FIELD TEST DELTA

Demonstration and Evaluation of Lighting Technologies and Applications

PHOTOVOLTAIC LIGHTING RETROFIT KIT FOR BUS SHELTERS

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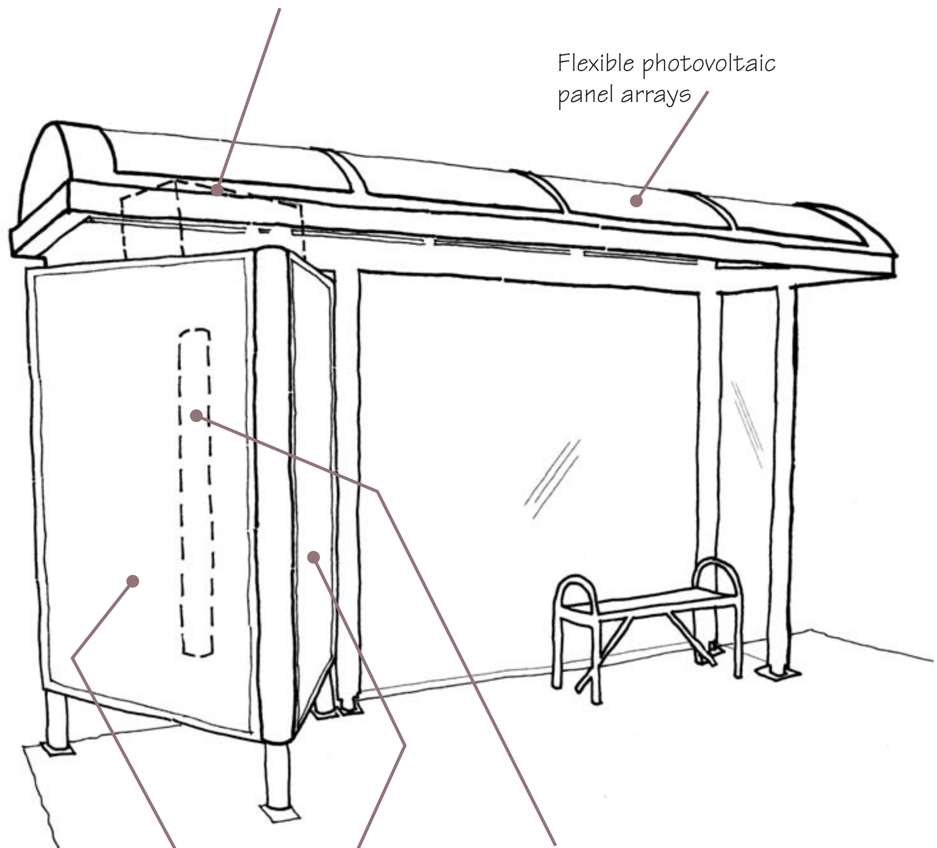


Project Profile

The DELTA research team at the Lighting Research Center (LRC) field tested an installation of a photovoltaic (PV) lighting retrofit kit for bus shelters on Long Island, N.Y. This solar-powered system provides a backlight for large advertising signs. This system is powered from a set of batteries that are charged from an array of PV cells and does not require an external electricity supply. The purpose of this field test is to evaluate the system's performance over an extended period of time and to gauge public reaction to the system at night.

Field Test Objectives

DELTA tested the photovoltaic bus shelters in the field to:

- Verify performance in the field
- Evaluate people's acceptance of the system compared to other bus shelters
- Quantify visibility at night
- Quantify energy cost savings

Overview of the Photovoltaic Lighting Retrofit Kit for Bus Shelters

The photovoltaic (PV) lighting retrofit kit is an integrated lighting/power system intended to be installed on existing bus shelters. The kit is customized for the shelter by the PV assembly manufacturer, SunWize Technologies. The kit typically contains PV panels, mounting hardware, batteries, controller, timer relay, photosensor, and a fluorescent luminaire with a wrap diffuser.

This PV lighting kit is unique because of its flexible PV panels that are directly integrated into the bus shelter rooftop. Other solar lighting kits use flat PV panels that would appear poorly integrated with the typical barrel-vaulted bus shelter. The rooftop integration is aesthetically appealing and minimizes the risk of vandalism, because the PV panels, batteries, and controls are not visible.

Additionally, the flexible PV panels can collect solar energy over a range of shelter orientations, although not as well as traditional, flat, rigid panels with optimized, south-facing orientation.

Product Description

The solar-powered retrofit kit for bus shelters consists of a PV charging system and a luminaire that backlights two advertising posters. PV panels integrated into the roof charge a set of batteries. An electronic controller determines appropriate charging times. A small photosensor informs the controller when to turn on the luminaire, and a timer relay turns the system off after a prescribed period of time.

A triangular, enclosed space at one end of the bus shelter forms a light box for backlighting the advertising posters. The shape of the light box serves to not only aim the posters at passing motorists, but also to house the light source for backlighting. A large sheet of fiberglass material hangs behind each of the two posters to diffuse the light coming from the lamps.

