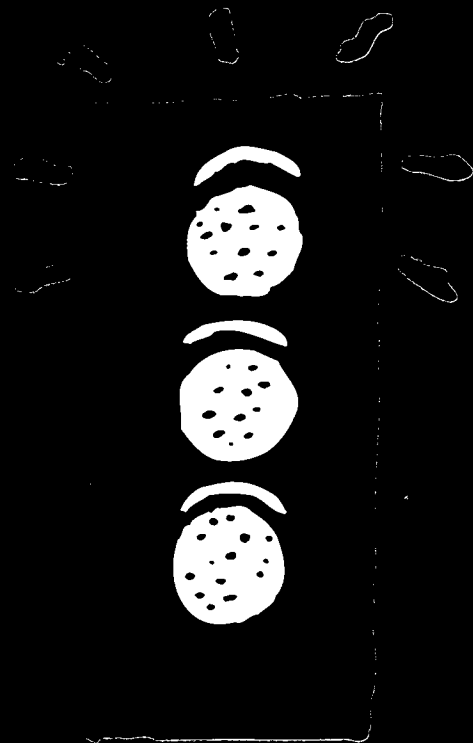


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 Crystal Growth  
 1981-1982



# LIGHT EMITTING DIODES FOR TRAFFIC SIGNAL DISPLAYS

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Edward G. Rendell, *Mayor*

# CITY OF PHILADELPHIA

## LIGHT EMITTING DIODES FOR TRAFFIC SIGNAL DISPLAYS

### URBAN CONSORTIUM ENERGY TASK FORCE

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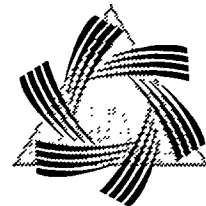
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December 1995



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URBAN CONSORTIUM

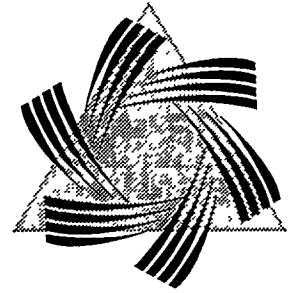


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# Background



**URBAN CONSORTIUM**

Public Technology, Inc. (PTI), is the non-profit technology organization of the National League of Cities (NLC), the National Association of Counties (NACo), and the International City/County Management Association (ICMA). PTI's mission is to bring technology to local governments. Through collective research and development efforts in its member jurisdictions, PTI creates and advances technology-based products, services, and enterprises for all cities and counties.

Four active task forces, each composed of members of PTI's Urban Consortium (UC)—which represents fifty of the nation's largest and most progressive cities and urban counties—drive PTI's research and commercialization efforts. One of these task forces is the Urban Consortium Energy Task Force (UCETF), which was established to address critical energy needs of urban America.

## THE URBAN CONSORTIUM ENERGY TASK FORCE

The UCETF is the nation's most extensive cooperative local government program to improve energy management and technology applications in local governments. Its membership is composed of local government officials from America's large urban centers. The four major goals established by UCETF members are to:

1. Pursue collaborative solutions to interrelated energy, environment and economic development issues at the local level;
2. Improve energy efficiency, reduce costs and develop revenue from local energy assets;
3. Promote practices and efforts at the local level to assure that energy and environmental considerations are broadly integrated into local decision-making, and to address the interrelationships between energy, environment and economic policies; and
4. Act as the implementation arm for NLC and NACo policies.

Under an annual program partly funded by the U.S. Department of Energy (USDOE), a number of city and county projects propose to meet UCETF objectives. Projects selected for each year's program are organized in thematic units, such as Utilities/Buildings, Transportation, Sustainable Communities, and Technology Transfer, to assure effective management and ongoing peer-to-peer exchanges. The results of these research projects are documented in reports such as this one, and made available for broad dissemination among other local governments through PTI.

**The research and studies described in this report were made possible by grants from the MUNICIPAL ENERGY MANAGEMENT program of the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy.**

*The statements and conclusions contained herein are those of the grantees and do not necessarily represent the official position or policy of the U.S. Government in general or USDOE in particular.*



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**PECO Energy Co.** of Philadelphia, PA provided laboratory testing services, and field installation of monitoring devices. Thanks are extended to Raymond Connolly, P.E. and the staff of the PECO Corporate Laboratories in Valley Forge, PA., and Bernard McGinley of PECO Major Commercial Accounts Division.

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**The City of Philadelphia Traffic Engineering Division** provided installation, record keeping, and maintenance services at field locations and at the equipment field test site. The assistance of Gerard Ebbecke, Chief Traffic Engineer, Charles Trainor, Assistant Chief Traffic Engineer, and Ronald Mayrant, Signal Services Supervisor, is appreciated.

**The Pennsylvania Department of Transportation** provided participation in field demonstrations, and processed and approved requests for experimental installations. Appreciation is extended to Arthur Breneman, Chief, Traffic Engineering and Operations Division, and staff.

**Electro-Tech's, Inc.** of Anaheim, CA served as private sector partner in this program, and developed and manufactured the prototype LED units. Ray Deese, President, provided invaluable assistance in product development, troubleshooting, and general program assistance.

