NORMAN PELLETT: I am not sure what your experience with thermostats has been, but they appear to be very difficult to control.

HARRISON FLINT: Just a comment on controlling medium temperature with a thermostat. For relatively good control the trick is to keep the sensing unit close to the cable. If you keep the sensing unit too far from the cable, the medium will overheat close to the cable.

DAVE BAKKER: I think we nursery people are often cheap when we buy thermostats. You can buy thermostats with a 1 to 2 degree differential, if you order special.

A COMPARISON OF DIFFERENT HEAT SOURCES IN OUTDOOR MIST BEDS[1]

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Abstract. A comparison was made of five different unheated or heated insulated outdoor mist systems and a heated greenhouse mist system. Systems were evaluated for seasonal operating and construction costs as well as rooting efficiency of broadleaved and narrowleaved evergreens and deciduous plants. Spring propagation is practical in southern New England and three successive crops could be obtained in a heated outdoor system.

REVIEW OF LITERATURE

Increased cost of fossil fuels has placed plant producers in the U.S. northeast at an economic disadvantage. It has also stimulated research in designing both energy efficient plant production procedures and structures (1,2,3,4,5,6,7,8,10).

Recent studies have shown that it is not practical to attempt to provide all of the heat necessary for propagation from solar energy on an annual basis because of the limited efficiency of present solar energy systems in the north (11). However, it has been shown that such systems can be used to supplement conventional fossil fuel systems with fuel cost

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savings of up to 40 to 50% (11). Such savings over a number of years should offset initial capital outlay for a solar energy system (11).

One of the most efficient designs of a propagation or production bed is to supply heat directly to an insulated bed as bottom heat, since this is where root activity takes place (3,7).

MATERIALS AND METHODS

This research was done to determine the feasibility of propagating commercially important crops in outdoor beds which were insulated and heated only in the rooting medium and only during the seasons of higher solar radiation.

This approach appeared to be practical since the technology is available to make use of solar energy as well as improved insulation which reduces the required ratios of collector panels to area of bed space.

The idea of propagating coniferous crops in outdoor mist beds is not new. It has been done for many years in southern New England (9) but little, if any, spring or summer propagation was done with broadleaved evergreens, particularly rhododendron, because of the time required to attain a good root system. Also, if existing beds were insulated, fuel savings could be realized as well as reduced time of production for each crop. This could result in at least three crops per season with no building required and no energy expended on fans for cooling. It was also the objective of the work to compare construction costs for different bed designs as well as monthly operating costs for energy expended. Previous work at this experiment station had shown outdoor propagation was possible, but without the addition of heat in cool summers, crops required considerable more time than was available in summer.

Five outdoor mist beds were constructed in 1982-83 at the Rhode Island Agricultural Experiment Station. Concrete blocks laid without mortar joints were used for the sidewalls. The walls and bottom of the beds were insulated with 2.5 cm rigid foam polyisocyanurate (R = 7.2 at 20°C). The bottom insulation was sloped toward the middle with a 7.5 cm gap provided down the center for water drainage. In addition, one bed was constructed without insulation.

All outdoor beds had separate propagating areas of coarse sand and of a 50:50 mixture of sphagnum peatmoss and medium grade vermiculite. Coarse sand was used in each case to bring the medium level to approximately 20 cm above the bottom heat.

During the 1983 spring (April 1 to June 16) propagation period, all beds were covered with a 0.6 cm layer of microfoam through which the cuttings were placed.

In two beds, hot water was circulated through 2 cm (O.D.) polyethylene pipe placed 15 cm apart in the bottom of each bed. Feed and return pipes alternated to facilitate uniform heat distribution. A small, thermostatically controlled pump (Taco No. 007) provided water circulation in each bed. One of the beds was supplied with heat from a 50 gal electric hot water heater using one 4500 watt heating element and 40°C thermostat setting. The other bed obtained supplemental heat from a 300 gal storage tank heated by six Revere solar panels (Model No. 42121) mounted on a 23 degree (5 in 12 slope) south-oriented shed roof. A drain back system, controlled by a differential thermostat (Independent Energy No. C-30), was used for solar energy collection. The six, 0.91 × 2.44 m, panels had a combined total solar energy collection area of $13.4 m^2$ providing a collector-to-bed area ratio of approximately 7.