The fluorescent luminaire is mounted vertically on the back wall of the light box (shown during retrofit kit installation).

Luminaire

The PV retrofit kit provides a more efficacious light source than comparison bus shelters using other types of lamps, such as mercury vapor. The kit features a standard linear fluorescent luminaire retrofitted with two direct current (dc) ballasts. The ballasts operate two standard F32 T8 linear fluorescent lamps. A white plastic diffuser spreads the light evenly. The luminaire is mounted vertically on the back wall of the light box.

The fluorescent luminaire is ready for field installation. The white plastic diffuser is in the foreground.

Photovoltaic Panels

Flexible PV panels are fitted to the roof of the bus shelter. Mounting hardware conceals the wires connecting the panels to the batteries. The panels can be installed in the field, or the roof can be retrofitted at a factory and installed in the field.

PV panels conform to the shape of the roof.

Enclosure (Batteries, Electric Relays, Controller)

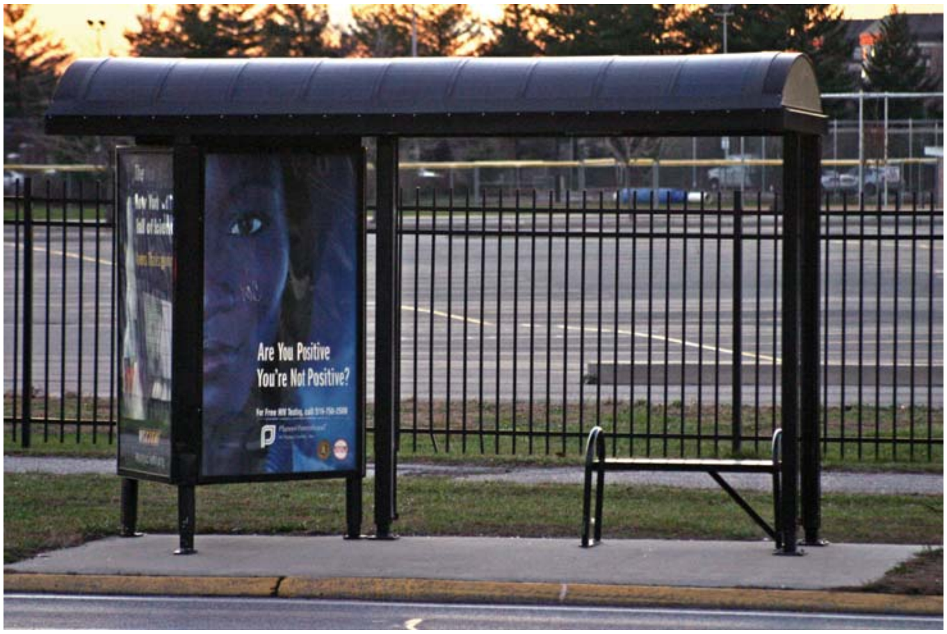
The enclosure houses two 12-volt, 102 amp-hour batteries. These batteries require no maintenance over their expected 10-year lifespan. Batteries and lamps are the only parts of the kit that are expected to need replacement over the life of the system.

The controller monitors the charge state of the batteries, sets the charging current to avoid overcharging, and controls luminaire operation. A timer relay allows for adjustment of the duration that the system is in operation each evening.

Adjacent to the battery/controller enclosure is a small photocell. This faces downward and senses light reflecting off the ground. When light levels become sufficiently low, the controller turns on the luminaire.

Due to patent restrictions, the enclosure could not be located within the light box, despite sufficient space. Instead, the enclosure is located in the space between the light box and the roof of the bus shelter. It is concealed from potential vandals by a steel plate fitted to the arched contours of the space under the roof.

The enclosure for the batteries and controller is mounted above the light box (arch-shaped concealing plate removed for photo).



This shelter (left) is located in an open area near a fenced parking lot.

Field Test

With assistance from the New York State Energy Research and Development Authority (NYSERDA), a partnership was created between SunWize Technologies (the manufacturer of the PV retrofit kit), and Culver-Amherst (the advertising company and owner of several thousand bus shelters) to install and evaluate solar-powered, illuminated bus shelters in the New York City area. Typically, Culver-Amherst provides bus shelters free of charge, which benefits the bus companies, bus riders, and the communities at large. In exchange, the company can sell advertising space to local and national businesses. Illuminated advertising space is appealing to advertising companies, because it can be billed at higher rates than non-illuminated advertising space.

The bus shelters are maintained by the advertising company. Shelters are visited regularly to replace advertising posters, and the posters are easily accessed by opening the glass doors.

Test Site

Twelve mercury-vapor lighted shelters in Long Island, N.Y., were retrofitted with the PV kit. The evaluation was conducted on three representative shelters in Uniondale, N.Y. These shelters were located along the intersections of two main boulevards, in the vicinity of a large college campus and an indoor events stadium. The area could be considered urban, as it is in close proximity with New York City. Security is a concern of bus riders in this area at any time of day.

