

TABLE OF CONTENTS

OVERVIEW	1
HISTORY	1
INTERIOR CURTAIN SYSTEMS	
HEAT RETENTION	2
SHADE & COOLING	2
SYSTEM CONFIGURATION	2
Gutter to Gutter Systems	
Truss to Truss	
DRIVE MECHANISMS	6
Push Pull Drive	
Cable Drum Drive	
Chain and Cable Drive	
SUPPORT SYSTEMS	9
COVERING MATERIALS	10
Shade and Heat Retention	
Blackout (Photoperiod)	
SIDEWALL CURTAIN SYSTEMS	11
EXTERIOR CURTAIN SYSTEMS	11

Please note: when choosing any curtain material you must address the issue of fire. We recommend the use of flame resistant materials throughout all retail, educational, and research greenhouses. For all other applications, we recommend flame resistant curtain material be alternated with standard (non flame-resistant) material; the resistant materials serve as fire breaks. Every second, third, or fourth curtain panel should be flame-resistant where flame-resistant material is not used throughout. We also recommend that flame-resistant material be used over heaters, generators, electrical panels, and anywhere sparks or open flame may be present.

OVERVIEW

Greenhouse curtain systems are called shades, screens and even blankets. No matter what they are called, they consist of movable panels of fabric or plastic film used to cover and uncover the space enclosed in a greenhouse. Curtains may cover an area as small as a single bench or more than an acre. Small systems are often moved by hand, while large systems are commonly motor driven.

Internal shade systems mount to the greenhouse structure below the rigid or film covering of the house. They are used for heat retention, shade (and the cooling effect of shade) and day length control or blackout when the covering material transmits less than 1% of the incident light.

Advancements in drive system and shade cloth technology have made moveable exterior curtain systems practical in the 1990s. Exterior systems are used in two ways. In some cases, the curtain replaces the greenhouse covering, while in others the system is installed above a standard greenhouse structure. Typical applications of the first type of system are to provide a hardening-off area or to add seasonal square footage in jurisdictions where zoning restrictions make it difficult to permit and build a traditional structure. The second type of outdoor system provides shade for light intensity control and blocks the light before it enters the greenhouse, giving an improved cooling effect.

HISTORY

At the beginning of 1973, oil sold for US\$2.50 a barrel. By the end of 1974, OPEC actions had driven the price to US\$11.25, and energy costs of all kinds followed the sharp rise in oil prices. Heating costs for greenhouses in cold climates reached nearly a dollar per square foot per month. The world had changed and growers had a dramatic incentive to search for ways to cut energy costs. One approach to conservation of fuel and dollars that growers tried was internal curtain systems for heat retention.

The relentless rise in energy prices continued through 1980, when oil prices peaked at US\$37. The acceptance of curtain systems for heat retention in greenhouses paralleled this trend. As the installed base of curtain systems increased, growers identified other benefits of these systems. It became apparent that they had value for daytime shade and cooling and dampened the noise of fans and heaters. In markets where shortages caused public utilities to put growers on natural gas allotments and restrictions the energy savings provided by curtains remained important. They sometimes allowed a greenhouse to expand by installing curtains for heat retention because the energy savings made it possible to build additional square feet without needing more gas.

By 1998, just over 34% of growers polled reported they have curtain systems. An additional 31% planned to retrofit curtain systems into existing houses and 38% said they plan to include a curtain system in any new houses that they build.

HEAT RETENTION

Any interior curtain system can be used for heat retention at night when heating demand is greatest. The percentage of shade does not matter under these conditions and blackout systems can serve this purpose, even when day length control is not a consideration. The amount of heat retained and fuel saved varies according to the type of material in the curtain. Experimental results indicate savings of 50-60% of fuel cost in greenhouses with heat retention curtains vs. uncovered houses. Growers who have installed curtain systems commonly report annual savings of 30% or more.

Curtain systems can save energy in three ways. First, they trap an insulating layer of air between the curtain and the greenhouse roof. Second, they reduce the volume that must be heated. Third, curtain fabrics with aluminum strips woven in reflect heat back into the greenhouse rather than letting it escape through the roof.

A curtain system used for heat retention traps cold air between the fabric and the roof. This cold air falls into the space below when the curtain reopens in the morning. To avoid stressing the crop it is important to uncover the curtain gradually to allow this cold air to mix with the warm air below. Alternatively, if the crop can tolerate the shade, the curtain can be left covered until sunlight warms the air above the system.