Low voltage resistance wire heating was used in the third bed. Two 500 watt transformers (120 volt primary, 16 volt secondary), with thermostat control, were used to feed No. 10 gauge galvanized wire having 17.5 cm bed spacing. The length of resistance wire powered by each transformer was about 29 m, providing a capacity of approximately $97 W/m^2$.

A fourth bed received supplemental heat from a south-oriented solar heated air panel having a 25 degree slope. Heat storage for the propagation bed was provided by a layer of 5 to 6 cm stone approximately 53 cm deep covered with 8 cm of pea stone. This was located beneath the 20 cm propagation medium. The rock storage had 5 x 40 cm air supply ducts along each side and a 10 x 40 cm return air duct down the center. These ducts were connected to the solar air panel. Air circulation was provided by a small fan (Dayton No. 4C666) controlled by a differential thermostat. The on-site built solar panel consisted essentially of a corrugated fiberglass cover, 5 cm air space, over matte black-painted collector plate (aluminum flashing), 1.9 cm air flow space, 0.6 cm plywood, 2.5 cm polyisocyanurate insulation and 0.9 cm plywood bottom. The 1.22 x 4.88 m panel provided a 0.6 ratio of collector to bed area.

The fifth outdoor bed was unheated and served as a control.

A raised bed of conventional design located in a quonset-type polyethylene-covered greenhouse was also utilized in this study. No bottom heat was provided but a minimum temperature of 20°C was maintained by a forced hot air furnace.

Thermostats were set to maintain bed temperatures of 20°C in 1982 and in the spring of 1983. Bed temperatures were recorded at 6 hr intervals (6 a.m., 12 noon, 6 p.m. and 12 midnight) by a 24 point strip chart recorder.

Electrical energy used for supplemental heat in the electric hot water and resistance cable beds was metered and recorded. Electrical energy consumption during 1983 was also monitored for the pumps used with the solar hot water panels and bed.

Selected cultivars of broadleaved and narrowleaved evergreens, and deciduous plants were propagated during the summers of 1982 and 1983 and in the spring of 1983. Broadleaved evergreen plants were propagated in a medium of equal parts of sphagnum peat moss and medium grade vermiculite; the others were propagated in coarse sand. Twenty-five cuttings of each cultivar were placed in each bed of each of the six systems.

A minimum grade was set for all cuttings. Broadleaved evergreens were not considered rooted unless there was a rootball of at least 2 cm; the number of roots per cutting were not counted unless they were at least 25 mm long. When cuttings in any bed had roots of sufficient length, cuttings of that cultivar in all beds were harvested (Table 1).

RESULTS

Temperature of Media. If the propagating medium had no mulch, the heated beds outdoors had the capacity to maintain a temperature differential between outside air and the medium of approximately 10 to 15°C. If mulched with microfoam they could maintain a difference of 15 to 20°C (Table 2). The greatest fluctuation in minimum average temperatures occurred in the solar-heated beds. Minimum night temperatures in Rhode Island in the summer of 1983 averaged 20°C which means little heat was needed to maintain a temperature of 25°C. Costs were significantly higher when heated beds were used in April or May but dropped rapidly thereafter.

Differences in the temperatures maintained in the beds by the various supplemental heating systems were not great except for periods of rainy weather. During these times, especially with rainfalls of 10 to 13 cm in 24 hr as occurred in the spring and early summer of 1983, the heat required to maintain desired bed temperatures exceeded the capacity of the systems. In addition, temperature reductions were greater and occurred for longer periods in the solar heated beds as solar energy collection was minimal in this rainy and cloudy weather.

Table 1. Average rootball diameter[1] (cm) and rooting percentage of five *Rhododendron* cultivars in outdoor and indoor progagating beds — 1982.

