TEMPERATURE ENHANCEMENT EXPERIMENTS

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Introduction

Since the initial ITEX meeting at Kellogg Biological Station (Michigan State University) in December 1990, the manipulation of temperature around tundra plants has been the subject of intense discussions. Over the past two years a number of investigators have field evaluated several designs for manipulating temperature around tundra plant species (Debevec and MacLean 1991; Marion and Pidgeon 1992; Marion et al. 1993). These designs included: greenhouses, open-top chambers, ground covers, and wind shields. Materials used included fabric, plexiglass, fiberglass, and plastic.

At the Boulder meetings (March 1992), a consensus was reached that for the Level I experiments, the temperature manipulations should: (1) be permanent structures that can be left in place year-round, (2) be structurally strong to withstand high winds and extreme cold, (3) give a significant temperature enhancement, and (4) minimize unwanted ecological effects. These constraints virtually forced some type of ”open-top” design. Advantages of open-top designs over complete enclosures include: (1) lower temperature extremes, especially on sunny days, (2) better light quality and quantity due to more direct solar radiation to plants, (3) more natural levels of humidity and CO_2 levels around plants, (4) more direct precipitation, and (5) easier access of pollinators and herbivores to plants.

At the 4th ITEX Meeting in Oulu, Finland (December 1992), a consensus was reached that the open-top fiberglass chamber would be the method of choice for temperature manipulation and the ”ITEX Corners” would be an alternative design for the ITEX experiments (Fig. 1). The principal advantage of the open-top chambers vis-a-vis the ITEX corners is a greater temperature enhancement because these chambers act both as windshields and solar traps. Advantages of the ITEX corners vis-a-vis the open-top chambers include lower cost, ease of installation, and easier access to plants.

The objective of this section of the ITEX Manual is to describe the construction of the ITEX designs and to recommend how temperature should be measured in the chambers.

Temperature Enhancement Devices

Two open-top enclosures (cone and hexagon) were field tested and are suitable for the ITEX experiments (Fig. 1). The cone and hexagon designs share two important features. First, both are made of Sun-Lite HP (0.040 inch thick), a fiberglass material especially designed for solar applications. This material is made by: Solar Components Corporation, 121 Valley St., Manchester, New Hampshire, 03103 USA (telephone: 603-668-8186). This material has a high solar transmittance in the visible wavelengths (86%) and a low transmittance in the infra-red (heat) range (< 5%). A second feature that these two chambers share is that both have inwardly inclined sides (60° with respect to the horizontal). There are two major

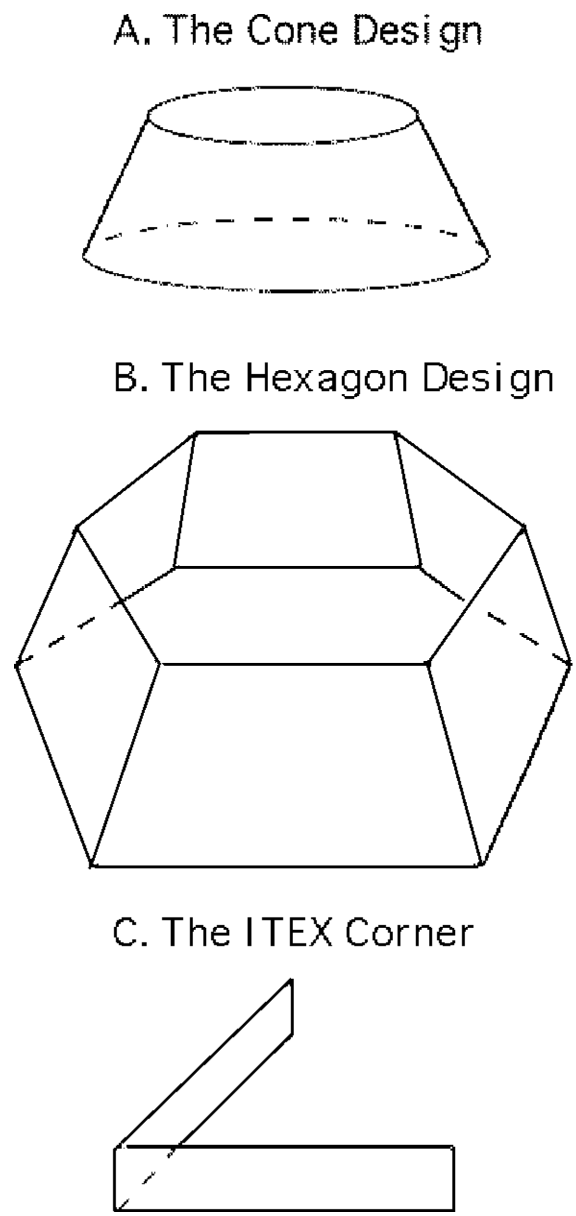


Fig. 1. The ITEX designs.