Before retrofit, mercury vapor lamps backlight the advertising posters.

The wide boulevards are punctuated by fast-food restaurants, coffee and donut shops, motels, and other businesses that cater to the needs of college students. There are several other bus shelters in the area, some illuminated by mercury vapor lamps and others that are not illuminated. Each shelter is separated from the roadway by a strip of concrete sidewalk of varying width and reflectivity.

High-pressure sodium, cobra head-style streetlights are scattered intermittently along the boulevards. High-wattage floodlights are also found in nearby parking lots.

Installation

In the winter of 2003-2004, retrofit kits were installed at bus shelter sites selected by the manufacturer. Site selection was based on the need to avoid shade from trees to ensure that the PV panels could charge the system sufficiently. Due to inclement weather, the PV panels were mounted on new shelter roofs in a factory, and then moved to the field test locations. At each location, a team of four workers removed the old roof, placed the new roof on the structure, added the battery enclosure, and installed the new luminaire in the light box (see photos on p. 3).

Methodology

DELTA monitored the performance of the PV bus shelter system by testing electrical conditions, photometric conditions, operational consistency, energy and environmental implications, and human factors.

Testing the electrical conditions provided by the ballast

Laboratory tests were conducted using three samples of the dc ballasts used in the luminaire. LRC laboratory staff tested the starting and operating conditions provided by the ballast.

Measuring photometric conditions on a prototype unit

DELTA measured the photometric conditions of the retrofit lighting system under controlled conditions at the manufacturer's loading dock. The dark loading dock was advantageous because it had neither roadway luminaires nor passing headlights. The prototype was the same as those used in the field test sites. The figure on page 9 shows the luminance values of white paper with no graphics.[1] The remaining figures on that page show illuminances on the ground and face planes. DELTA researchers used a battery-powered data logger to monitor how light output decreases over the course of each evening.

Checking for consistent operation

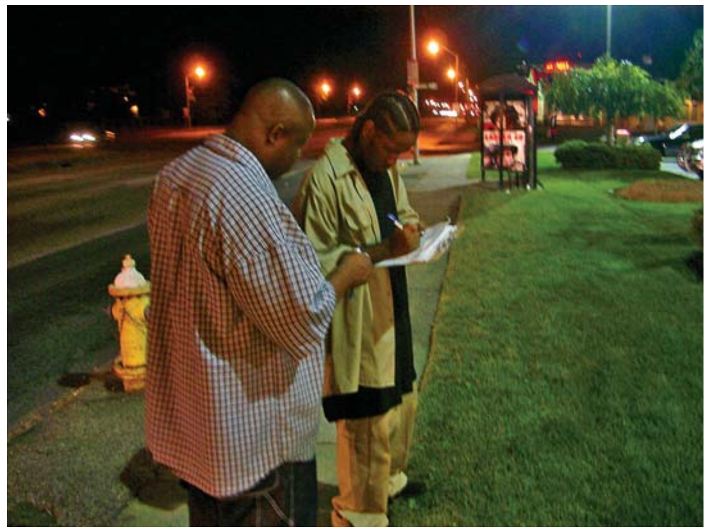
To check for consistent operation in the field, technicians installed battery-powered data loggers in five retrofitted bus shelters and a sixth electric utility-powered shelter. (In addition to the three retrofitted shelters at the Uniondale field test site, two other retrofitted shelters were selected from those located elsewhere in Long Island. Also, one mercury vapor-equipped shelter was monitored for comparison.) The data loggers recorded the times at which the luminaires turned on and off. Data were collected for four weeks.

Data logger

[1] Shelters in the field study used a white fiberglass diffusing material behind posters. DELTA tested the photometrics of the prototype with just the white fiberglass material, without posters.

Calculating energy savings and environmental implications

Based on the monitoring described above, energy usage and savings were calculated assuming four hours of operation for a PV shelter, compared to 24 hours for a mercury vapor shelter. Environmental implications were estimated using a pollution calculator from the U.S. Environmental Protection Agency (EPA). DELTA researchers used this calculator to correlate kilowatt-hours (kWh) saved to environmental emissions avoided.



Verifying visibility and collecting subjective opinions from bus shelter users

To obtain feedback on visibility and preferences about the lighting retrofit kit, DELTA hired 20 subjects from a temporary employment agency and performed a human factors study one evening in the fall of 2004. The participants lived in the area and were familiar with the urban security issues faced at the site. DELTA attempted to recruit regular bus users (see charts on page 7). The subjects included 17 men and 3 women, ranging from late teens to 40 years of age.