Propagation duration (weeks)	Cultivar	Unheated		Electric hot water		Solar hot water		Indoor greenhouse bed	
		Average diam. (cm)	Percent rooted[2]	Average diam. (cm)	Percent rooted	Average diam. (cm)	Percent rooted	Average diam. (cm)	Percent rooted
9½	'Boule de Neige'	4.7	22	5.8	53	5.2	38	8.1	67
13½	'Nova Zembla'	5.0	70	6.6	96	7.3	91	7.4	70
15	'English Roseum'	5.1	91	7.4	98	7.5	99	8.7	97
9	'Mrs. P. Den Ouden'	5.2	74	8.3	94	7.7	94	8.1	77
9½	R. × *chionoides*	5.2	40	5.6	86	6.9	80	6.7	51
	Average - all cultivars	5.0	59.4	6.7	84.5	6.9	80.4	7.8	72.4

[1] Twenty-five cuttings per treatment.

[2] Percent calculated on cuttings with a minimal root ball diameter of 2.0 cm

Table 2. Comparison of average night temperature of propagating medium of peatmoss and vermiculite in different heated and unheated outdoor mist systems — 1983.

Heating system with surface mulched (microfoam)	Spring (4/6-6/17)	Summer (6/20-9/30)
Low voltage galvanized wire	69 ± 7.4[1]	71 ± 6.0
Solar hot water	70 ± 10.5	77 ± 6.0
Electric hot water	71 ± 6.6	74 ± 5.0
Greenhouse hot air	72 ± 7.6	74 ± 9.0
Solar air	—	74 ± 9.0
Unheated	60 ± 11.0	70 ± 7.3
Air	52 ± 11.8	65 ± 10.0

[1] Mean ± standard error.

In the summer direct solar radiation on the insulated beds often resulted in temperatures exceeding the thermostat settings for a 24 hr period.

Cuttings of two *Taxus* cultivars rooted well in the outdoor heated system and in the heated greenhouse but did not root in the unheated outdoor bed (Table 3).

Table 3. Rooting results of two *Taxus* cultivars[1] in outdoor heated and unheated mist beds and heated greenhouse mist bed.

Taxus cultivar and propagation duration	Outdoor mist bed				Greenhouse mist bed	
	Electric hot water		Unheated		Hot air	
	% rooted	index*	% rooted	index	% rooted	index
T. × *media* 'Hicksii' 4/5-6/13	100	1.6	8	.08	100	1.8
T. cuspidata 'Densiformis' 4/7-6/13	92	1.1	0	0	96	2.1

[1] Twenty-five cuttings per treatment.

* Index = a measure of number of roots/cutting over 25.4 mm. 1 = 0-10, 2 = 11-20, 3 = 21-30, 4 = 31-40, 5 = over 40.

Rooted cuttings were equal to similar liners produced by local nurseries by November, 1983. Commercial cuttings were propagated in heated greenhouses in November, 1982 and maintained in the greenhouse until June, 1983 when they were planted in liner beds.

Heated outside beds produced larger *Rhododendron* rootball diameters than the unheated bed in 1982 but higher summer temperatures in 1983 resulted in less difference between the outdoor beds in 1983. Results with deciduous plants also showed less difference in the summer when compared with spring propagated plants.

Rooting results varied slightly among outdoor heated bed types but in general were equal to those obtained in the greenhouse.

DISCUSSION

It is an accepted fact that systems involving either solar-heated water or air are more expensive to construct than the low voltage or electrically heated outdoor systems, since either a storage area for rock or water is required as well as a solar collector area. Construction costs for the beds in this study were calculated (Figure 2). Operating costs were also calculated and found to be almost in the reverse order of the construction costs (Figure 1). When one considers the construction cost of either a greenhouse ($4.50 to 6.00/sq ft) or plastic-covered greenhouse ($1.10 to 1.40/sq ft) (1) and added costs for heating ($1.75 to 1.00/sq ft) and/or ventilating ($.60-.80/sq ft) (1), it is apparent that the cost of all but the solar-heated system is less than a greenhouse system and similar to that of a plastic house since either structure would also have to include the additional cost of a propagation bed. However, both electrically-heated systems approach the costs of a greenhouse in operation, except in summer when no energy need be expended for cooling outdoor systems (Figures 1,2). However, when surface area mulch was removed in the summer and minimum temperatures were raised, energy costs increased for fossil fuel systems. Labor costs are not included in any of the comparisons.