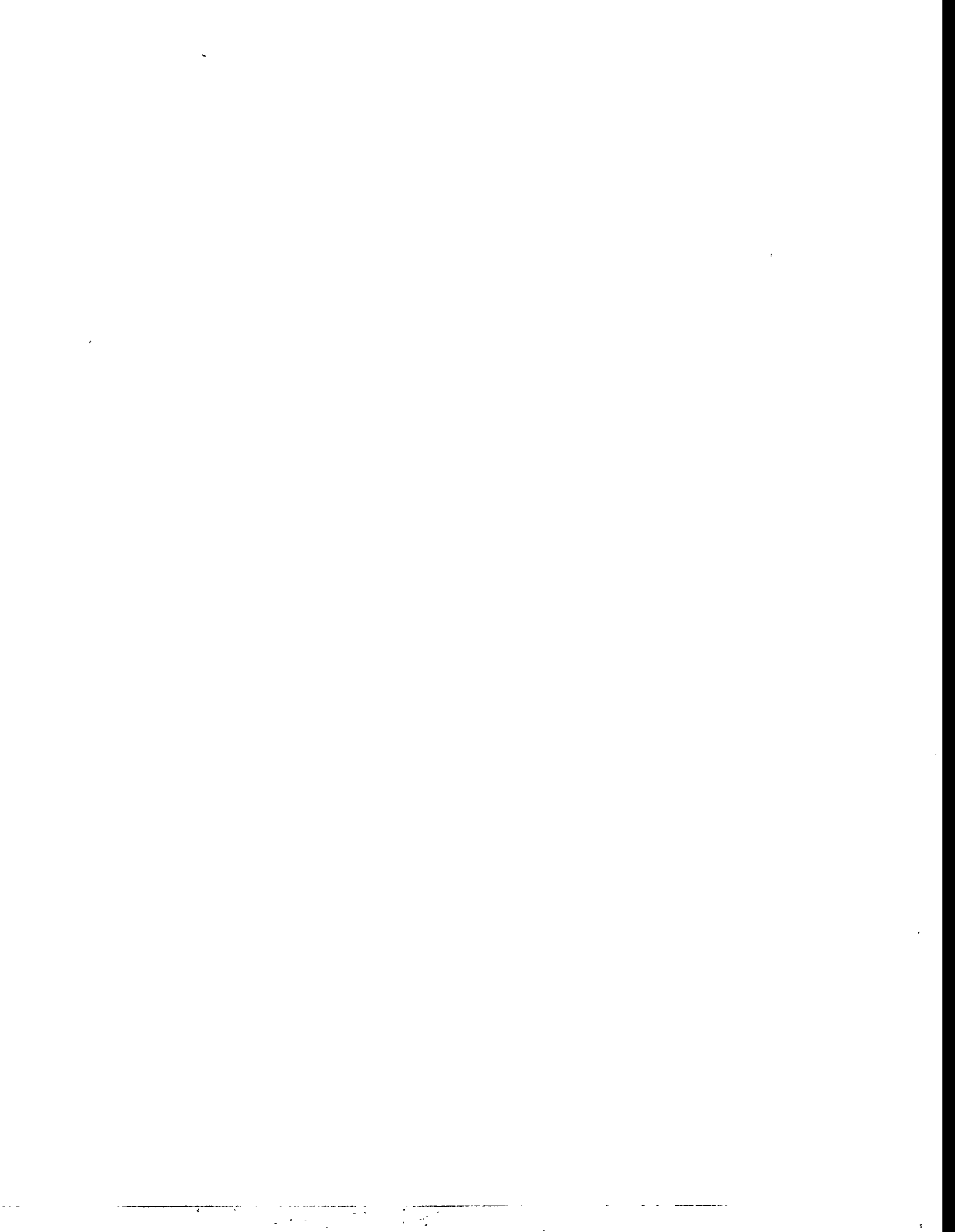
Special thanks is extended to Harold Becker of Dallas, Texas, developer and promoter of LED signal technology, who was instrumental in the development and success of this program.

Three agencies participated in this project by providing volunteers to participate in the blind observational study in West Philadelphia. The agencies and individuals coordinating this effort are as follows:

**AAA Mid-Atlantic**, Garvin Kissinger, Vice President

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# Table of Contents

## **SECTION 1**

Executive Summary .....1

## **SECTION 2**

Background .....3

## **SECTION 3**

Project History .....5

## **SECTION 4**

Economic Analysis of LED Signals .....9

## **SECTION 5**

Project Tasks and Findings .....17

## **SECTION 6**

Other Considerations .....25

## **SECTION 7**

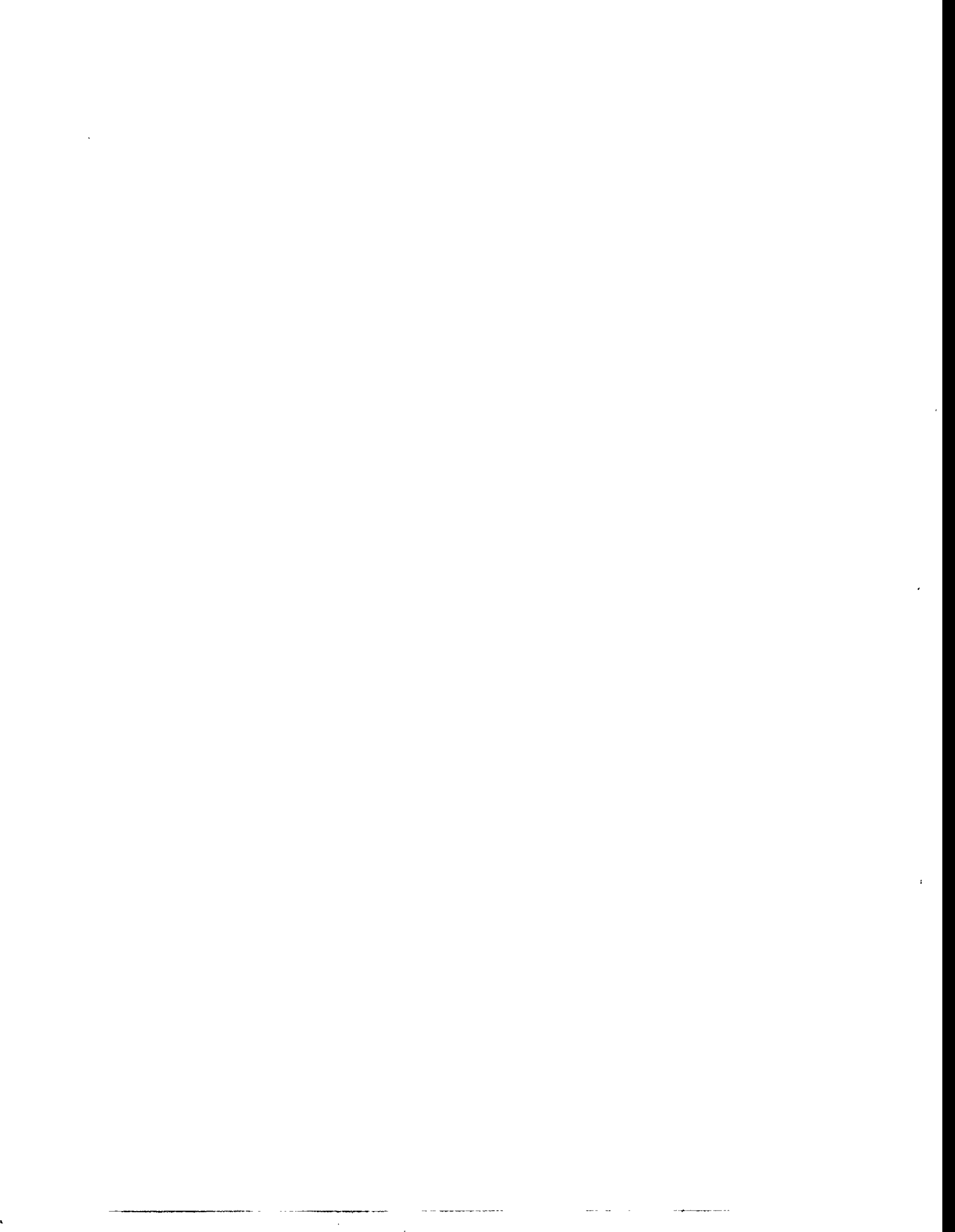
Summary of Findings and Conclusions .....29

## **APPENDICES**

**Appendix A.** PECO Energy Laboratories LED Signal Tests

**Appendix B.** West Philadelphia Study Forms and Data

**Appendix C.** 'SigCalc' Software Data Screens



## Executive Summary

**T**his project investigated the feasibility of using light emitting diodes (LEDs) for red traffic signals in a demonstration program at 27 signalized intersections in the City of Philadelphia. LED traffic signals have the potential to achieve significant savings over standard incandescent signals in terms of energy usage and costs, signal relamping costs, signal system maintenance costs, tort liability, and environmental impact. Based on successful experience with the demonstration program, the City of Philadelphia is currently developing funding for the conversion of all existing red incandescent traffic signals at approximately 2,700 intersections to LED signals. This program is expected to cost approximately \$4.0 million and save about \$850,000 annually in energy costs.

During late 1993 and early 1994, 212 red LED traffic signals (134 8-inch signals and 78 12-inch signals) were installed at 27 intersections in Philadelphia. The first group of 93 signals were installed at 13 prototypical intersections throughout the City. The remaining group of signals were installed on a contiguous route in West Philadelphia consisting of standard incandescent signals and LED signals interspersed in a random pattern.

Projected life cycle costs of LED signals are affected by the following factors:

- Capital costs of LED signals, which can be positively impacted by utility rebates and federal and state grant programs. Capital costs per red LED signal are in the range of \$140 to \$280.
- Local energy costs are generally related to usage only, but impacted by demand and facilities charges in some jurisdictions. Energy cost for Philadelphia traffic signals is currently \$.1141 per kilowatt-hour. Energy cost reductions of 80 to 90 percent can be expected for red LED signals.
- Maintenance costs include relamping costs, and signal system electrical component maintenance. Maintenance cost savings are based on optimal extension of relamping schedules based on elimination of red signal burn-outs, and based on reduced electrical component failure due to reduced electrical system loads.
- Tort liability is positively impacted by red LED signals through reduction in red signal "burn-out," and reduced component failure. Reduction in tort liability is difficult to quantify, but can represent significant potential savings.

Project tasks consisted of the following:

- **Performance monitoring**—This task involved on-going monitoring of LED signal operation and observation of all LED signals for over 800,000 composite hours of LED signal operation. None of the 212 LED signals experienced any string failures or observable brightness degradation. Four signals failed during the test period due to a design flaw in an integral bridge rectifier/surge protector, which was subsequently corrected.

- **Laboratory performance**—In this task, comparative performance of LED signals and incandescent lamps was determined in a test program performed by PECO Energy Company's laboratories. The test protocol recorded electrical and optical performance of LED signals and standard incandescent traffic lamps under varying conditions of input voltage and temperature.
- **Power consumption field measurements**—A kilowatt-hour meter was installed at a field installation with red LEDs. Theoretical calculated power consumption was compared with actual measurements.
- **Driver's Observational Study**—A "blind" study using volunteer drivers was performed on a five mile, 30 intersection route in West Philadelphia having randomly placed incandescent and LED signals. This study evaluated signal brightness and color (chromaticity) of the observed signals. Results of the study indicated that motorists perceived LED signals to be significantly brighter than incandescent signals; however, the color observations were inconclusive.
- **Power calculation software development**—Spreadsheet software was developed to provide a means of accurately determining electric demand and power consumption in actual installations having any combination of LED and incandescent signals.