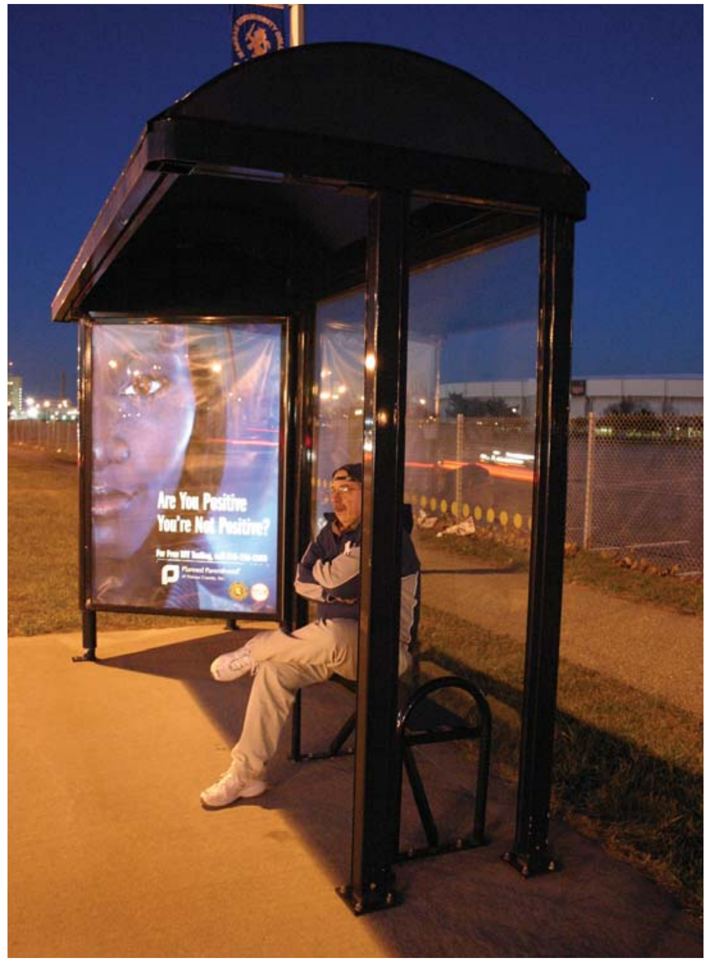
The subjects arrived before sunset by bus and by car and gathered at a large parking lot near the site.

They were not told about the solar nature of the field test. Before starting the study, the subjects were given a chance to review the evaluation forms and perform a practice evaluation.

The DELTA team identified six shelters to be evaluated in the human factors study. Two shelters had the PV retrofit lighting kit, two had the standard mercury vapor lighting kit, and two were not illuminated at all. All six shelters displayed the same multicolored advertising sign.

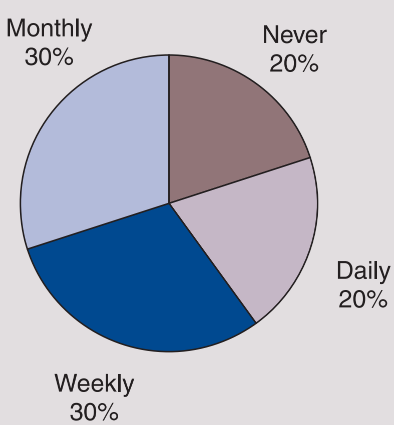
Subjects were separated into three groups, each with a DELTA leader. After dark, the three groups visited the six shelters following a different prescribed path, to ensure that each group saw the shelters in a different order and at a different time.

The subjects were asked to evaluate each of the shelter sites when passing cars were not present, in order to minimize the impact of stray headlights on their opinions about the shelters. However, ambient light levels varied at the six shelters, due to the different locations of parking lot luminaires and cobra head streetlights in the vicinity of each shelter.

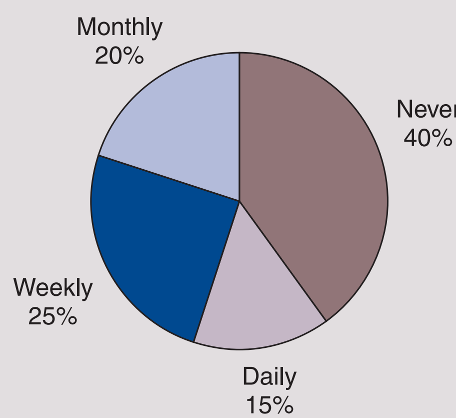


Bus ridership among study subjects

Question:
How frequently do you ride on a bus?



Question:
How frequently do you wait at a bus stop after dark?



Field Test Results

Benchtop Lab Test Results

DELTA tested the output of the dc ballast used in the photovoltaic shelter. The dc ballast underdrives the lamp slightly. Instead of driving the lamp at 32 W, it operates at 29 W. Ballast factor was measured at 0.80. This translates to reduced light levels but is not likely to have a negative impact on lamp life. Lamp life is not a priority of this system, since the units are maintained frequently for advertising changes.

Advertising signs may not be conspicuous relative to adjacent lighting in high ambient conditions.

Field Test Results: Operation

The luminaires in the field test installation were set to operate for four hours each night, beginning after dusk. In the fall of 2004, DELTA monitored the operation of five of the solar shelters. Over four weeks of operation, all of the shelters operated as expected.