It is possible to propagate *Taxus* cultivars and other narrowleaf evergreens outdoors or indoors in the spring within 2 months as opposed to indoor winter propagation which requires 6 months in heated structures, as is commonly done in New England. Production costs for these plants were not computed but since cuttings are more closely spaced than broadleaved evergreens and rooting occurs in 6 to 8 weeks instead of 8 to 10 weeks, costs would be low.

Selected cultivars of deciduous plants propagated in the spring in outdoor-heated beds and subsequently placed in 15 cm containers reached a standard grade of 60 to 72 mm by November 1, 1983. It is recommended that minimum temperatures in summer be maintained at 20°C to reduce operating costs.

It would appear that insulated, heated outdoor mist beds could be used to produce a variety of woody plants at competitive prices. It is up to the individual manager to determine which type of heat source is adaptable to the facility. (Tables 4 and 5).

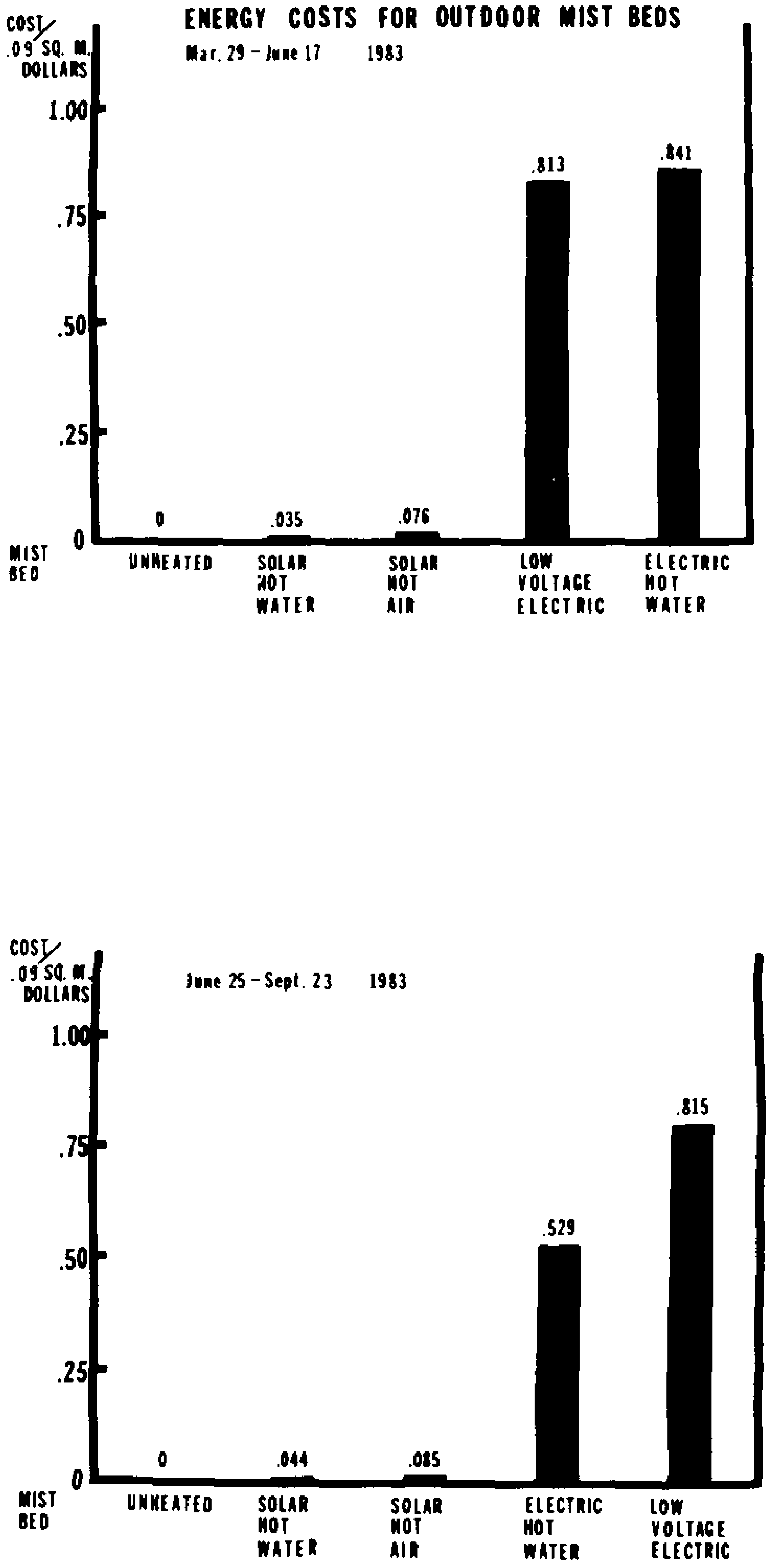

Figure 1. Energy costs for outdoor mist beds.
Above. Spring propagation period. March 29-June 17, 1983.
Below. Summer propagation period. June 25-September 23, 1983.