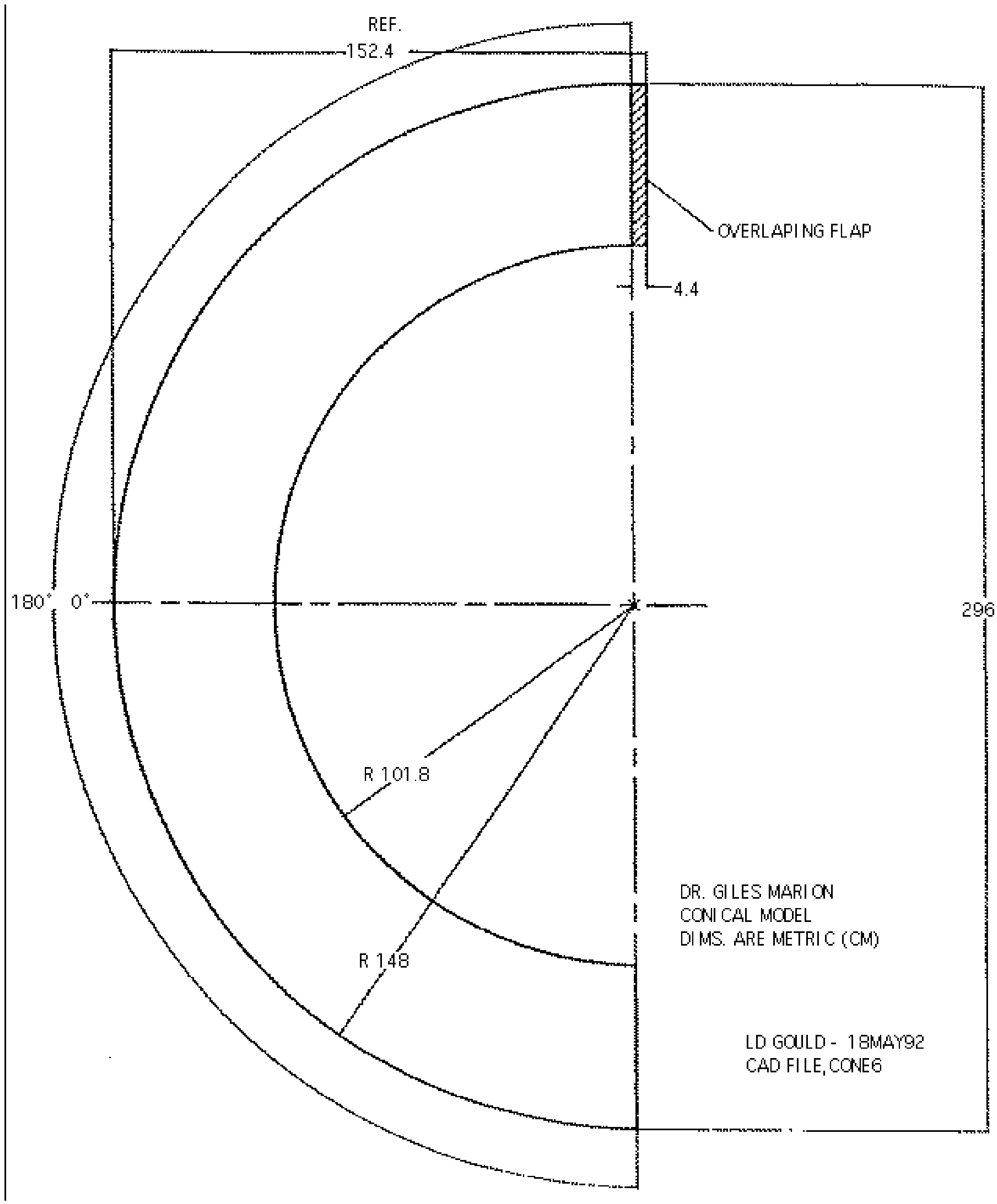


Fig. 2. The two-dimensional pattern for building a 60°, 40 cm tall, 1.48 m basal diameter cone chamber.

reasons for the inclined sides. First, and probably foremost, the inclined sides help trap part of the heat within the chamber like a greenhouse. Second, the inclined sides are more favorable for transmitting solar radiation into the chamber. Optimal transmittance occurs when solar radiation strikes the surface at a right angle.

