the pH value. This will have the effect that the residue film can be rinsed off with a water spray before plants are shipped for sale.

Improvement in the design of a fog-cooled greenhouse over the NMSU installed system would be to combine the fog with forced air (or fan induced) ventilation. The natural ventilation in the north greenhouse is strongly influenced by outside wind and weather conditions. During light to moderate winds, the ventilation rate increases beyond desirable rates. Much of the moisture added to the air leaves the greenhouse quickly, thus creating an environment that is too hot and/or too dry. This can be overcome by using fan induced ventilation similar to the fan/vent arrangement in the fan and pad greenhouse. The result would allow maximum control over greenhouse temperature and humidity conditions.

5.0 GREENHOUSE COVER

The greenhouse facility glazing consists of prefabricated stressed skin panels. The stressed skin panels were manufactured by SERAC Ltd. of Aldingbourne, England, which holds the patents for the stressed skin technology.

The panels consist of an extruded aluminum frame of the desired size and the two film covers. The aluminum extrusion is shaped to accept clips on both sides which are used to clamp down a transparent film stretched over the frame. The continuous clipping system is air and water tight, provides a UV shield along the film/aluminum contact surface, and secures films of varied thickness perfectly. After mounting the film in the frame, the film is heat-shrunk to pull it taut and flat. Films are mounted on both sides of the frame to result in a double glazed panel with an optimum dead air space of about 3/4 inch between the films. The space between the two films is vented to prevent moisture condensation. A typical panel is 4 feet wide by 16 feet long and very lightweight, about 18 pounds. The panels are interlocking and are attached to the greenhouse purlins with mounting bolts. Along the greenhouse gable ends and at other irregular shaped surfaces, the stressed film panels are manufactured to fit the specific space.

The NMSU geothermal greenhouse facility uses different film materials in different bays of the greenhouse. All sidewall panels use Softglass® for the outside film and Melinex® on the inside. The roof of the northern bay of the southern greenhouse has a combination of Softglass® and Agrifilm®. The southern bay of the same greenhouse uses a Softglass® and Melinex® combination. The

northern greenhouse has Tedlar® film on both outside roof surfaces, an inner film of Tedlar® on the southern bay, and an inner film of Melinex® on the northern bay. Table 1 summarizes the film materials for the different greenhouse surfaces.

TABLE 1
GLAZING MATERIALS FOR THE NMSU GEOTHERMAL GREENHOUSE
FACILITY

HOUSE	BAY	ROOF	WALLS	GABLE
South	South	ODC/M	ODC/M	D
South	North	ODC/A	ODC/M	D
North	South	T/M	ODC/M	ODC/M
North	North	T/T	ODC/M	ODC/M

Explanation:

ODC: Softglass® manufactured by Dow Corning

M: Melinex® manufactured by ICI

A: Agrifilm® manufactured by Southwall Corp.

T: Tedlar® manufactured by Du Pont

D: Dracolon®

A description of the film materials follows:

5.1 ODC Softglass®

The ODC Softglass® film is a silicone-coated fiberglass fabric. Total thickness of the film is 10 to 12 mils. The film is claimed to have excellent weathering properties as well as long-term flexibility. The manufacturer's published life expectancy of the film is in excess of 20 years. The woven glass fabric serves as the reinforcement material to give the film its strength. Light transmission depends on the specific fabric chosen. Interior light is diffused by the fabric.

The film is strong, resists tearing (similar to rip-stop nylon), and can be patched easily.

After one year of exposure, the following observations regarding the Softglass® film are noteworthy. The Softglass® film is not elastic. As thermal contraction of the stressed skin panel occurs, the film becomes wrinkly and flutters in the wind. The fluttering may affect the longevity of the Softglass® film using this mounting technology.

Light transmission of the film is low. In May 1986, the film transmission was measured both over the total solar spectrum (using a pyranometer) and in the PAR (photosynthetically active radiation) spectrum (using a Quantum sensor). Resulting transmissivity was 78 percent and 77 percent, respectively.

Finally, the film appears to attract and retain dust particles. These particles accumulate on the film and adhere to it so strongly that rainstorms and wind conditions in southern New Mexico's desert climate don't appear to remove the dust film. Only mechanical cleaning with a soft wet brush can remove the dust film. The dust accumulation affects the light transmission of the film and gives it an unattractive light brown appearance.