SHADE AND COOLING

Interior curtain systems are widely used to reduce indoor light intensity and help control temperature during the day. Because they are moveable, they can be covered when needed and uncovered on cloudy days. This ability significantly increases the fraction of the day when near ideal light levels are available for the crop. Curtain systems also eliminate the recurring cost of materials and labor to apply (and possibly remove) shading paint.

Most curtain systems now use fabric made of alternating strips of clear and aluminized polyester. The aluminized strips reflect light back out through the roof of the greenhouse. This reduces the cooling load under the shade significantly. The USDA's Florist and Nursery Crops Laboratory in Maryland reports that greenhouses with aluminized shade systems can be kept about 10° F cooler than unshaded houses during the summer.

SYSTEM CONFIGURATION

The fabric panels in a curtain system can be driven gutter to gutter across the width of the greenhouse, or from truss to gutter-connected house. In a truss to truss system, the panels are wide enough to span the distance between one truss and the next, and as long as the combined width of the total number of houses covered.

In either configuration each panel of curtain material has a stationary edge and a moving or "lead" edge. The drive system moves the lead edge back and forth to uncover and cover the curtain, while the stationary edge holds each curtain panel in place.

GUTTER TO GUTTER SYSTEMS

In a gutter to gutter curtain system, the curtain panels are pulled flat across the width of the greenhouse at gutter height. This configuration minimizes the volume of greenhouse air below the curtain that must be heated. These systems require less installation labor than a typical truss to truss system:

- The installers work at the lowest possible height.
- The stationary and lead edges of each panel are straight, and their total length is typically less than in a truss to truss system.
- There is a single panel of fabric per house instead of multiple panels as in a truss to truss system. Gutter to gutter curtain systems are not suitable for every greenhouse.

- If unit heaters or circulation fans are mounted above gutter height, the curtain will block them from heating or circulating the air under the system where the crop is.
- The bottom chords of the trusses can't be used for hanging baskets because the baskets would obstruct the curtain.
- Though the volume of greenhouse space that is heated is minimized in this configuration, the amount of cold air above the system is maximized. This makes it harder to mix and reheat the air above the system when it uncovers in the morning.
- Retrofitting a gutter to gutter system can require that electrical conduits, gas lines and heating pipes be moved, since these items are often run under the gutters.
- When covered for shade/cooling the space above a gutter to gutter system becomes very hot and this trapped hot air reduces the cooling effect of the shade. The "attic" space above the curtain can be ventilated with a louver and exhaust fan in opposite gable ends of each house to reduce this effect.
- Because the curtain panels are as wide as the greenhouse (typically 24-42 feet), when the curtain is uncovered the curtain material forms a large bundle under each gutter. This bundle can be a source of unwanted shade

TRUSS TO TRUSS SYSTEMS

In a truss to truss curtain system the panels of curtain material move across the distance between one truss and the next. This distance (typically 10-12 feet) leads to more compact bundles of fabric when the system is uncovered than are possible with gutter to gutter systems. These systems can be configured in any of three ways:

1. Flat, at gutter height. As with the gutter to gutter system, this configuration minimizes the volume of greenhouse space to be heated and is relatively easy to install. It has the same restrictions on equipment in the gables and prevents the use of truss bottom chords for hanging baskets.
2. Slope-flat-slope where the profile of the curtain system follows each slope of the roof part way up the truss, with a flat section joining the two sloped segments. This configuration allows the curtain system to be installed over equipment mounted above gutter height as unit heaters and some fans often are. The bottom chords of the trusses remain available for hanging baskets. This configuration leaves clearance for roof vents and provides a chimney effect when used for shade/cooling if a 6-12" gap is left instead of fully covering the system.
3. Slope-slope where the profile of the system parallels a line drawn from the gutter to the peak of the truss. This configuration minimizes the amount of cold air trapped above the curtain and maximizes clearance from equipment mounted above gutter height. The bottom chords of the trusses remain available for hanging baskets.

The slope-flat-slope and slope-slope truss to truss configurations have some drawbacks:

- They require more work to install because they are higher off the floor.
- They require more lead edge and stationary edge materials than a flat system that covers the same amount of growing area.
- They leave more greenhouse volume to heat than a flat system.