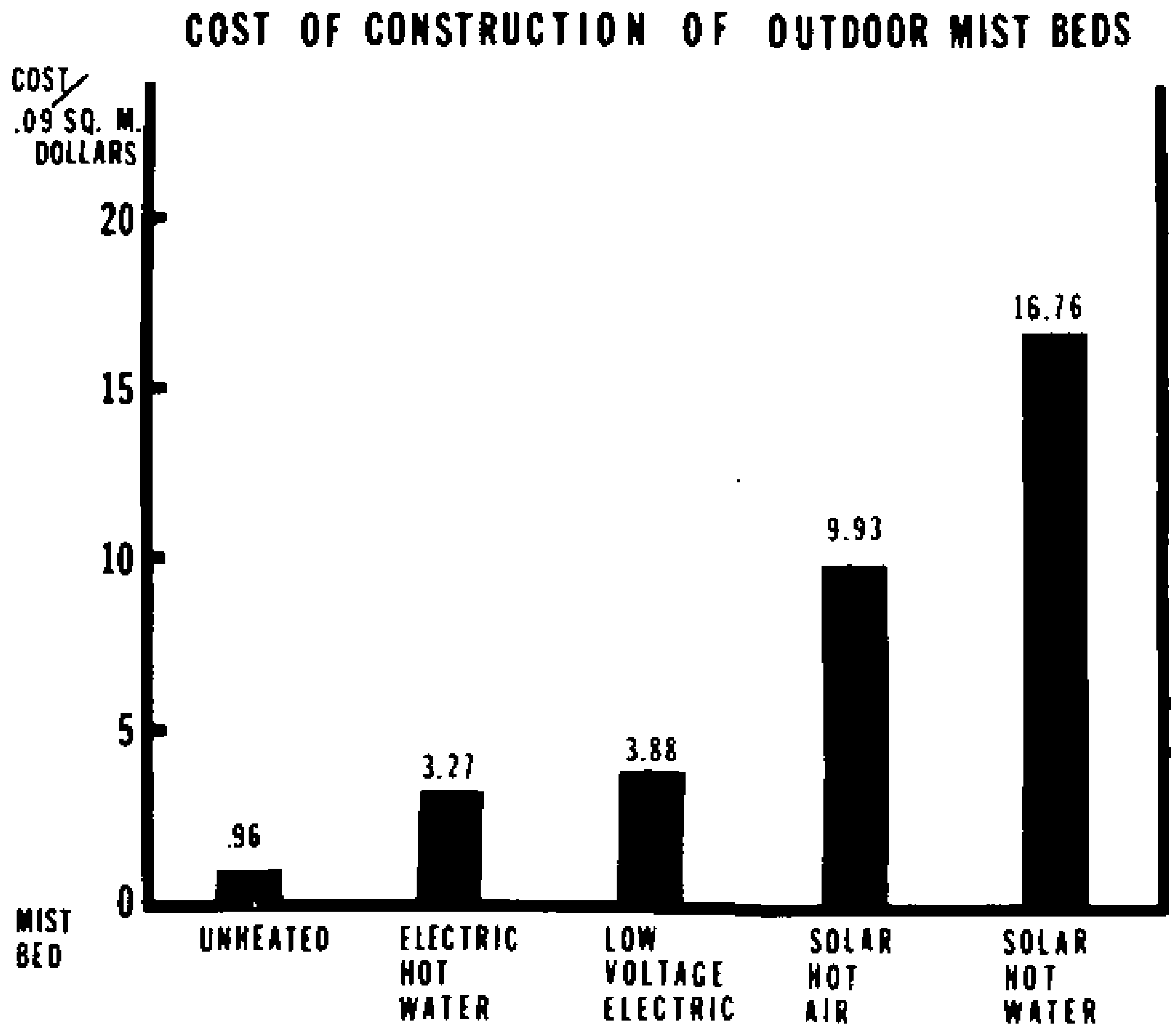

Figure 2. Cost of construction of outdoor mist beds (labor not included).

Table 4. Rooting results of selected broadleaved evergreens[1] in outdoor heated and unheated mist beds and greenhouse mist bed.

	Outdoor mist bed				Greenhouse mist bed	
	Electric hot water		Unheated		Hot air	
Plant and propagation duration	Percent rooted	diam. (cm)	Percent rooted	diam. (cm)	Percent rooted	diam. (cm)
Rhododendron 'Nova Zembla' 4/7-8/2 Growth regulator — Hormex 45	48	5.4	48	3.8	24	3.7
Kalmia latifolia 'Pink Surprise' 4/6-8/4 Growth regulator — IBA 2000 ppm aqueous dip 5 sec.	60	7.8	63	6.3	30	7.2

[1] Twenty-five cuttings per treatment.

Table 5. Rooting efficiency of selected deciduous shrubs[1] in heated and unheated mist beds — 1983.

	Solar air		Solar water		Electric low voltage		Hot water		Unheated outdoor		Greenhouse	
Cultivar and Propagation Duration	Percent rooted	index*	Percent rooted	index	Percent rooted	index	Percent rooted	index*	Percent rooted	index	Percent rooted	index*
Hibiscus syriacus 'Lady Stanley' 7/25-8/9	100	1.0	100	1.0	100	1.0	100	1.0	100	1.0	100	2.1
Viburnum carlesii	92	1.9	76	1.0	96	1.9	84	1.2	96	1.7	100	1.9
Viburnum sieboldii	96	2.5	96	2.0	100	3.0	96	1.9	80	1.3	96	2.4
Viburnum plicatum forma *tomentosum* 'Pink Beauty' 7/23-8/23	88	1.4	92	1.5	92	1.8	88	1.4	76	1.0	80	1.4