5.2 Melinex® Film

Melinex® 071 is a UV stabilized polyester film with an interior anti-misting/condensation surface. The film is glass-clear and has a high light transmissivity. Our measurements showed 94 percent transmission in both the total energy spectrum and the PAR range. Film thickness used in the geothermal greenhouse is 3 mils. The film

has a very good impact resistance, however, once it is accidentally punctured, the tear tends to propagate easily. The manufacturer's estimated life of the film is 10 years. The geothermal greenhouse complex utilizes Melinex® 071 on several interior surfaces. The anti-mist/condensation treatment appears to work well. We have not noted any condensation dripping off the film. The high light transmissivity of the film is beneficial for plant growth.

5.3 Tedlar®

The Tedlar® polyvinyl fluoride film is manufactured by Du Pont Corporation. The film has good weatherability and remains very strong over its expected life of 5 to 8 years. The solar transmission of the film is high. Our measurements showed 91 percent transmissivity over the total spectrum and 93 percent in the PAR range. Film thickness is 3 mils. The film is strong enough to support an adult standing in the center of a 4 foot by 16 foot panel. The film shrinks about 2 to 3 percent when heated to 250°F. This makes the film suitable for the stressed skin panel system.

The Tedlar® film has performed well as a glazing material for the greenhouse. In combination with the Melinex® film or a second interior Tedlar® film, it shows a high light transmissivity which benefits the crop.

5.4 Agrifilm®

The Agrifilm® is manufactured by the Southwall Corporation. Agrifilm® is based on a clear 3 mil UV stabilized polyester film. The film has an anti-fog coating on the interior surface and a selective

coating on the exterior surface. The purpose of the selective surface is to both prevent radiative heat loss from the greenhouse as well as shielding out the near infrared solar wavelength to prevent excessive solar heat from entering the greenhouse. By proportionally passing more of the photosynthetically active radiation than the near infrared heat radiation, the film cuts cooling requirements without affecting the crop's photosynthesis.

Our measurements confirm the film's selective transmissivity. The total solar energy passing through the film is reduced to 74 percent, whereas 83 percent of the photoactive radiation (PAR) reaches the greenhouse interior.

We could not evaluate the effect of the Agrifilm® on plant growth and quality since our commercial greenhouse tenants frequently changed and rotated their crop.

The anti-fog coating of the Agrifilm® appears to work as designed. We did not observe excessive condensation or dripping from the film.

5.6 Light Transmission

Measured light transmissions of individual films and double film combinations are summarized in Table 2.

6.0 HEADHOUSE

The greenhouse facility is served by the headhouse building. The purpose of the headhouse is to provide:

- work space for potting,
- shop space for maintenance and repair tasks,

TABLE 2.

MEASURED FILM TRANSMISSIVITIES

Film Material	Transmission Total Spectrum	Transmission PAR
<u>Individual Sheet</u>		
Softglass®	78%	77%
Melinex®	94%	94%
Tedlar®	91%	93%
Agrifilm®	74%	83%
<u>Panel</u>		
Softglass®/Melinex®	53%	54%
Softglass®/Agrifilm®	42%	49%
Tedlar®/Melinex®	86%	87%
Tedlar®/Tedlar®	86%	86%

- storage space,
- a small office space, and
- house the heating equipment and controls.

The headhouse is a 2,400-square-foot metal building erected on a 40 foot by 60 foot concrete floor. The building was manufactured by Midwest American, Inc., and erected by a local contractor. Eave height of the building is 12 feet. The building has two personnel access doors, a 10 foot by 10 foot overhead door for vehicle access, six windows for the office space and four skylights in the main work area.

Three offices were partitioned off the main work area. The offices are 16 feet by 12 feet, 12 feet by 12 feet, and 12 feet by 12 feet, respectively. A bathroom and a lockable tool room are also installed in the building. The offices and work space are made available to the greenhouse tenants as part of the lease.

Most of the heating equipment is housed in the metal building. This includes the geothermal heat exchanger, the circulating pumps, the backup hot water heater, and the pump controls for the submersible pump in well PG-4.

The headhouse also provides an excellent facility for the reception of visitors that tour the greenhouse facility. Visitors can view the geothermal heating equipment and be given a presentation of the facility layout before entering the greenhouses.

7.0 COMPUTER DATA ACQUISITION

In order to monitor the performance of the greenhouse facility, a data acquisition system was installed to sample temperatures. The data acquisition system is based on a Hewlett Packard HP-85 micro-computer and a Hewlett Packard model 3497A data acquisition interface.