Additional factors that should be considered in determining the feasibility of red LED traffic signals:

- LED signal performance is extremely sensitive to input voltage fluctuations requiring remedial measures.
- Brightness of LEDs diminish over time, affecting useful life. Data on expected light degradation of current generation of LEDs has not yet been developed.
- Adherence to current traffic signal standards is essential, however modification of the standards to reflect LED technology should be pursued.
- The development of viable green LED signals will likely enable a major redesign of traffic signal control and display systems, substantially reducing size, loading characteristics, and electrical requirements.

Other LED signal programs currently underway by other agencies such as the National Cooperative Highway Research Program and the California Department of Transportation, will provide additional relevant data regarding LED performance.

## CONCLUSIONS

During a 20 month evaluation period in the City of Philadelphia, red LED traffic signals provided superior performance and significant energy cost savings as compared to standard incandescent signals.

The City of Philadelphia is committed to maximizing the financial and environmental benefits of this technology, and is currently developing programs to maximize the use of red LED signals.

The City of Philadelphia will support on-going efforts to develop economically viable green LED traffic signal displays

## THE CHALLENGE

**T**raffic signals represent one of the most inefficient uses of electrical energy. A single standard 12 inch traffic signal uses up to 150 watts of electric power, generally 24 hours a day, simply to provide a color indication to motorists. Standard traffic signals use incandescent lamps and monochromatic filters. Little of the energy generated is actually utilized for signaling purposes; most is lost either as invisible infrared, or as visible light absorbed through a monochromatic lens which provides the color indication. Incandescent lamps used for traffic signals are less energy efficient than standard incandescent lamps, since they are designed primarily to extend lamp life.

## LED SIGNAL OPPORTUNITY

**R**ecent technological advances in the development of light emitting diodes (LEDs) have made these devices feasible for use as traffic signal displays. LEDs are semi-conductors that emit electromagnetic energy coincident with the change of energy state at a diode junction. The wavelength of the energy depends upon the materials used for the junction. Certain combinations of materials produce light at frequencies used for standard traffic signal displays (red, yellow, and green). This light is monochromatic, therefore little energy is wasted outside of the visible spectrum or in filtering. As a result, LEDs are extremely energy efficient for traffic signals, using up to 90% less energy than an incandescent traffic signal. Unlike incandescent lamps that function by "burning" a filament until it eventually fails, LEDs have no burn out or failure mechanism. Light expectancies in excess of 10 years are based on conservative projections of component failures, or reduction in light output. This compares to a 1 to 3 year life for a traffic signal lamp.

A single LED produces very little light, therefore to be useful for traffic signal displays, an array of LEDs are mounted on a circular 8 inch or 12 inch disk. This disk is retrofitted into a traffic signal housing, replacing the incandescent lamp, reflector, and color lens.

LED traffic signals can potentially result in significant energy, environmental, signal maintenance, and tort liability savings, which will be analyzed throughout this report. Replacement of all the red signals at 2,700 intersections in the City of Philadelphia is projected to save about \$850,000 annually in energy costs alone. The environmental benefits of such a program would avoid 7.4 million kilowatt-hours annually, thus avoiding 5,978 tons of Carbon Dioxide (CO<sub>2</sub>), 69 tons of Sulfur Dioxide (SO<sub>2</sub>), and 22 tons of oxides of nitrogen (NO).

## Background

Eventual replacement of all of the remaining signal colors (yellow and green) with LEDs would avoid an additional 6 million kilowatt-hours annually, and result in an estimated additional \$700,000 in annual energy savings.

## MISSION

The primary mission of this program was to determine the feasibility of using LED traffic signals in common use, both in terms of life cycle cost savings and effectiveness as a traffic control device. Life cycle costing addresses the impact of these devices on capital, energy, maintenance, and liability costs. Traffic control effectiveness addresses the objective adherence to current accepted standards, and the subjective impact on transportation professionals and the general public.

The secondary mission was to determine the relative feasibility of replacing only red LED signals within a short time frame, rather than waiting for anticipated technology development of viable and economically feasible green and yellow LED signals. Despite the current absence of viable green and yellow LED displays, the economics of stand alone red LED signal retrofits is such that, in most applications, the red LED signal will have recouped its initial investment long before three color LED signal systems are expected to achieve viability.

Based on the successful results of this program, the City of Philadelphia is committed to optimizing the use of red LED traffic signals, and promoting the continued development of three color LED signal systems.

## Project History

LED traffic signals became commercially available in the past three years, but little effort was made initially to market the devices based on energy cost savings. In May 1993, as part of a UCETF 1992/93 program, Electro-Tech's Inc. of Anaheim, CA agreed to partner with the City of Philadelphia in a demonstration project to explore the feasibility of LEDs for mass application to traffic signal displays. The original program scope explored the feasibility of retrofitting all three signal colors. However, state-of-the-art LED technology is such that LEDs in the red portion of the spectrum are inherently more efficient, and the other two colors, particularly green, were not, and to date, are still not economically feasible.

In the Summer of 1992, Electro-Tech's Inc. under the City's direction produced 12 experimental LED signal heads, of both 8 inch and 12 inch size, with various configurations of LED brightness and placement. A demonstration site was set up in the parking lot of the Pennsylvania Department of Transportation (PennDOT) District 6-0 offices. The prototype signals were observed by representatives of PennDOT and the City's Traffic Engineering Division. The display included red, yellow, and green signals. As a result of these meetings and observations, it was generally agreed that green LED signals had not achieved the chromaticity and light output to be considered feasible for actual installations. Yellow LED signals were marginally acceptable, but were not economically justifiable, except in the case of full three color replacement. Yellow signals (except in some special uses such as flashing warning beacons) have a duty cycle of 3 to 5 percent, and would never independently repay their investment.

Various configurations of red LED signals were displayed, and based on subjective visual observations, prototypes using 750 millicandela (mcd) LEDs with 30 degree beam spread were tentatively approved for actual installations.