Magnolia stellata 7/11-9/8	84	1.8	76	1.4	52	1.0	60	2.0	40	0.8	36	.0
Euonymus alata 7/13-8/23	88	1.4	92	1.5	92	1.8	88	1.4	76	1.0	80	1.2

* Index = a measure of the number of roots/cutting over 25.4 mm. 1 = 0-10, 2 = 11-20, 3 = 21-30, 4 = 31-40, 5 = over 40.

[1] Twenty-five cuttings per treatment.

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CHARLIE PARKERSON. Did you put microfoam over the beds to keep the heat in? If so, how did you harvest the cuttings?

JOHN MCGUIRE: Yes, we did in the spring and just pulled the cuttings through. We did not use microfoam in the summer.

PETER VERMEULEN: Were the *Callicarpa* made from hardwood cuttings?

JOHN MCGUIRE: Yes, they were.

MIKE KOCZOROWSKI: Do you expect any moisture accumulation in your isothiocyanate beds?

JOHN MCGUIRE: The bed is quite deep with 9 in of medium and the rooting zone is quite far up from the base.

MIKE KOCZOROWSKI: Do you know if moisture will cause any accelerated deterioration of the insulating material? We have found that moisture will deteriorate Thermex.

JOHN MCGUIRE: We are not sure because this is only the second year. I would recommend that the side insulation be put on the outside.

GERALD VERKADE: Just a comment. This system looks like it might be useful for December rooting of Japanese maples.