DRIVE MECHANISMS

Drive mechanisms use an electric motor and gearbox to extend and retract the panels of curtain material in a system. They solve the problem of translating the rotary motion of the motor and gearbox into the linear motion needed to move the curtain panels. Three types of drive mechanisms are in common use:

1. Push pull
2. Cable/Drum
3. Chain and Cable

PUSH PULL DRIVE

This system is used for truss to truss configurations. It uses rotating pinion gears to drive toothed racks long enough to span the distance between two greenhouse adjacent trusses. These racks attach to rigid metal tubes that are the length of the greenhouse, less one truss to truss spacing. In each bay¹ a second tube fastens to the drive tubes at right angles. This second tube carries the lead edge of the curtain material back and forth across the bay.

The motor and gearbox for a push pull drive are usually mounted near the center of a greenhouse. They can be mounted in any bay except the first and last at the gable ends, because the rack drive mechanism needs one truss to truss bay spacing of freedom to travel.

CABLE/DRUM DRIVE

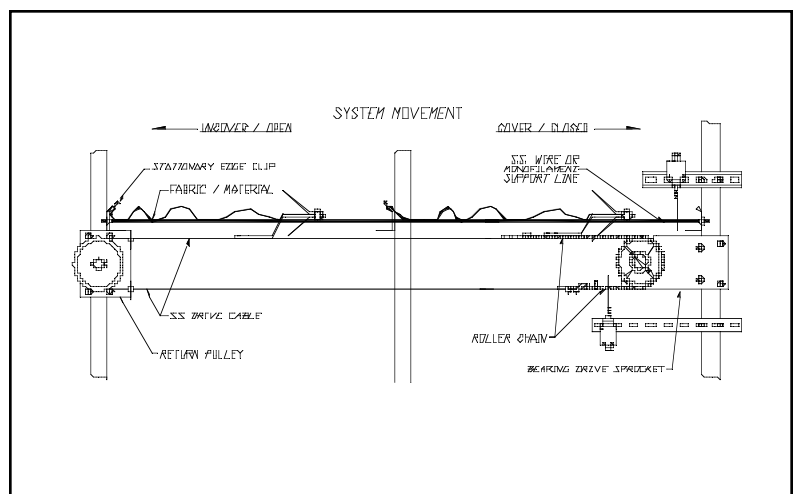
A cable/drum drive system can move a curtain from gutter to gutter or from truss to truss. In these systems the cable is galvanized or stainless steel wire rope (also called aircraft cable). Lengths of wire rope carry the lead edge of the curtain material. A coil of cable wraps around a motor driven drum or tube. The length of the cable in the coil is equal to the width or truss spacing of the greenhouse. As the drive rotates the drum, one end of the coil unwraps and the other end of the coil rewinds on the drum.

A cable/drum drive typically mounts in the plane of movement of the curtain system at one gable end (truss to truss), or one sidewall (gutter to gutter) of the greenhouse. By using pulleys to route the cables downward, the drive motor and gearbox can be mounted at any convenient height on a side or end wall.

CHAIN AND CABLE DRIVE

A chain and cable drive system can move a curtain from gutter to gutter or from truss to truss. In this system, lengths of roller chain² are spliced into loops of wire rope that span the length or width of the greenhouse. The length of roller chain equals the truss to truss or gutter to gutter distance that the curtain panels must span. The motor and gearbox drive a toothed wheel ("sprocket") that engages the chain and drives the loop of cable back and forth. Lengths of rigid tubing attached to the cable at right angles to its direction of travel carry the lead edge of the panels of curtain material.

A chain and cable drive system typically mounts on the side or end wall of a greenhouse and uses pulleys and idler sprockets to transfer the motion of the drive into the plane of motion of the curtain system.



¹In this case the "bay" means the area between two adjacent trusses in a single house, whether freestanding, or part of a gutter connected block of houses.