Advantages of the cone include a simpler design (one piece) which should be structurally stronger with less ground shading than the hexagon. Advantages of the hexagon are that it can be built to larger sizes and is less wasteful of fiberglass material. A disadvantage of both designs is that some sort of portable scaffolding is needed to access the interiors of the chambers for monitoring purposes.

Cone

Figure 2 is a pattern for building the maximum diameter 60°, 40 cm tall cone chamber. The maximum sheet width of the Sun-Lite HP fiberglass is 152.4 cm (5 ft) which limits the maximum basal diameter to 1.48 m. The geometry of a 60° cone is simple in that the arcs that must be cut are exactly 180°, plus a little extra for the overlapping flap (Fig. 2). The Sun-Lite HP fiberglass material is sufficiently flexible that it can be cold bent into the proper cone shape (Fig. 1) and is held together with nuts and bolts. Note that the radius of the 2-dimensional pattern is equal to the diameter of the 3-dimensional cone.

To build a smaller diameter 60° chamber requires specifying the chamber height and diameter; all other dimensions fall out from geometric relations. For example, specifications for a 30 cm tall chamber with a 50 cm top opening are diagrammed in Figure 3. Given the 60 ° angle and the 30 cm height, the hypotenuse is 34.6 cm and the base of the side triangles are 17.3 cm. This leads to a basal diameter of 84.6 cm for a top diameter of 50 cm. The corresponding radii of the 2-dimensional arcs (Fig. 2) would be 84.6 cm and 50 cm, respectively.

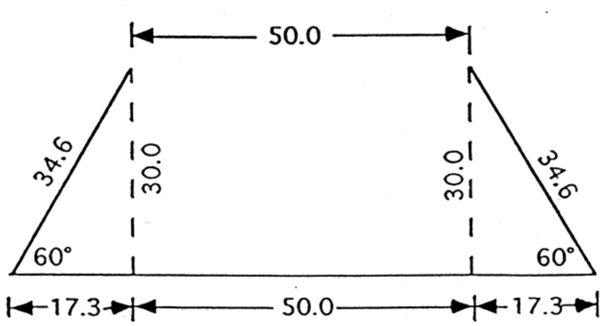


Fig. 3. A schematic for building a 60°, 30 cm tall, 50.0 cm top diameter cone chamber.

Hexagones

Specifications for building a 50 cm tall, 1.5 m open-top hexagon are included in Figures 4 and 5. This is the design currently being used by Greg Henry and Michael Jones on Ellesmere Island, Canada. Building smaller or larger chambers will require appropriate scaling changes. Fixing the 60° inclination of the panels, the height, and a diameter (basal or top) fixes all other dimensions through geometric relations. Michael Jones recommends cold temperature and UV resistant cable ties as ordinary ties experienced some breakage.

An alternative material for the hexagon design is LEXAN™ (or equivalent UV-resistant Polycarbonat Ultra®). The advantage of this material is that it can be cold bended and is almost unbreakable which makes it possible to use a more simple design (Fig. 6). This type isused all around the year at several european sites. Due to material costs this design is more expensive than the fiber-glass hexagone.

The fibre-glass OTC consists of six pieces which have one side bend 60° inwards so the margin will tighten to the next side (Fig. 6). Three pairs of holes are drilled at each side where cable ties fit the sides together (Fig. 6). The lower corner of the overlapping part makes the OTC stick better (freeze winter time) to the ground. The most frequently used size has 60.0 cm side (plus 4.0 cm margin) which gives a side-to-side basal diameter of 104 cm. Other sizes can be calculated using previously descibed geometry. Attachment to ground will be sufficient with three, approx. 3mm, UV-resistant wires (polyuretan) to the ground. Recommended thickness, and most commonly used, of the plexiglass is 3 mm. In Finland, Urban Nordenhäll is using 2 mm material, which is somewhat cheaper but the hexagone will not be as stable as with the thicker one. This has caused some temporal deformation, fromheavy snow-pressure during winter on the OTCs placed in slopes.