Over the course of several nights, DELTA observed the operation of the field test units at sunset. The units turned on before the environment became totally dark. Therefore, switching is unlikely to be a distraction to passing motorists.

DELTA also monitored the operation of a prototype PV bus shelter unit installed at the manufacturer's parking lot. This unit was set to operate for eight hours per night. Over the course of 15 days, this unit occasionally failed to turn on in order to avoid draining the battery following some significantly overcast conditions. Thus, the more conservative recommendation of four hours of use appears to be justified.

Field Test Results: Output

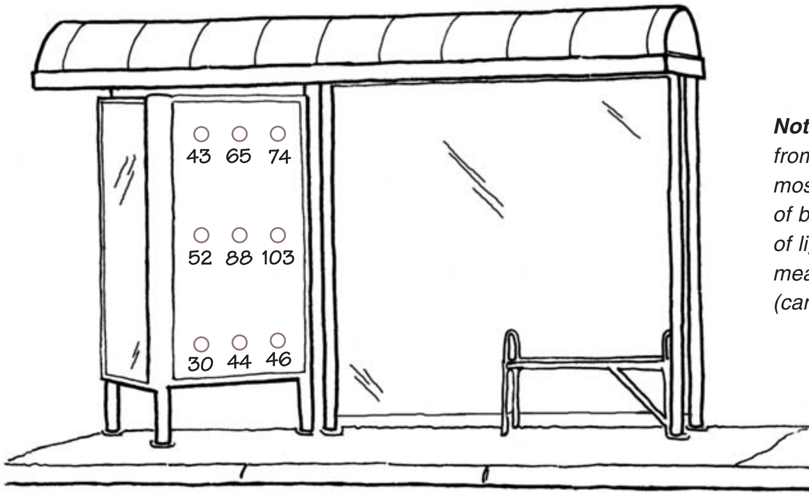
DELTA researchers commented that luminance levels were comfortable to look at, even in the low ambient conditions of a dark parking lot. However, in high ambient conditions, the advertising signs may not be conspicuous relative to adjacent, electrically powered advertising.

The manufacturer of the PVretrofit kit has optimized the key features (number of batteries, available area for PV panels, and number of lamps and luminaires) to provide illumination for the bus shelter ads. Large increases in luminaire output will only be possible with increases in panel area or increases in the collection efficiency of the PV panels. As future panels become more efficient, the manufacturer will be able to increase the number of lamps used in the units. This will allow the manufacturer to offer higher output options to visually compete with electrically powered advertising in a variety of ambient lighting conditions.

Other strategies will slightly increase the output of the retrofit kit. Metal surfaces on the interior of the light box are unpainted gray steel. The output of the light box could be increased slightly by painting these surfaces white before installing the retrofit lighting kit.

DELTA measured the luminance of a fiberglass diffuser and the illuminance in the surrounding environment (refer to the figures on page 9). The luminance of the poster area was uniform, with no lamp image visible. Diffusion is achieved by two means: a sheet of white fiberglass material behind each advertising poster and a diffuser on the luminaire. Removing one of these diffusers could increase the luminance of the poster.