²Roller chain is the type of chain used on bicycles

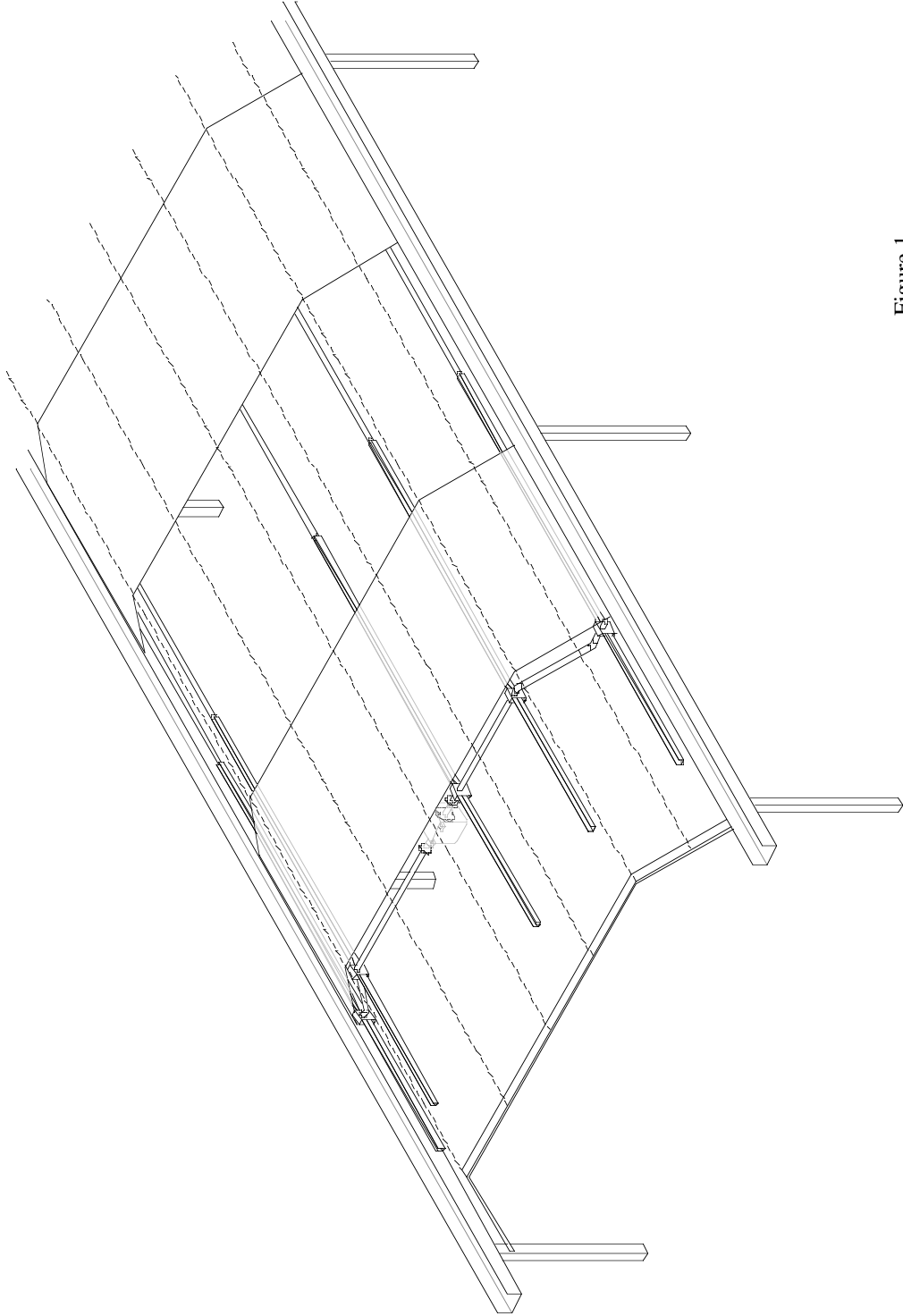


Figure 1.
Push-pull curtain drive system with
lay-flat suspension system

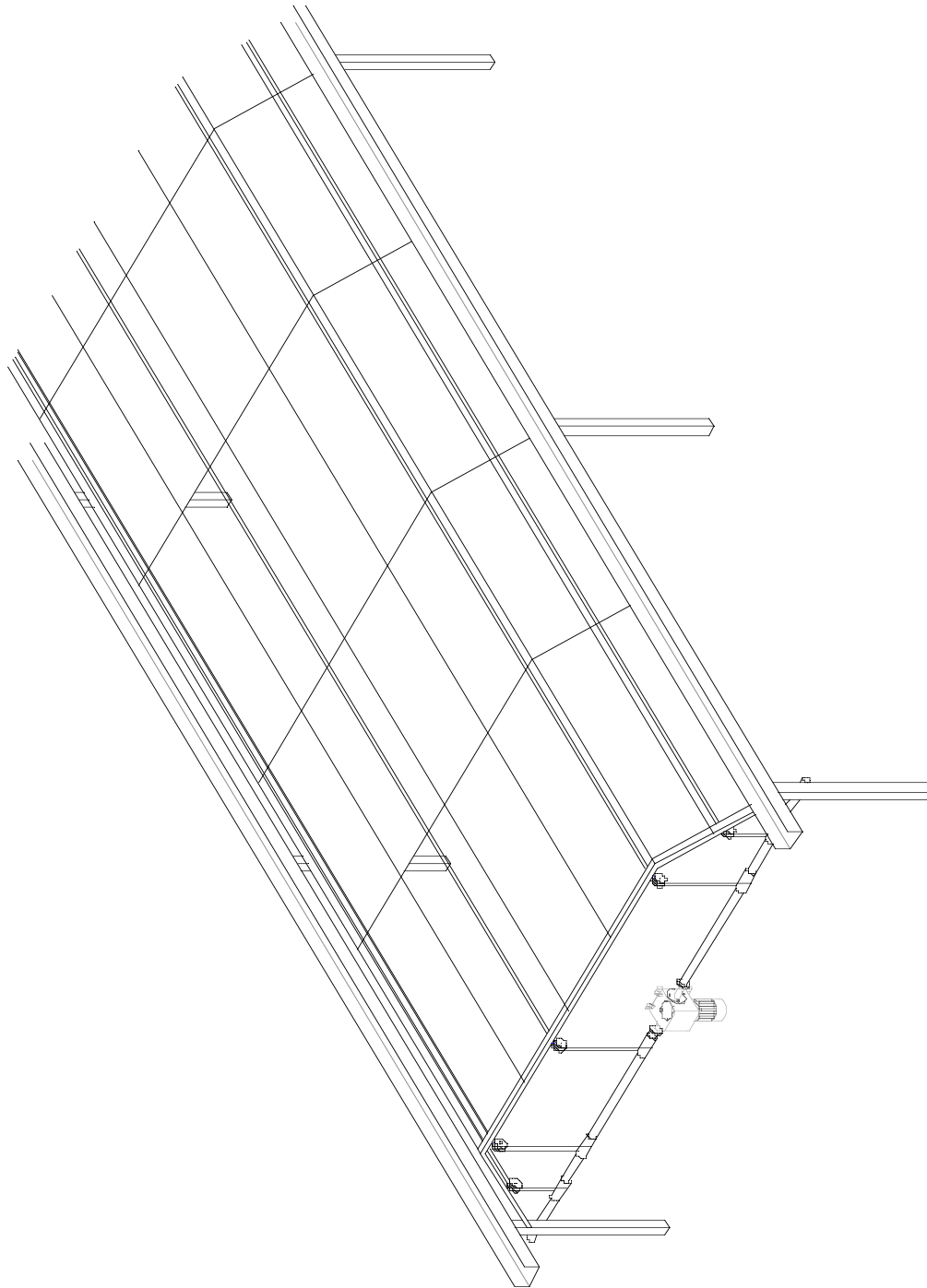


Figure 2.
Cable/drum curtain drive system
with lay-flat suspension

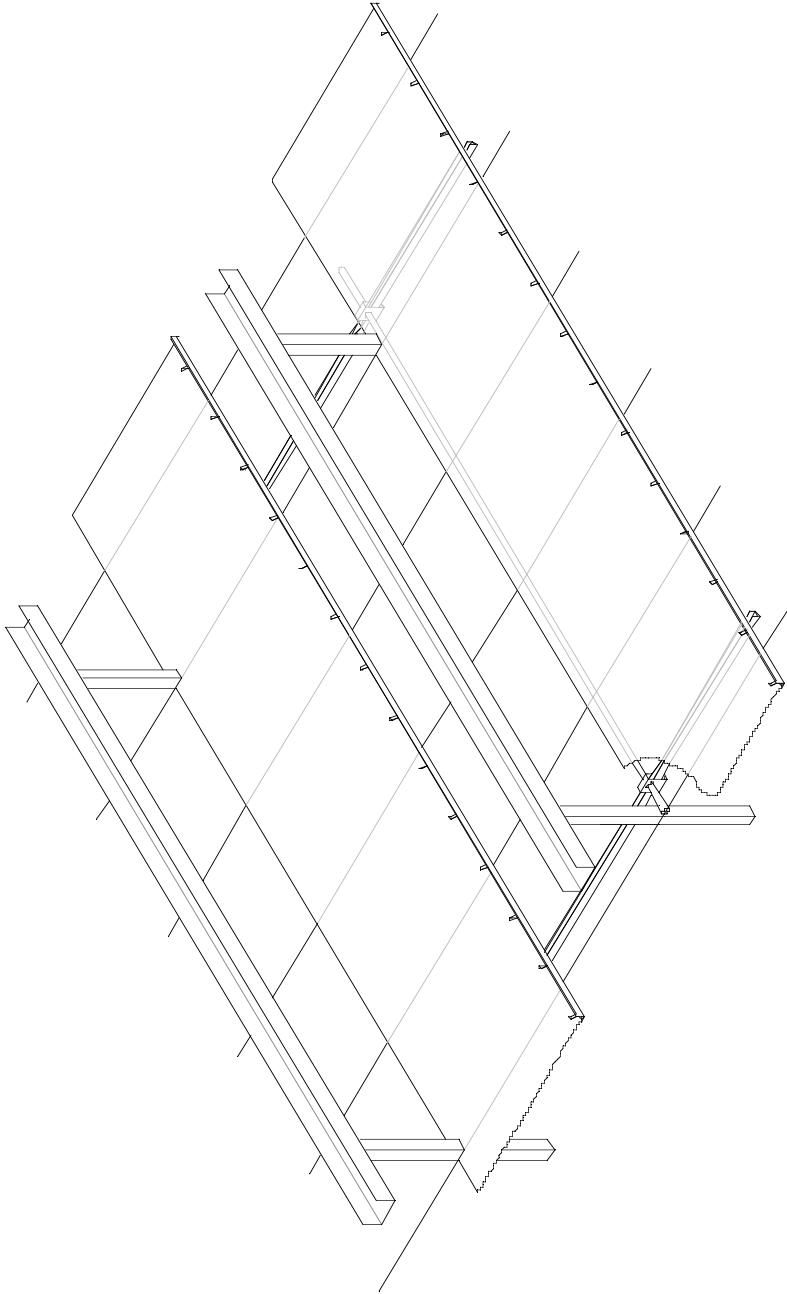


Figure 3.
Lay-flat curtain support system with
push-pull drive.

SUPPORT SYSTEMS

Curtain systems support the panels of curtain material on wires or nylon monofilament lines parallel to the direction of movement of the curtain. These lines are uniformly spaced across the greenhouse at distances of eighteen inches to four feet on center, depending on the design of the system. Two support systems are commonly used. In a lay-flat system the curtain panels lie on top of the support lines. In a suspended system the curtain panels hang from the support lines on plastic hooks.