Other permutations of LED signals, including arrow indications and pedestrian signals, were also briefly considered for this program. Arrow indications (left or right turn arrows) have even higher potential energy savings than a standard circular indication. An incandescent arrow indication uses the same wattage lamp as a solid circular indication. The signal lens is masked to produce the arrow display. In an LED arrow indication, the LEDs are arranged to form the arrow display, resulting in significantly fewer LEDs (and watts consumed) than a solid LED indication. Since red arrows are not used in Pennsylvania at this time, and the remaining colors are not currently acceptable or cost effective, LED arrows were not used in this project.

Another potential application for LEDs is pedestrian signals. Graphic pedestrian signals ("hand" and "walking man") are gaining popularity (as opposed to the verbal "WALK" & "DON'T WALK" indications), and the LEDs could be easily arranged to mimic these graphics. Unfortunately, current specifications require

*“To date,  
these LED  
signals have  
functioned  
continuously  
without  
incident.”*

that the signal colors be “Portland Orange” for the “Don’t Walk” indication and “lunar white” for the “Walk” indication. The Portland Orange color can be easily achieved with existing LEDs, but lunar white is not available with current technology. A change in specifications to allow a green walking man could make LED pedestrian signals feasible. No LED pedestrian signals were used in this program.

## PROTOTYPE INSTALLATIONS

In October 1992, after receiving experimental approval from PennDOT, eight of the original prototype red LED signals were installed at the intersection of 17th and Arch Streets in Philadelphia. These signals have various permutations of LED distribution and background color, and were used as a basis for the development of signal specifications for the 27 intersection demonstration project. To date, these LED signals have functioned continuously without incident. They are located adjacent to the City’s administrative offices, but generally go unnoticed by pedestrians or motorists.

Based on the results of this prototype installation, specifications were prepared, and purchase orders issued for the red LED signals at 26 additional intersections. The specifications were written to be flexible, with a range for many parameters such as LED layout, light distribution angle, background color, and lumen output. The specifications required procurement over four separate purchase orders to permit on-going product development and refinement. However, due to delays in processing the purchase orders, and general satisfaction with the product after the first purchase order, the signals were completely procured over two essentially equal purchase requisitions.

The first purchase requisition was used to install 91 red LED signals at 13 intersections during the Fall of 1993. This group of signals targeted a variety of types of intersections and geographic locations. Included were standard narrow right angle intersections common to Philadelphia, and major arterial intersections. The first group of signals used 750 millicandela (mcd.), wide angle LEDs, which were adopted as the standard over slightly narrower angle 600 mcd. LEDs. A homogenous distribution of LEDs was also adopted as standard, since it was generally agreed that it was visually preferable over signals with a “hot spot,” or concentration of LEDs at the center of the signal. Most observers felt that the “hot spot” served no purpose except to mimic an incandescent display. The only remaining variable parameter was the color of the background of the LED circuit board.

Two colors, red and black, were used in equal numbers in the Phase 1 signals. Black provided a neutral background, however most observers felt that the red background was slightly preferable for two reasons: First, when the red signal was off, it appeared more similar to the red lens of an “off” incandescent signal; and secondly, with the red LEDs on and at close viewing distances (pedestrians within 25 feet) the red background tended to “smooth out” the display making it appear more homogeneous rather than individual point light sources. As a result, all of the signals ordered in Phase II have red backgrounds. Clear lenses were used on all of the signals in this project. Colored lenses, accurately matching the light frequency of the LED signals are another option. Colored lenses would have the advantage of appearing similar to a standard incandescent signal, would filter

incoming light to reduce heat build-up, and can be used to provide light diffusion to further control visibility angles. The use of colored lenses would make the issue of circuit board background color insignificant.

The second group of signals was installed during Spring 1993. This group was installed as part of a "blind" test and evaluation route in West Philadelphia. A five mile 33 intersection route was established consisting of two arterial one-way streets, and a two way collector street. Fourteen of the intersections in a random pattern had red LED signals installed on all approaches. The remaining intersections continued to have standard red incandescent signals. A formal study of relative visual impact of these signals using volunteer observers was conducted on this route in May and June, 1994. This study is discussed in greater detail later in this report. An additional one or two intersections will be outfitted with red LED signals using signals originally held as spares or used for electrical and optical tests.

The LED signals supplied for both phases utilized Hewlett-Packard HLMP-C100 series LEDs rated at 750 millicandela nominal output. These LEDs use "AlGaAs" technology, employing aluminum, gallium, and arsenic as junction materials to achieve high energy efficiency, producing monochromatic red light at 644 nanometers dominant wavelength. The 12 inch signals consist of a total of 595 LEDs each in 7 strings consisting of 84 series-parallel circuits. The 8 inch signals consist of a total of 425 LEDs each in 5 strings consisting of 45 series-parallel circuits.

The LED signals installed under this program are shown in **Table 1**.