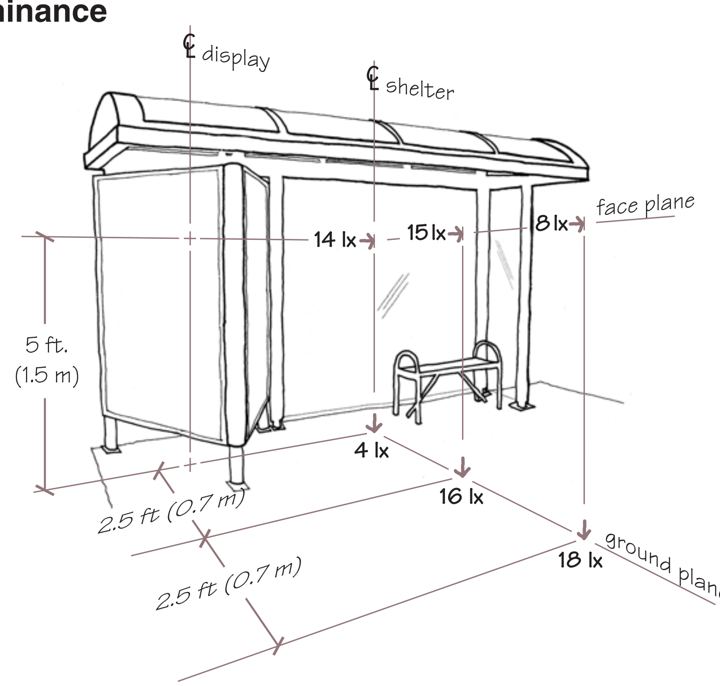
Luminance

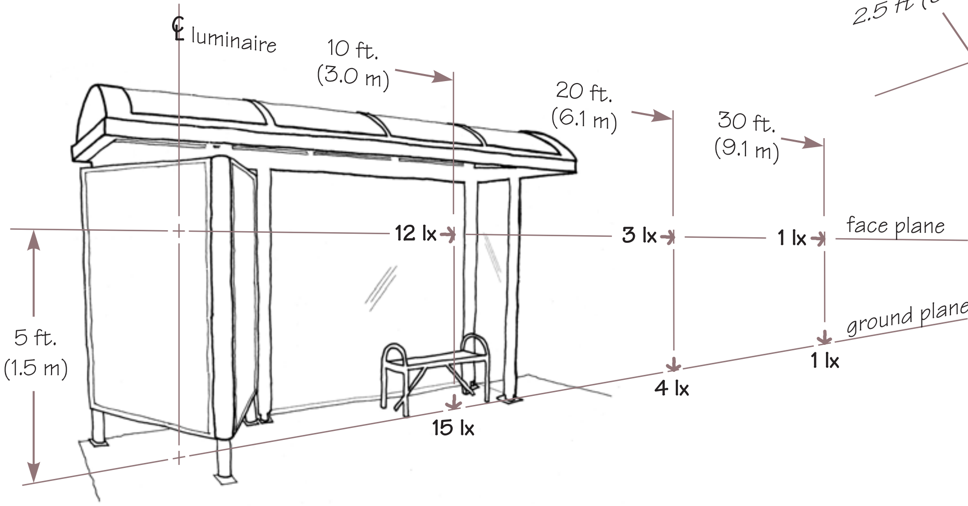


***Note:** luminance is a measure of light coming from a surface. It is the photometric quantity most closely associated with one's perception of brightness. Luminance refers to the amount of light that reaches the eye of the observer, measured in units of luminous intensity (candelas) per unit area (m^2).*

Average luminance values in cd/m².

Illuminance





10.76 lx = 1 fc

***Note:** illuminance is a measure of light falling on a surface, measured in lux (lx). Illuminance measurements will vary from one installation to the next, depending on luminaire proximity, surface reflectivity, and many other light loss factors.*

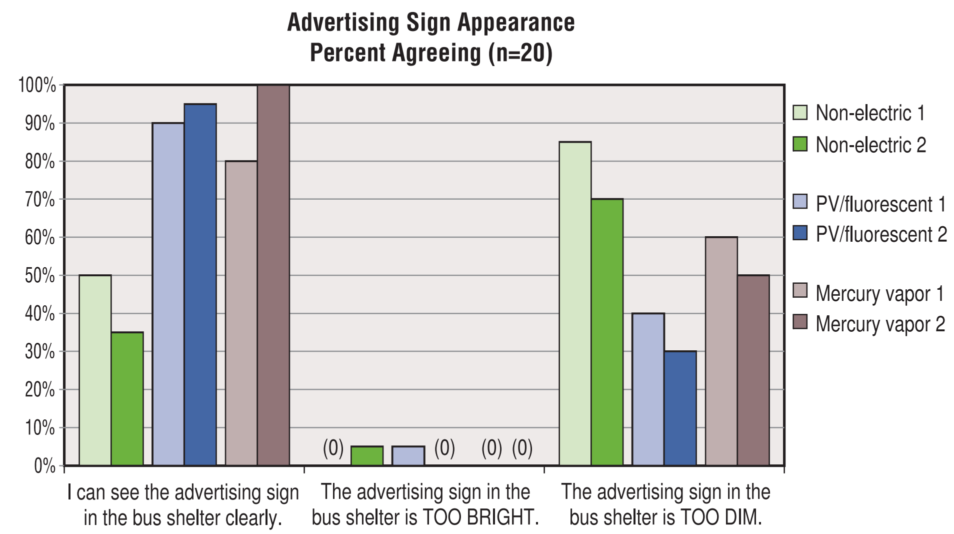
Illuminance measurements on ground and face planes.