ITEX corners

The ITEX corners are designed to shield plants from winds which provides a heating effect immediately around the plant (Fig. 1). The shields are made of translu-cent plexiglass (Lexan) 2 mm in thickness. This material transmits about 90% of the photosynthetically active radiation and is sufficiently flexible to be bent at a right angle. For small rosette plants, a 10 cm high shield with 50 cm sides is recommended with the plant approximately 10 cm from each side. For larger plants these dimensions can be scaled up. Work on Disko Island, Greenland by Per Mølgaard indicated that the corners created the largest temperature enhancement when the opening faces toward the south. This direction provides maximum direct solar radiation to the plant and surrounding ground.

All chambers and corners need to be staked to the ground. Where strong winds prevail, one might also consider guy wiring, especially to windward, for additional protection.

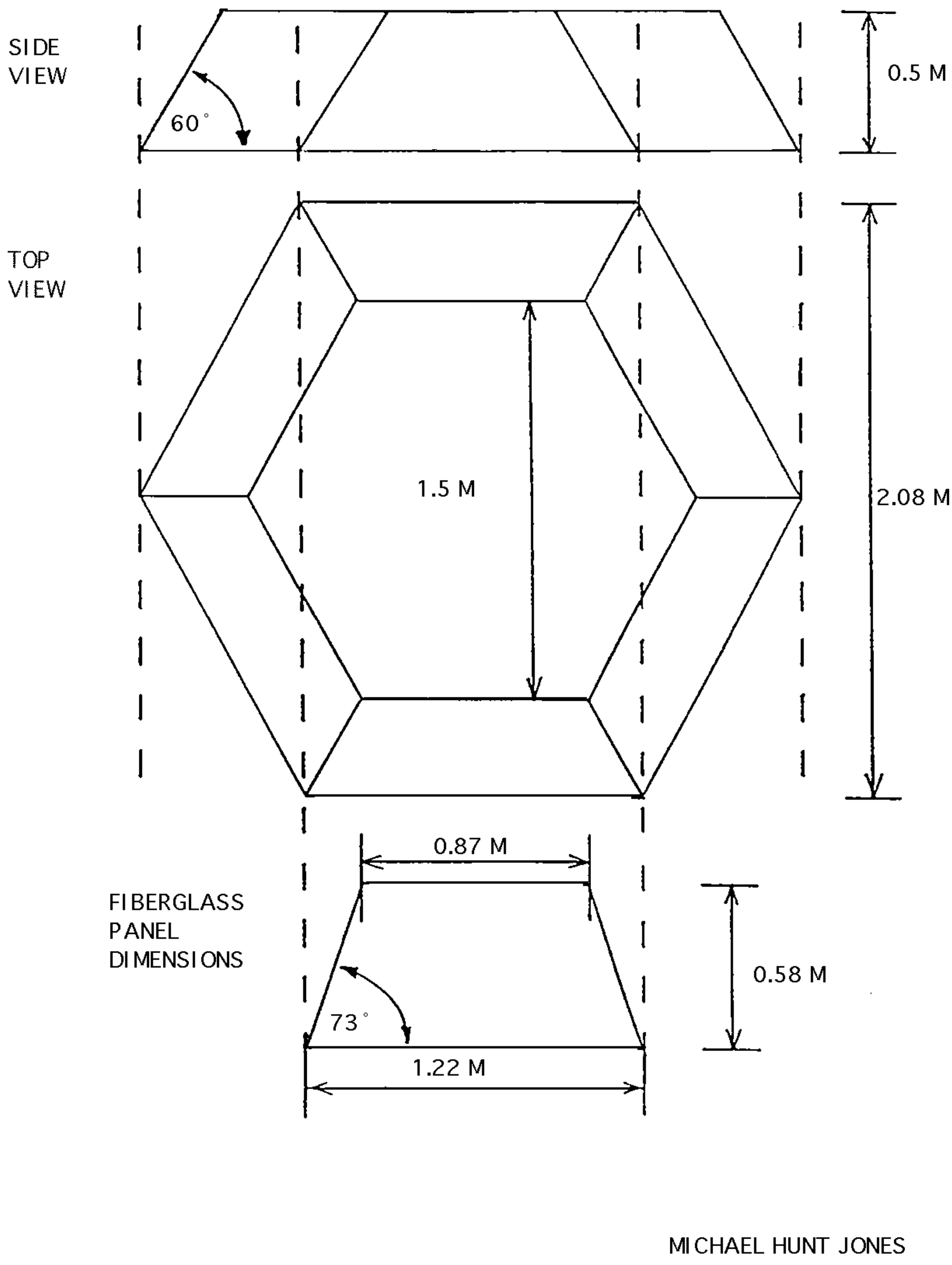


Fig. 4. Schematics for building a 60°, 50 cm tall, 2.08 m basal diameter hexagon chamber.