The HP-85 computer was programmed in BASIC to:

- (1) take temperature readings once every 20 seconds,
- (2) average these temperature readings over 6 minutes,
- (3) store the 6-minute averages once per day on magnetic tape for later evaluation, and
- (4) display the current temperatures on screen.

The temperature probes are made from T-type thermocouple wire. Twelve temperatures are constantly being monitored:

- Six greenhouse air temperatures (three in each bay) at plant level,
- outside air temperature,
- water temperature at the inlet and outlet of each of the two heaters, and
- soil temperature in one of the planters.

Data are retrieved from the magnetic tape and stored on floppy disk for evaluation and plotting on a HP-87 computer at NMSEI.

Figures 1 through 3 show some typical plots.

Figure 1 shows three air temperatures for the north greenhouse (the fog-house) for the day of January 1, 1987. The x-axis is the 24-hour time scale, the y-axis shows the temperatures in degrees Celsius. Trace #2 is the air temperature in the center of the south bay, trace #5 is the air temperature in the center of the north bay, and trace #7 is the outside temperature. Figure 2 shows the heating water temperatures at inlet (trace # 8) and outlet (trace #9) for the south-bay heater. Also shown is the greenhouse air temperature from the west end of the south bay (trace #1). Figure 3 shows the same plot for the north bay heater.

8.0 GEOTHERMAL HEATING SYSTEM

The geothermal greenhouse heating system consists of several components: the geothermal production system, the heat exchanger,

Figure 1. North Greenhouse Air Temperatures, January 1, 1987

Figure 2. South Bay Heater Supply and Return Water Temperatures, January 1, 1987

Figure 3. North Bay Heater Supply and Return Water Temperatures, January 1, 1987

the heat delivery system, a disposal pond, and a gas-fired emergency backup heater. Each of the components is discussed in detail below. Figure 4 shows a schematic of the heating system.

8.1 Geothermal Production

The NMSU geothermal greenhouse research facility can draw heat from two NMSU campus production wells, namely PG-1 and PG-4.

8.1.1 Well PG-1

Production well PG-1 was drilled as part of the NMSU geothermal campus heating demonstration project. The well is approximately 860 feet deep and has a casing size of 12 inches. A 75 HP Johnston line shaft pump produces up to 250 gallons per minute (gpm) of geothermal water at 141°F. This water is utilized on the NMSU campus for domestic water heating, space heating, and heating of the natatorium pools.

In order to connect the greenhouse complex to well PG-1, approximately 1,000 feet of pipeline was constructed. The pipeline is made from 2 inch PVC buried approximately 18 to 24 inches underground. The pipeline is connected to the campus geothermal system at the well head of PG-3. Uninsulated PVC pipe was chosen in order to keep the cost of pipe and installation reasonable without causing excessive heat losses over the 1,000 foot length.

The pipeline performed well. During the coldest part of the winter, the geothermal fluid arrived at the heat exchanger in the headhouse with a temperature of about 136°F at a flow-rate of 64

Figure 4. Geothermal Greenhouse Heating System

gpm. The heat loss between the well and the heat exchanger was only 5°F. At the reduced flow rate of 38 gpm, the heat loss increased slightly to about 9°F.

The PVC pipeline developed leaks on several occasions. In every case the leak occurred at a joint between connecting pipe sections. These leakage problems were expected since the PVC pipe material is not rated for hot water service. Specifications state that at 140°F PVC pipe retains only 22 percent of its original strength (rated 280 PSI at 73°F). Every leak was caused by a pressure transient (water hammer) caused by valve adjustments at wellhead PG-1. The cemented joints proved to be the weakest part.

Overall the pipeline performed well at a very economical cost.

8.1.2 Well PG-4

Production well PG-4 was drilled in 1984, and deepened to 1,012 feet in April of 1986. A flow test was also conducted. Figure 5 shows the well completion. (Larry Icerman and Stephen K. Parker (eds.), New Mexico Statewide Geothermal Energy Program, New Mexico Research and Development Institute, Santa Fe, NM, 1988). PG-4 has a 14 inch diameter surface casing down to 688 feet. At a depth of 658 feet, the casing is necked down to 8 5/8 inches. A screen is set from 744 feet to 971 feet.