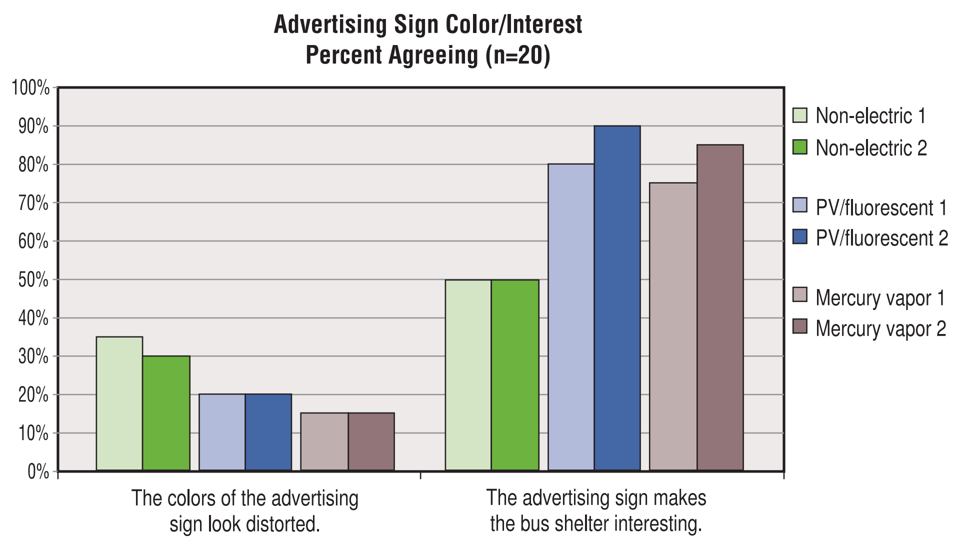
Human Factors Evaluation Results

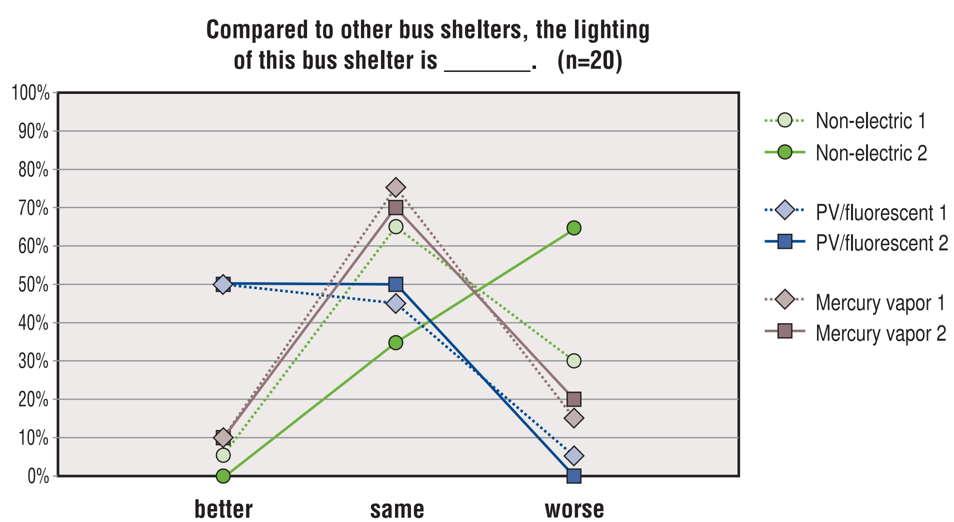
DELTA asked the field test subjects about the visibility of the advertising signs, the appearance of the shelter, and their overall impression. DELTA researchers also asked questions relating to the perception of safety and ability to see people inside the shelter, but omitted these from analysis because the PV retrofit shelters had higher levels of ambient illumination from surrounding streetlights and other electric lights than the other shelters.

Subjects were asked to answer each question from both inside the shelter and at a distance. Since answers for viewing from a distance were similar to those within the shelter, they were not included in the graphs.

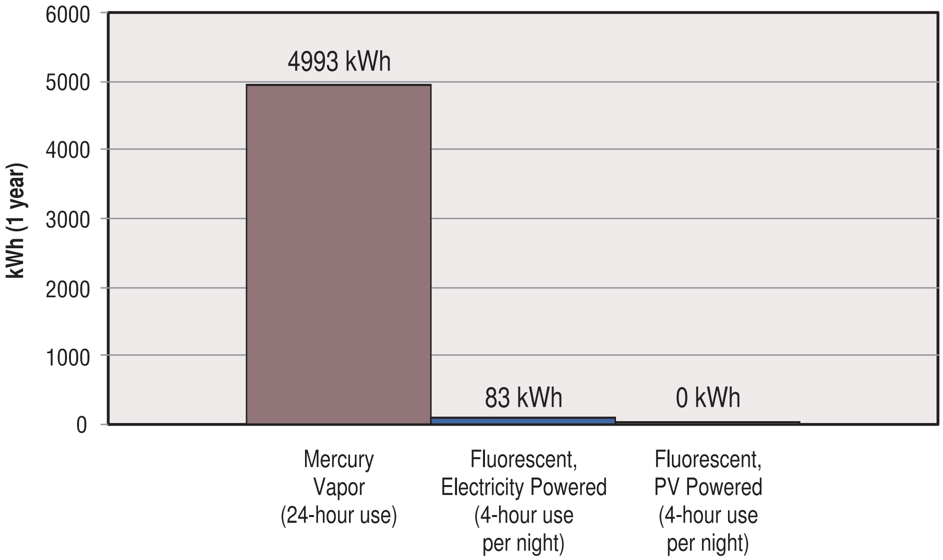
The graphs at the right show the results of the human factors evaluation. As expected, the subjects said that the advertising signs were more visible with illumination than without. There was little difference in visibility and visual preference between the fluorescent and mercury vapor light sources. Neither light source type was considered too bright. The lighted shelters were considered more interesting. Despite the poor color-rendering properties of mercury vapor, subjects did not rate color higher in the fluorescent shelters. Overall, the PV retrofit shelters were preferred to the standard mercury vapor-lighted shelters, as well as the non-illuminated shelters.