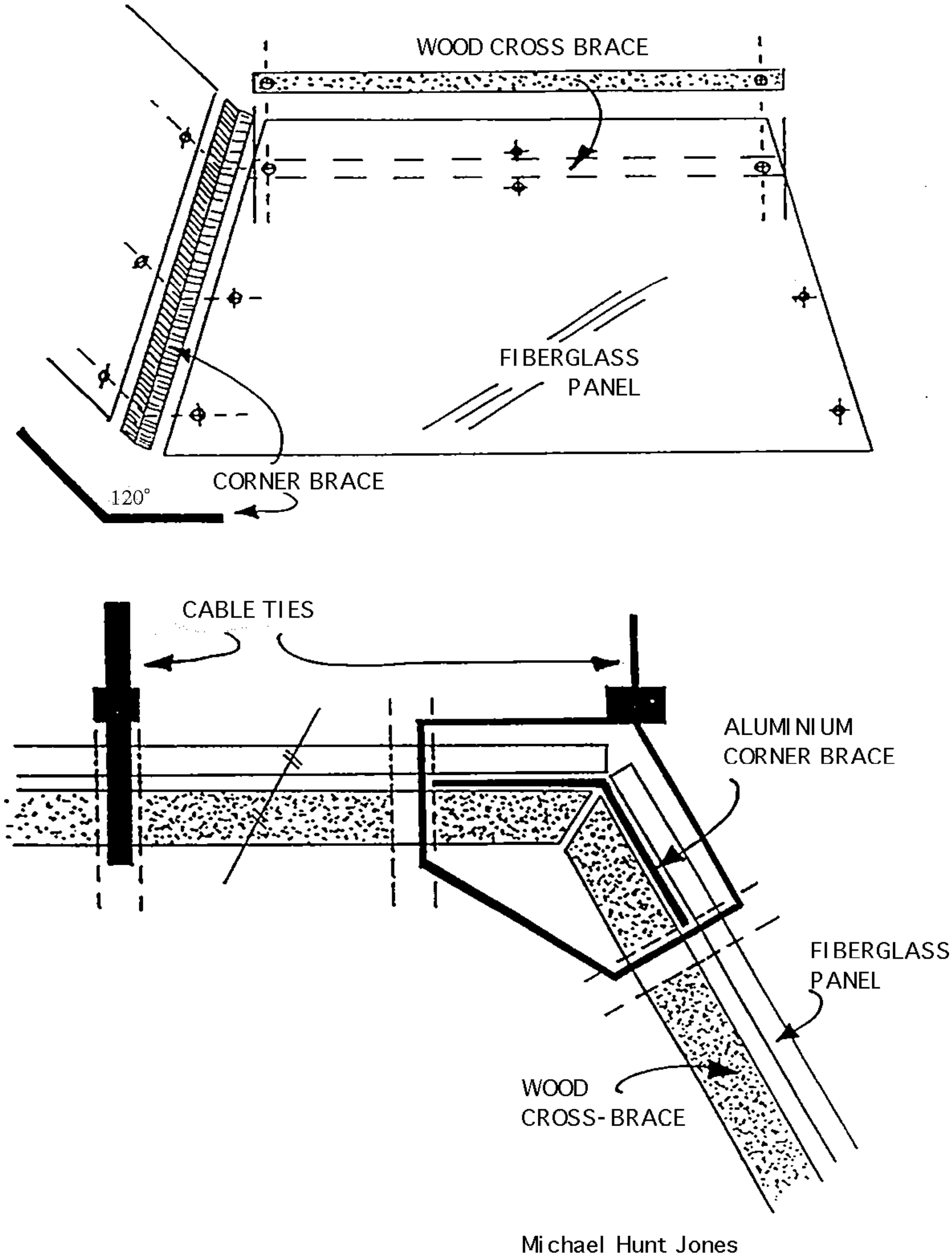


Fig. 5. Schematics for building a 60°, 50 cm tall, 2.08 m basal diameter hexagon chamber.