Production temperature of the well is 147.6°F. Water quality averages at 1,775 mg/l total dissolved solids. The static water level is 347 feet below casing top, and the productivity is very good, in excess of 100 gallons per minute per foot of drawdown. The well

Figure 5. PG-4 Well Completion

(From: New Mexico Statewide Geothermal Energy Program, Larry Icerman and Stephen K. Parker (eds.), New Mexico Research and Development Institute, Santa Fe, NM, 1988).

will be connected to the NMSU campus geothermal system at some time in the future.

Following the completion and characterization of PG-4, a submersible pump was ordered to supply geothermal water from the well to the greenhouse complex. The pump is a Grundfos Model SP8-25 stainless steel submersible pump furnished with a Franklin stripper well motor of 10 HP size. Table 3 summarizes the pump specifications.

TABLE 3

SPECIFICATION OF GRUNDFOS SP8-25 SUBMERSIBLE PUMP

Pump Model	SP8-25 submersible
Flow	22 gal/min @ 624 feet head 53 gal/min @ 355 feet head
Motor HP	10 HP
Electrical	460V, 60Hz, 3 phase
Service Factor	1.15
Speed	3,450 RPM
Current Draw	17 Amps
Minimum Flow	0.25 ft/sec
Temperature Rating	160°F
Setting depth	434 feet
Diameter	4"
Length: Pump and Motor	7'11"

The pump was ordered in September 1986 but was not delivered until March 1987 due to difficulties in manufacturing the motor. On March 2, 1987, the pump was set in the well at a depth of 434 feet. The 3 1/2 inch Hydrill drill stem was used as pump column.

The pump control panel includes overload protection to shut the pump off in case of excessive current draw. The system can be run manually or automatically by control from thermostat.

The pump was tested to produce a maximum of 53 gallons per minute at 148°F. This flow is adequate to maintain greenhouse temperatures in the 65°F to 70°F range during annual average low outside temperature conditions. The well is connected to the heat exchanger by a short run of 2 inch iron pipeline.

8.2 Heat Exchanger

Water from either of the geothermal wells enters a plate and frame heat exchanger located in the headhouse. The heat exchanger was manufactured by Tranter, Inc. It consists of 47 stainless steel (type 316) plates which make up the heat transfer area of 181.6 square feet. The plates are 0.024 inches thick. Overall size of the heat exchanger is 52 inches by 24 inches by 60 inches. The frame of the heat exchanger is of sufficient size to allow for at least three fold expansion by adding more plates.

The heat exchanger was designed for a maximum flow of 80 gallons per minute on both the geothermal and the fresh water side. The approach temperature of the heat exchanger at the 80 gpm design flow is 10°F. A summary of the heat exchanger specifications is included as Table 4.

As the geothermal fluid passes through the heat exchanger, heat is transferred to fresh water circulating through the heat exchanger in the opposite direction. The heated fresh water is then pumped to the greenhouse heaters.

TABLE 4

HEAT EXCHANGER SPECIFICATIONS

Manufacturer	Tranter, Inc.
Model #	UX-216-HP-47
Size	52 x 24 x 60 inches
Number of Plates	47
Area	181.6 ft ²
Plate Material	316 Stainless Steel
Thickness of Plates	0.024 inches
Design Flow	80 gpm
Pressure Rating	100 psi
Pressure Drop @ Design Flow	14 psi

8.3 Geothermal Disposal

Following the extraction of heat, the cooled geothermal water is piped to a surface disposal pond. The pond was originally constructed to hold geothermal water produced during the flow test of PG-4. The pond is 46 feet by 46 feet, and 15 feet deep. High soil permeability at the pond bottom allows for adequate drainage of the water.

A ground water discharge plan for the surface disposal of geothermal fluid was approved by the Oil Conservation Division of New Mexico Energy and Minerals Department.

While disposing the maximum of 64 gallons per minute into the pond during January 1987, the pond level rose to approximately 2 1/2 feet before drainage, evaporation and inflow balanced out. Deposition of minerals occurs at the bottom of the pond and along the edges. These mineral deposits accumulate and appear to affect the drainage. It is recommended to clean out the bottom of the disposal pond once per year during the summer.

8.4 Greenhouse Heating System

Hot fresh water is circulated in a closed loop from the heat exchanger in the headhouse to the four heaters installed in the greenhouses. The circulating supply pipe is three inch diameter black iron pipe. At each heater, a 1 1/2 inch supply line is branched off for the heater, and the main supply line is reduced in size by 1/2 inch.

A reversed return design is used to assure balanced hot water flow through each of the four heaters. Two circulating pumps of 1/3 and 1/2 HP size in the headhouse continuously move the water around. The pumps are installed in parallel and can be run individually or combined. The total round trip distance of the hot water loop is about 560 feet.