**TABLE 1 Philadelphia LED Signal head locations - 6/30/94**

DATE <u>INSTALLED</u>	INTERSECTION		LED SIGNALS		CUMUL HRS.	
	<u>NORTH-SOUTH</u>	<u>EAST-WEST</u>	<u>8"</u>	<u>12"</u>	<u>8"</u>	<u>12"</u>
29-Oct-92	17th Street	Arch Street	5	3	73080	43848
15-Sep-93	9th Street	Race Street	8	0	55296	0
15-Sep-93	Delaware Avenue	Dock Street	3	6	20736	41472
10-Dec-93	25th Street	C.B. Moore Avenue	2	0	9696	0
10-Dec-93	26th Street	C.B. Moore Avenue	2	0	9696	0
10-Dec-93	5th Street	Snyder Avenue	4	4	19392	19392
10-Dec-93	6th Street	Snyder Avenue	4	0	19392	0
28-Dec-93	65th Street	Woodland Avenue	0	4	0	17664
28-Dec-93	66th Street	Woodland Avenue	4	0	17664	0
04-Nov-93	Roosevelt Blvd.	Pratt Street	2	11	11424	62832
09-Dec-93	Roosevelt Blvd.	Bridge Street	4	13	19488	63336
26-Apr-94	Torresdale Avenue	Megargee Street	2	4	3120	6240
27-Apr-94	Torresdale Avenue	Tolbut Street	4	4	6144	6144
		<b>SUBTOTAL</b>	<b>44</b>	<b>49</b>	<b>265128</b>	<b>260928</b>
22-Mar-94	52nd Street	Cedar Avenue	8	0	19200	0
22-Mar-94	56th Street	Cedar Avenue	8	0	19200	0
22-Mar-94	57th Street	Cedar Avenue	8	0	19200	0
23-Mar-94	60th Street	Cedar Avenue	8	0	19008	0
23-Mar-94	61st Street	Cedar Avenue	8	0	19008	0
24-Mar-94	53rd Street	Walnut Street	6	3	14112	7056
24-Mar-94	54th Street	Walnut Street	6	3	14112	7056
24-Mar-94	59th Street	Walnut Street	5	4	11760	9408
25-Mar-94	60th Street	Walnut Street	5	2	11640	4656
25-Mar-94	62nd Street	Walnut Street	6	3	13968	6984
23-Mar-94	61st Street	Chestnut Street	6	3	14256	7128
23-Mar-94	59th Street	Chestnut Street	6	3	14256	7128
24-Mar-94	58th Street	Chestnut Street	4	5	9408	11760
24-Mar-94	53rd Street	Chestnut Street	6	3	14112	7056
		<b>Subtotal</b>	<b>90</b>	<b>29</b>	<b>213240</b>	<b>68232</b>
		<b>TOTALS</b>	<b>134</b>	<b>78</b>	<b>478368</b>	<b>329160</b>
		<b>TOTAL LED HEADS:</b>		<b>212</b>	<b>Total hrs</b>	<b>807528</b>

The factors affecting the life cycle cost of LED signals include capital costs, energy costs, signal lamping costs, signal system maintenance costs, and liability costs.

## ENERGY COSTS

The greatest potential for reduction in life cycle costs for traffic signal systems is the projected energy cost savings for LED signals vs. existing incandescent signals. For a given signal lamp, savings of 75 to 90 percent can be expected. The actual overall savings at an intersection is dependent upon the relative burn time of the LED signals vs. the remaining incandescent signals at the intersection. Theoretical reductions in power consumption and usage for the prototype signals used in this project have been verified through the PECO Laboratories test program, and through on-site measurements. These energy savings have averaged about 83% for both the 8 inch and 12 inch signals.

Table 2 is a spreadsheet which calculates projected annual energy cost savings and simple payback based on a matrix of LED capital costs and average unit energy costs. The two examples shown are based on data obtained for the 8 inch and 12 inch signals used in this program. This spreadsheet (LED-ECO.wk1) is contained in the software diskette.

## SIGNAL RELAMPING COSTS

Most traffic signal lamps are replaced on a group relamping basis, generally on a one to two year schedule. Standard traffic signal lamps are rated at about 8000 hours life (50th percentile failure point); however, 130 volt lamps burned at 120 volts have up to 22,000 hours average life (with reduced energy efficiency).

Generally, group relamping should be done at a point in the lamp failure curve where the cumulative failures and rate of failure is still relatively low. Lamp failures that occur prior to relamping, particularly red signal lamps, are extremely costly due to potential liability of burned out red signals, and the high cost of spot lamp replacement. To minimize potential liability, red burn outs, when reported, must be responded to immediately at potentially high labor cost. A properly managed lamp replacement program determines the point on the lamp failure curve that optimizes the cost of group relamping vs. spot relamping and average liability costs, thus optimizing overall costs.

The eventual development of cost-effective three color LED signals will essentially eliminate signal relamping due to lamp burn-out. There will still be a need to occasionally clean signal lenses, and to respond to some, currently unknown level

# Economic Analysis of LED Signals

**TABLE 2: LED Traffic Signal Energy Cost Savings Analysis**

**Signal Size: 8 INCH**

**LED WATTS: 12 BURN TIME (%): 55 INCANDESCENT WATTS: 60**

Average Cost (Kwh):	\$0.04	\$0.06	\$0.08	\$0.10	\$0.12	\$0.14	\$0.16
Ann. Energy Savings:	\$9.25	\$13.88	\$18.50	\$23.13	\$27.75	\$32.38	\$37.00

**SIMPLE PAYBACK ANALYSIS (Years to repay investment)**

<u>LED SIGNAL COST</u>	<u>AVERAGE COST (KWH)</u>						
	<u>\$0.04</u>	<u>\$0.06</u>	<u>\$0.08</u>	<u>\$0.10</u>	<u>\$0.12</u>	<u>\$0.14</u>	<u>\$0.16</u>
\$80.00	8.65	5.77	4.32	3.46	2.88	2.47	2.16
\$100.00	10.81	7.21	5.41	4.32	3.60	3.09	2.70
\$120.00	12.97	8.65	6.49	5.19	4.32	3.71	3.24
\$140.00	15.13	10.09	7.57	6.05	5.04	4.32	3.78
\$160.00	17.30	11.53	8.65	6.92	5.77	4.94	4.32
\$180.00	19.46	12.97	9.73	7.78	6.49	5.56	4.86
\$200.00	21.62	14.41	10.81	8.65	7.21	6.18	5.41
\$220.00	23.78	15.85	11.89	9.51	7.93	6.79	5.95
\$240.00	25.94	17.30	12.97	10.38	8.65	7.41	6.49
\$260.00	28.11	18.74	14.05	11.24	9.37	8.03	7.03
\$280.00	30.27	20.18	15.13	12.11	10.09	8.65	7.57