Curtain panels can lie on top of the support lines if monofilament or smooth stainless steel wires are used. This approach reduced installation labor, as the curtain panels need only be draped over the wires. The friction of the panels against the smooth wires does not appear to cause premature wear on the panels. In houses with roof vents lay-flat panels should be trapped from above by additional stainless steel or monofilament lines. These lines are spaced on 4'-6' centers and prevent the curtain panels from billowing up as air circulates in the house.

Curtain panels can also be suspended from the support lines with plastic hooks. Fewer support lines are required, but the hooks must be installed in the curtain panels, and then attached to the lines. Typically, reinforcing strips are sewn into the curtain panels where the hooks attach so that the hooks do not tear through the curtain material in use. Makers of textiles for greenhouse curtain systems now offer fabrics with reinforcing strips woven into the cloth.

Hybrid suspension systems for slope-flat-slope configurations skid the curtain panels on the sloped and flat portions of the system, but suspend them at the transition points from sloped to flat sections. These transition points can abrade the curtain panels and suspending the panels at these points transfers the stress from the curtain material to the plastic suspension hook.

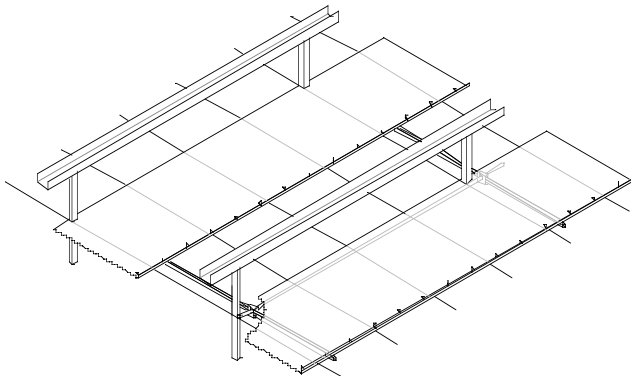


Figure 5.
Push/pull driven lay-flat shade
curtain system.