The greenhouse heaters are high efficiency fan-coil units manufactured by Modine. Three of the units are model GLW 330S, the fourth unit with twice the capacity is model GLW 660S. Table 5 is a summary of the heater specifications.

The hot water flows through the copper/aluminum-fin heater coils. As air is drawn through the coil unit, the air picks up heat from the water. The hot air is then blown into the greenhouse through a 24 inch diameter inflated polyethylene tube with 1 inch diameter holes punched into it on 1 foot centers. Hot air exits from these holes downwards into the greenhouse. The heaters are installed at the east side gable end of each bay of the greenhouses. The heaters are elevated 8 feet above ground level to keep them and the distribution polyethylene tube out of the way. The polytube

runs east to west for the entire length of the greenhouse and is tied off at the end opposite the heaters.

TABLE 5
MODINE HEATER SPECIFICATIONS

Hot water coil	1/2" O.D. copper, aluminum fins
Maximum pressure	300 psi
Maximum temperature	180°F
Motor	3/4 HP, three phase
Poly tube	24" diameter
Air flow	3,850 cubic feet per minute

The heater motors are 3/4 HP, 208V, three phase motors, and are controlled by the Wadsworth control system. Heat is withdrawn from the circulating water only when the heater fans are running. The heater efficiency depends heavily on the differential between the entering air temperature and the entering water temperature. Typical operating conditions at the geothermal greenhouse complex are as follows:

Entering water temperature	130°F
Entering (greenhouse) air temperature	70°F
Entering temperature differential ETD	60°F
Water flow rate through heater	15 gpm

Under these conditions, each model GLW 330S heater is capable of delivering 150,000 Btu/hour of heat to the greenhouse. The drop in water temperature under these operating conditions is 20°F. Thus water that enters the heater at 130°F will be leaving at 110°F.

8.5 Backup Heating System

It is critical to have heat available in the greenhouse at all times. Sensitive crops in the greenhouse can be severely damaged by low temperatures in a very short period of time. The geothermal greenhouse facility has effectively two backup systems which can be switched on quickly. The first backup is geothermal: Either PG-4 or PG-1 can be used to deliver heat to the greenhouse. If one of the wells or well pumps develops a problem, hot water can be drawn from the other well.

The second backup uses a propane fired hot water heater. The circulating secondary water that delivers heat to the greenhouse heaters can be pumped through a 1 million Btu/hour hot water heater. The heater was manufactured by ACE Buehler, Inc., and modified for propane operation. The heater can be operated by thermostat control such that it automatically turns on if the circulating water temperature to the greenhouse falls below a set point temperature. Propane is drawn from a 500 gallon LPG tank that is installed behind the headhouse building.

During the first part of the heating season in October/November 1986 it was necessary to run the greenhouse entirely on the propane fired backup heater since neither geothermal well was operating. This time period provided some valuable experience with operating the backup system. The propane hot water heater was found to be properly sized and capable of maintaining safe greenhouse temperatures without being oversized. Water temperature recovery and heat delivery is adequate for all but the coldest outside temperature conditions. During November 1986, with

typical night temperatures in the mid twenty's, the greenhouse complex required an average of 70 gallons of propane per 24 hours, at a cost of \$42 (\$0.60 per gallon of propane). The comparable cost of heating one acre of greenhouse would be approximately \$150 per 24 hours or \$4,500 per month (November) per acre. Clearly, designing a greenhouse for propane operation (other than emergency backup) is not likely to be cost effective.

After the greenhouse complex heating was switched over to geothermal, the backup system was required twice for short periods due to problems with the geothermal pipeline.

8.6 Heating System Performance

The data acquisition system allowed NMSEI to determine the thermal performance of the greenhouse and the heat delivery systems. The coldest night that was encountered during the winter occurred on January 18, 1987. Outside temperatures dropped to 9.5°F in the early morning. Figure 6 shows the temperature record (trace #7 is the outside temperature). With the heaters running continuously, the inside temperature was maintained at 65°F. Heat input was derived from 60 gallons per minute geothermal fluid arriving at the heat exchanger. Secondary water outlet temperature, (i.e., the hot water flowing to the greenhouse heaters) was at 134°F. Temperature drop across the greenhouse heaters averaged 21.5°F. Figures 7 and 8 show the heater supply and return temperatures. With an average flow of 15 gallons per minute of hot water through