**Signal Size: 12 INCH**

**LED WATTS: 18 BURN TIME (%): 55 INCANDESCENT WATTS: 105**

Average Cost (Kwh):	\$0.04	\$0.06	\$0.08	\$0.10	\$0.12	\$0.14	\$0.16
Ann. Energy Savings:	\$16.77	\$25.15	\$33.53	\$41.92	\$50.30	\$58.68	\$67.07

**SIMPLE PAYBACK ANALYSIS (Years to repay investment)**

<u>LED SIGNAL COST</u>	<u>AVERAGE COST (KWH)</u>						
	<u>\$0.04</u>	<u>\$0.06</u>	<u>\$0.08</u>	<u>\$0.10</u>	<u>\$0.12</u>	<u>\$0.14</u>	<u>\$0.16</u>
\$80.00	4.77	3.18	2.39	1.91	1.59	1.36	1.19
\$100.00	5.96	3.98	2.98	2.39	1.99	1.70	1.49
\$120.00	7.16	4.77	3.58	2.86	2.39	2.04	1.79
\$140.00	8.35	5.57	4.17	3.34	2.78	2.39	2.09
\$160.00	9.54	6.36	4.77	3.82	3.18	2.73	2.39
\$180.00	10.74	7.16	5.37	4.29	3.58	3.07	2.68
\$200.00	11.93	7.95	5.96	4.77	3.98	3.41	2.98
\$220.00	13.12	8.75	6.56	5.25	4.37	3.75	3.28
\$240.00	14.31	9.54	7.16	5.73	4.77	4.09	3.58
\$260.00	15.51	10.34	7.75	6.20	5.17	4.43	3.88
\$280.00	16.70	11.13	8.35	6.68	5.57	4.77	4.17



of LED signal component failure. However, significant relamping cost savings still can be achieved by replacement of red signals only. This is due to the following factors: Most of the potential liability is related to accidents caused by the burn out of red signals. The use of red LED signals will greatly reduce or eliminate this liability. Since the group relamping interval is a function of liability reduction, it appears to be cost effective to extend the intervals between relampings when only green and yellow indications are involved. Statistically, green lamps have longer average effective life than red signals, since the 'on' time of green signals is generally less than for red signals, particularly at multi-phase intersections. A green lamp failure results in minor accident potential, and replacement of these lamps can generally be performed as part of normal daily maintenance rather than on an emergency response basis. A burned out yellow lamp results in a moderately hazardous condition, but these occurrences are theoretically rare. The life expectancy of a typical yellow lamp burning 5% of the signal cycle is over 18 years, and with a one or two year relamping schedule, the statistical probability of burn-out is very low.

Signal lamps used in Philadelphia have an average life rating of 22,000 hours but are replaced in an annual relamping program (8,760 hours). The analysis in **Table 3** assumes a scenario in which all red signals are replaced by LEDs and the annual relamping schedule is extended to two years. Signal burn time (in percent) varies and is generally higher for red signals. However, to develop conservative data, burn time is calculated at 60% for red and green signals. The data developed in Table 3 is a composite of data based on preliminary estimates, and is shown primarily to illustrate the methodology of determining relamping cost savings.

**Table 3: Comparison of Maintenance Costs**

Relamping: 1 year, all incandescent vs. 2 year, red LEDs		
<u>SIGNAL TYPE</u>	<u>INCANDESCENT</u>	<u>RED LED</u>
Relamping Cost	\$250,000	\$250,000
Relamping Interval	One Year	Two Years
Annualized Relamping Cost	<b>\$250,000</b>	<b>\$125,000</b>
Cumul. Hours To Relamping	8,760	17,520
Burn Hours @ 60%	5,256	10,512
Total Red Lamps (Incandescent)	25,000	0
Total Green Lamps (Incandescent)	25,000	25,000
Est. Cumul. Lamp Failures (%)	8%	20%
Red Failure Response Cost	\$60	\$60
Red Failures	2000	0
Red Failure Spot Cost	<b>\$120,000</b>	<b>0</b>
Green Failure Response Cost	\$60	\$40
Green Failures	2000	5000
Green Failures Spot Cost	<b>\$120,000</b>	<b>\$200,000</b>
Total Relamping Cost (per cycle)	<b>\$490,000</b>	<b>\$450,000</b>
Total Relamping Cost (per year)	<b>\$490,000</b>	<b>\$225,000</b>
Annual Relamping Cost Savings:		<b>\$265,000</b>

Based on the assumptions made in this analysis, the elimination of red lamp spot replacement, and the extension of the relamping cycle to two years would result in relamping cost savings of \$265,000 annually. This analysis illustrates one scenario; various relamping periods should be analyzed to determine the optimal scenario.

## SIGNAL SYSTEM MAINTENANCE COST SAVINGS

The complete replacement of incandescent signals with LEDs will eventually permit a redesign and downsizing of signal controllers and field wiring, with a considerable potential reduction in electrical maintenance costs. However, replacement of only red signals with LEDs still will likely result in some noticeable maintenance cost savings. Most on-going signal system maintenance costs are due to mechanical failure of load switching contacts, field wiring, relays, etc. generally due to the effects of high current switching and distribution. These failures result in emergency response calls, and in the case of circuits serving red signals, greatly increased potential liability during the period that the circuit is inoperable.

A complete retrofit of an intersection with red LED signals will result in overall load reductions and current reductions of 40% to 60%, depending on the number of phases, and head sizes. While difficult to quantify, the expected impact is a moderate extension of life expectancy for common components (power relays and common bus circuits), and a major increase in life expectancy and reliability of components on red signal circuits (load relays, triacs, and mechanical contacts).