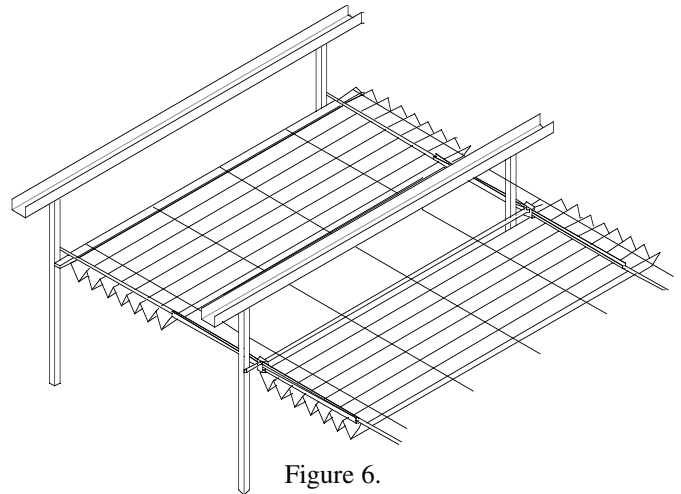


Figure 6.
Push/pull driven suspended shade
curtain system.

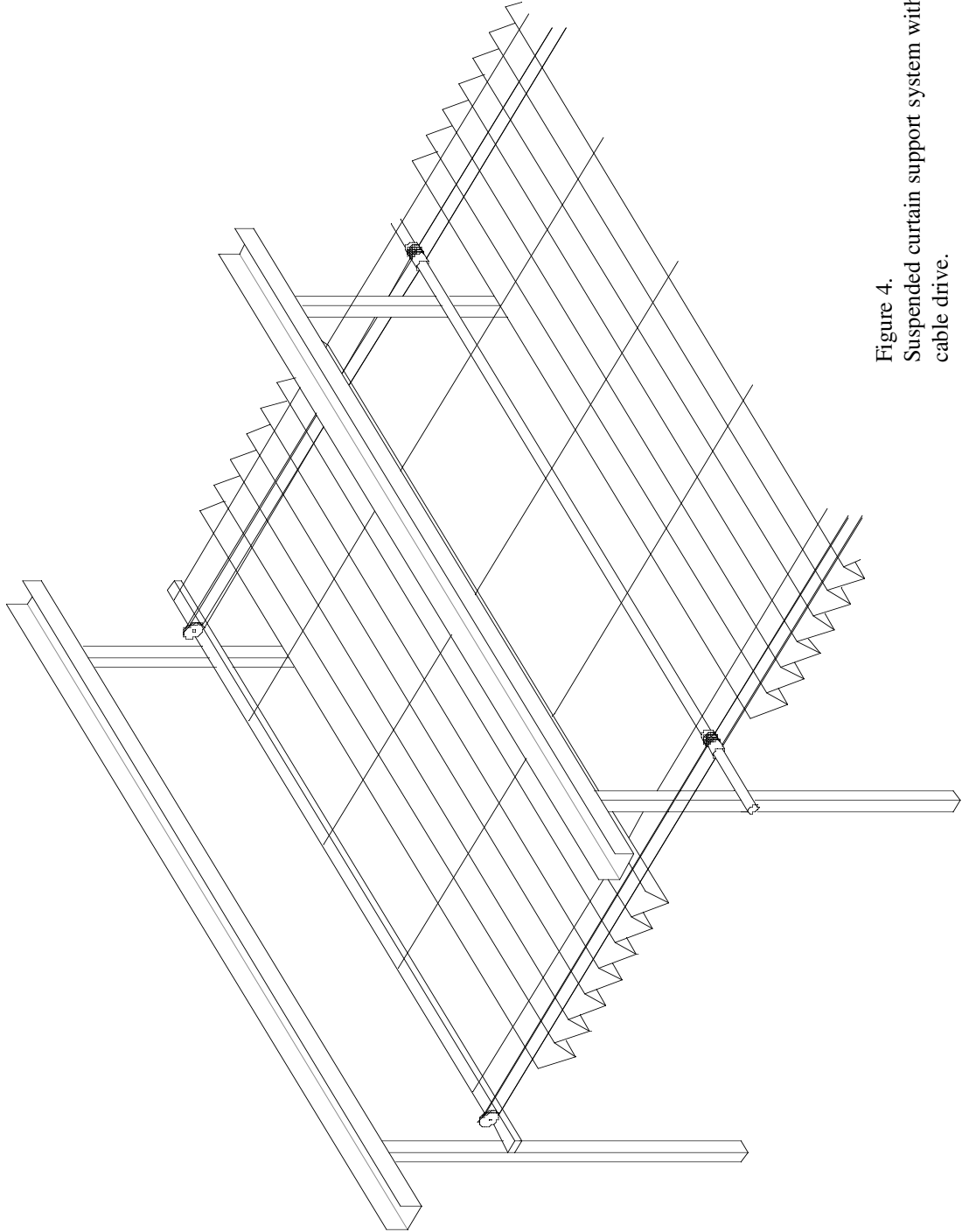


Figure 4.
Suspended curtain support system with
cable drive.

COVERING MATERIALS

SHADE AND HEAT RETENTION

Covering materials for shade and heat retention include knitted white polyester, non-woven bonded white polyester fiber and composite fabrics manufactured specifically for use in greenhouse curtain systems.

The white polyester fabrics offer excellent durability. Some systems are still using the original fabric panels after more than fifteen years.

White polyester has largely been superseded by composite fabrics made of alternating strips of clear and aluminized polyester or acrylic held together with a finely woven mesh of threads. These panels outperform white polyester because their aluminized strips reflect infrared light (i.e. heat) out of the greenhouse during the day and back into it at night. These fabrics can have service lives of ten years or more.

Available variations on composite fabrics include:

- Chemical stabilization against breakdown by UV light.
- Flame resistant fabrics to meet building code requirements.
- Fabrics where the clear strips are omitted leaving gaps for air circulation. (These are used principally for shading, though they have some value for heat retention by reflecting infrared light).
- Fabrics with colored aluminized strips for esthetic purposes.

BLACKOUT (PHOTOPERIOD)

Blackout curtain materials include polyethylene film, knitted polyester and composite fabrics where all the strips are either aluminized or opaque. Most blackout materials attempt to reduce heat buildup when the curtain system is covered for day length control in summer. So called black/white poly is a polyethylene film that is co-extruded with white top-layer for light reflection, and a black bottom-layer for opacity.

Knitted polyester is available with a powdered aluminum reflective coating bonded to one surface. Composite fabrics are typically offered as a two-layer system with the upper layer either white or aluminized to reflect light. Two layers are used because the looseness of the weave of these materials cannot always provide adequate darkening with a single layer.