Figure 6. North Greenhouse Air Temperatures, January 18, 1987

Figure 7. South Bay Heater Supply and Return Water Temperatures, January 18, 1987

Figure 8. North Bay Heater Supply and Return Water Temperatures, January 18, 1987

each of the heaters, the following amount of heat was delivered:

$$15 \frac{\text{gal.}}{\text{min}} \frac{60 \text{ min.}}{\text{hour}} \frac{8.34 \text{ lbs}}{\text{gal}} \frac{1 \text{ Btu}}{\text{lb}^\circ\text{F}} 21.5^\circ\text{F} = 161,379 \frac{\text{Btu}}{\text{hour}}$$

Since there are two heaters in each greenhouse, total heat input was about 323,000 Btu/hour per greenhouse. The heat input was not quite sufficient to keep the greenhouse temperature stable. Figures 6 through 8 show a very slow decline of the inside temperatures between 5:00 a.m. and 8:00 a.m. before sunrise. It should be remembered, however, that the greenhouse heating system was designed for 15°F minimum temperature condition. This is slightly lower than the Las Cruces long term average low temperature of 18°F. Given the extremely low outside temperature of 9.5°F (5.5°F below design temperature), the heating system performed very satisfactorily.

From this and similar calculations for less severe temperature conditions, an approximation was made of the heat requirement of a double glazed greenhouse in the Las Cruces climate zone. The average heat required for the NMSU greenhouse during the winter of 1986/1987 was about 1 Btu per hour per square foot of floor area per °F temperature difference between inside and outside:

$$\text{Heat demand} = 1 \text{ Btu/hour/ft}^2 \text{ floor area/}^\circ\text{F of } \Delta T$$

A similar double glazed commercial greenhouse should therefore have a heating system capable of delivering into the heated area: 2.2 million Btu/hour per acre of greenhouse (outside low: 15°F, inside 65°F).

This number may vary, of course, depending on the type of construction, glazing materials, floor area to surface area ratio, wind exposure, infiltration rates, etc. However, the 2.2 million Btu/hour per acre should be a good approximation of the peak demand of a well constructed double-glazed greenhouse in the Las Cruces climate zone.

9.0 TENANTS

The NSMU geothermal greenhouse research facility was successful in achieving its goal of providing incubator space for commercial growers. Both 6,000 ft² greenhouses were leased by the industry.

Flores de New Mexico, Inc. started leasing the southern greenhouse in June 1986. The company installed benches and a mist irrigation system before receiving the first shipment of carnation cuttings for propagation. During the summer of 1986, the company produced several hundred thousand potted miniature carnations. A temporary shade structure was erected at the greenhouse site to accommodate these plants. The company also started producing their own cuttings for further propagation. In the fall of 1986, Flores de Mexico started constructing a 10-acre commercial greenhouse range in Las Cruces. As parts of this range were completed, the company moved the miniature carnation crop to their new greenhouse, but left the propagation crop in the NMSU geothermal greenhouse facility. Production results (both quality and number) are confidential. In general terms, the company was very satisfied with these results.

The northern greenhouse was leased to Alex R. Masson, Inc. starting in September 1986. The company is headquartered in Linwood, Kansas, and owns and operates a 2-acre greenhouse range in Las Cruces. More importantly in the summer of 1986, Masson, Inc. was in the planning stage for a new geothermally heated greenhouse range in Radium springs. The company was therefore specifically interested in both the performance of the geothermal heating system and the fog cooling system. Construction of the new four-acre greenhouse range in Radium Springs was started in December 1986. The company benefitted from leasing the NMSU geothermal greenhouse by gaining valuable experience with both the geothermal and the fog cooling/humidification system. For example, after obtaining excellent results from the fog system during late summer and fall, the company decided to install fog in their new greenhouse range. The company grew potted chrysanthemums in the NMSU greenhouse for propagation. More than fifty different varieties were grown and evaluated. The humidity control combined with the ability to inexpensively maintain warm night temperatures (70°F to 75°F) markedly increased production and quality in the stock plants. Masson's Southwest also evaluated other crops in the greenhouse facility and obtained similar good results. The availability of the NMSU geothermal greenhouse research facility to these commercial clients proved invaluable for:

- gaining experience with southern New Mexico climate and growing conditions;

- evaluating heating, cooling, ventilation, and control technologies; and
- evaluating crop production, quality and scheduling for a wide variety of high-value crops.