Annual Purchased Electrical Energy of Various Light Sources for One Bus Shelter Unit



Emission savings by using PV-powered fluorescent lamps vs. electrically powered…

	mercury vapor lamps	fluorescent lamps
Pollutant	**lbs (kg)**	**lbs (kg)**
SO_2	25 (11.4)	0.4 (0.2)
NO_x	14 (6.4)	0.2 (0.1)
CO_2	9033 (4106)	150.2 (68.1)

Sulphur dioxide (SO_2) is associated with visible pollution (haze) and acid rain. SO_2 is also a direct lung irritant. Nitrogen oxides (NO_X) are a primary cause of ozone production (a main component in smog) and acid rain. Carbon dioxide (CO_2) is a possible contributor to future climate changes, such as global warming.

Energy Savings Calculations

The standard bus shelter has no switch-off mechanism, so it operates two 250 W mercury vapor lamps 24 hours per day. There are significant opportunities for energy savings in retrofitting shelters using standard mercury vapor and electrically powered fluorescent systems with solar-powered fluorescent lighting systems.

Both retrofit scenarios translate to significant environmental pollution savings, as shown in the table at the lower left.

Maintenance Issues

Bus shelters are occasionally targeted by vandals awaiting the bus or simply roaming the streets. Maintenance crews service the PV bus shelters frequently for advertising changes, repairs of broken glass, and cleaning. As such, lamps are frequently checked for failure. The manufacturer provides a lamp-test button to simplify this procedure.

Timers are set by the manufacturer and can be adjusted during installation. It is possible for timer settings to be extended during the summer, when greater solar collection is possible. However, the logistics of changing timer settings for multiple shelters makes this option impractical.

Findings and Recommendations

Findings

- The PV shelters provide the benefits of illumination while using no utility-powered electricity.
- The PV shelters offer significant energy savings by using an energy-efficient light source that is operated four hours per day and is powered by a PV array. The standard shelters use less efficient lighting systems that operate 24-hours per day.
- The flexible PV panels integrate seamlessly with the shelter roof, shielding the view of the battery and controls, thus avoiding the attention of vandals.
- It is not easy to adjust timer settings after installation; thus, initial settings are likely to become final settings.
- A lamp test button allows lamp checks to be performed easily.
- Conservative operation recommendations (four hours) appear to be justified.
- The solar units operate reliably when recommended timer settings are used.
- Units turn on inconspicuously between dusk and nightfall.
- Illuminated shelters are preferred over non-illuminated shelters.
- Acceptance of the PV system was equivalent to much higher-wattage mercury vapor system.
- Glare is not a problem; viewers rated the luminance of advertising panels as comfortable.
- Luminance uniformity is acceptable; no lamp images are discernable behind the advertising posters.

Recommendations for the Manufacturer

- The luminance of the sign is comfortable in low ambient lighting conditions but may need to be increased to visually compete with other advertising in typical commercial boulevard environments.
- As the collection efficiency of PV panels improves, the manufacturer may wish to provide the option for increased illumination and/or longer hours of illumination.
- The manufacturer could increase luminance levels by painting the inside of the light boxes white, rather than leaving the steel surface unpainted.
- Diffusers mounted both behind the posters and on the luminaire are unnecessary; the luminance of the advertising poster would increase with little or no impact on uniformity by removing one of the diffusers.

Current Product Status

- The PV-powered bus shelter is commercially available from Sun Wize Technologies (www.sunwize.com).

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Photovoltaic Lighting Retrofit Kit for Bus Shelters
September 2005

Field Test DELTA evaluates new energy-efficient lighting products to independently verify field performance claims and to suggest improvements. A primary goal of the Field Test DELTA program is to facilitate rapid market acceptance of innovative energy-efficient technologies.

Program Director: Jennifer Brons
Project Managers: Jennifer Brons, Patricia Rizzo
Product Development and Assembly: SunWize Technologies
Human Factors Survey: Peter Boyce, Jennifer Brons, Vasudha Ramamurthy, Jennifer Watkinson, Marc Dyble
Reviewers: Russ Leslie, Peter Morante
Editors: Jennifer Taylor, Dennis Guyon
Technical Assistance: Howard Ohlhous, Conan O'Rourke, Martin Overington, Ramesh Raghavan, Vasudha Ramamurthy
Illustrations: Vasudha Ramamurthy
Photography: Jennifer Brons, Dennis Guyon
Publication Production: Dennis Guyon

SPONSORS AND PROJECT PARTICIPANTS
New York State Energy Research and Development Authority (NYSERDA)
SunWize Technologies
Culver-Amherst

CREDITS
NYSERDA: Marsha Walton
SunWize Technologies: Richard Martino
Culver-Amherst: Paul Theisen, Richard McKay
Product Installation: Culver-Amherst

For publication ordering information, contact:

Lighting Research Center

Rensselaer Polytechnic Institute
21 Union Street
Troy, NY 12180-3590
(518) 687-7100
www.lrc.rpi.edu

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