Polyethylene film is by far the least expensive blackout material, but it is impermeable to water and water vapor. If the greenhouse leaks when it rains, water can build up in pockets the film and the weight can damage the support system of the curtain. Polyester knits and composite fabrics are porous and allow water and water vapor to pass through. This reduces the chance of water weight related damage to the system. Knit and composite products also offer a longer service life than does film.

SIDE WALL CURTAIN SYSTEMS

Sidewall curtain systems are used to form interior partitions, to cover walls in blackout systems, to shade south facing walls and to cover and uncover sidewall vent openings in place of a glazed vent or louvers.

Three common drive systems are used to raise and lower side wall curtains. In one system the curtain material is wrapped around a tube and the wall is raised and lowered by rolling and unrolling the material from the tube. The tube can be driven with a hand crank or with an electric motor and gearbox. A second approach uses a system of ropes and pulleys attached to the top edge of the side wall curtain to drop the curtain open or lift it closed. Finally, some systems use a tube to roll and unroll the material, but rotate the tube by cradling it in rope loops that run through pulleys back to a hand crank or to a block that travels up and down a motorized lead-screw.

Commonly used sidewall curtain materials include plastic films reinforced with fiber mesh, polyester knit fabric, and strengthened versions of the composite fabrics made for greenhouse use.

EXTERIOR CURTAIN SYSTEMS

Three types of exterior curtain systems are available.

- A motor and gear driven shade system can be mounted above the greenhouse roof to reduce the amount of heat and light that enters the structure.
- A dark colored or aluminized mesh can be stretched over the greenhouse roof and left in place for the duration of the high light season.
- The curtain system can serve as the greenhouse roof, uncovering for maximum light and ventilation and covering for weather protection.

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