Temperature Measurements

We recommend that temperatures within chambers and in control areas be monitored hourly with daily minimum, maximum, and mean temperatures recorded. We recommend that soil surface temperature be measured by thermocouples or thermistors in a position shielded from direct solar radiation (e.g., beneath vegetative cover). Within each chamber (or control site), a minimum of 4 temperature sensors should be used with a minimum of 20 replicate chambers (or controls).

The number of replicates (r) needed to detect a difference of a given magnitude (d) is given by:

$$r \geq 2\,(t_0 + t_1)^2\, s^2/d^2$$

where s is the standard error, t_0 is the t value associated with Type I error, and t_1 is the t value associated with Type II error (Steel and Torrie 1960). This equation simplifies to:

$$r \geq 2\,(t_0 + t_1)^2$$

where the difference to be detected (d) is equal to the standard error (s). For a completely randomized experiment with two treatments (warmed versus control) with probabilities of Type I error = Type II error = 0.1, the required sample size = 18 (df = 34). For probabilities of Type I error = Type II error = 0.05, the required sample size = 28 (df = 54). We compromised and selected 20 replicates which provides protection from Type I and II errors of < 0.10.

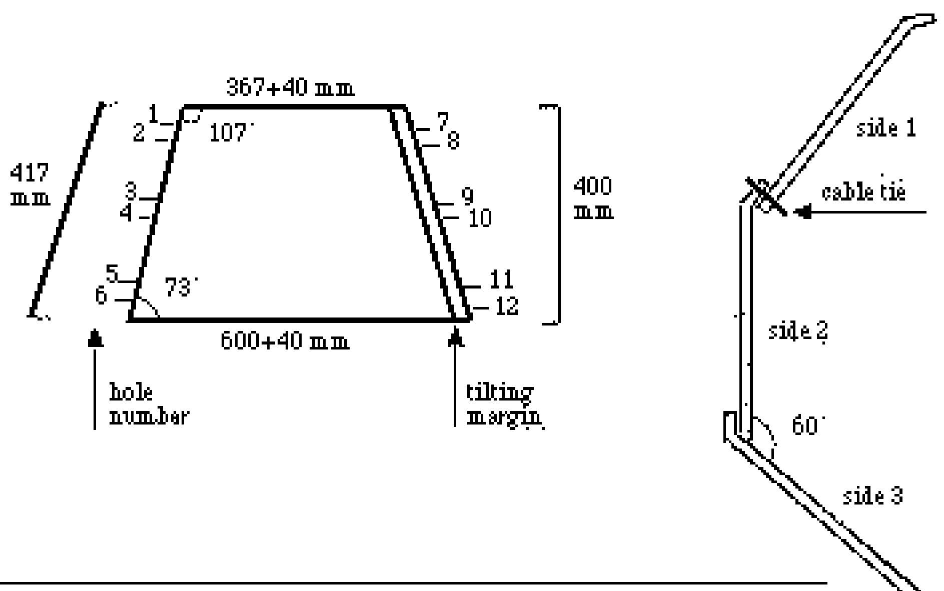
References

Debevec, E. M. and MacLean, S. F. 1991. Design of greenhouses for the manipulation of temperature in tundra. — Project Report to the National Park Service, Anchorage, Alaska.

Marion, G. M. and Pidgeon, D. E. 1992. Passive techniques for manipulating field soil temperatures. — USACRREL Spec. Report 92-14.

Marion, G. M., Henry, G. H. R., Mølgaard, P., Oechel, W. C., Jones, M. H., and Vourlitis, G. 1993. Passive techniques for manipulating field temperatures in tundra ecosystems. — In: Fourth International Symposium on Thermal Engineering and Science for Cold Regions. Hanover, NH. September 1993.

Steel, R. G. D. and Torrie, J. H. 1960. Principles and Procedures of Statistics. — McGraw-Hill Book Company, New York.



hole #	1	2	3	4	5	6	7	8	9	10	11	12
distance from side	20	20	20	20	20	20	18	18	18	18	18	18
distance from top	50	80	200	230	330	360	57	87	207	237	337	367

Fig. 6. Schematics for one plexiglass OTC side and how they are fitted to each other. Diameter of the holes ca. 4 mm. If hole number 4 and 10 are used as attachement point for the attachment wires then use 5-6 mm holes.