## TORT LIABILITY REDUCTION

Tort liability at traffic signal installations is primarily brought on by failure of components of the system which result in conflicting indications or loss of restrictive indications. The failure of a red signal results in loss of the most restrictive indication, and, absent a redundant indication (another visible red signal), results in a possible conflict with other movements having green or yellow indications. The loss of the red signal can be caused by any number of factors, each of which can have potential liability mitigated in part by the impact of LED signals. These factors are:

- **Lamp burnout**—Incandescent lamps fail totally and unpredictably, at any point on the life expectancy curves, with 1 to 3 years average life expectancy. LEDs have 10+ year life expectancy and are expected to exhibit gradual or partial failure permitting replacement while still serviceable.
- **Controller/field wiring failures**—Red circuit failures occur due to catastrophic failure of components such as breakers, relays, wiring, and connectors. The likelihood of failure increases as the current on a circuit approaches or exceeds the ampacity (current rating) of the circuit. LEDs reduce current requirements, thus extending component life.
- **Power failures**—Loss of power due to reasons external to the signal control system results in all movements through an intersection being “conflicting,” with resultant potential added liability. Generally, vehicle codes require motorists to treat “all-out” traffic signals as all-way stop signs. Unfortunately,

this does not always occur, particularly at intersections with an unbalance of traffic flow. A battery backup system at intersections to provide a short period (2 to 8 hours) of normal or flashing operation would greatly reduce this liability. Existing incandescent-based systems draw too much power to feasibly provide battery back-up; however, the minimal power requirements of LED signals may make flashing battery powered operation feasible. This is discussed more fully in a later chapter.

Quantification of potential liability reduction is difficult due to the lack of available data linking signal failures to actual liability settlements. The City of Philadelphia is currently performing a study of legal settlements during recent fiscal years related to related wholly or partially to the failure of red traffic signals. The results of this study will be used to determine potential liability reduction of LED signals, which will impact life cycle costs.

## LIFE CYCLE COST ANALYSIS

The actual benefit ratio based on energy savings in any given jurisdiction will be dependent upon the following factors:

- **Capital cost of the LED signals**—This cost (currently around \$160 to \$280 per red LED signal) is likely to drop over time as development costs are amortized, and circuit board fabrication is increasingly automated. Improved LEDs and optical systems may reduce the number of LEDs required per unit, further reducing capital costs.
- **Cost of capital**—The payback period is sensitive to the current cost of money; increasing with higher interest rates. Salvage value (if any) of displaced incandescent signal hardware (red lens and reflector) is considered to be negligible, and was not used in any of the economic studies.
- **Grants and utility rebates**—State and Federal grant funding for LED signals is currently under discussion by many agencies. Utility rebates, as part of demand side management (DSM) programs, are currently available from many utilities for strategies that reduce power generation and distribution requirements of the utility. Generally, the rebate is based on kilowatts of avoided demand, but often the rebate is negotiable.
- **Local electric power costs**—Power cost impact will be directly linear for electric tariffs based on usage; however, locations having fixed facilities charges or 'blocked' energy charges will likely experience savings less than those calculated for a fixed energy usage rate.
- **Signal relamping cost reduction**, where feasible, is the net cost reduction through extension of the re-lamping period.
- **Tort liability reduction**, results from reduction in red signal and electrical component failures.

Table 4 illustrates a spread sheet used to determine life cycle costs over a 10 year projected useful life for possible values of LED unit cost and various cost savings. Input values used for illustration are based on measured or estimated values in the Philadelphia demonstration program. Input parameters are as follows:

- **Cost of money (prevailing interest rate):** 7% used in illustration

*“Tort liability reduction results from reduction in red signal and electrical component failures.”*

- **Cost Escalation:** 3% used in illustration
- **Grants/rebates per signal head:** Not applicable to this demonstration
- **Duty cycle (% on time) of signal:** 52% average value used in examples
- **LED watts:** Average values of prototype units used for examples are 12 watts for 8 inch signals; and 18 watt for 12 inch signals. This is based on an extrapolation of data obtained from the PECO Energy laboratory, adjusted for expected ambient conditions.
- **Incandescent watts:** Watts consumed for most common incandescent traffic signal lamps; lamps used in Philadelphia include 67 watt, 130 volt (60 watts actual), and 116 watt, 130 volt (105 watts actual). Other standard lamps include 135 watt and 150 watt.
- **LED Capital Costs:** this figure should represent incremental capital costs if signals are being installed as part of a general signal upgrade. In this case, incremental installation costs are negligible and LED costs may be offset slightly by avoided hardware (red lens and reflector).
- **Relamping Cost Avoidance:** \$265,000 annually from previous example used.
- **Maintenance Cost Reduction:** estimated at \$20 annually per intersection = \$50,000.
- **Liability Cost Reduction:** estimate based on avoidance of one \$100,000 tort liability settlement attributed to red signal failure every 24 months for 2,700 intersections. Based on preliminary data of actual City of Philadelphia tort settlements, this figure may be extremely conservative.

The program develops annual energy savings, annual energy cost savings, annual emission reduction, amortized annual benefit and present worth. Based on the data used, the internal rate of return (IRR) of this scenario is about 45%, indicating a discounted payback period of two to three years. Economic benefit resulting from reduced environmental pollutants is not included in this analysis. This spreadsheet (LEDLFCYC.WK1) is contained in the software diskette.

**TABLE 4: Life cycle cost analysis—Red LED signals vs. incandescent signals**

SIGNAL SIZE	Input Data	
	8 INCH	12 INCH
LED Units :	16,000	9,000
LED Unit Capital Cost * :	\$140.00	\$200.00
Rebates/grants (per unit) #	\$0.00	\$0.00
LED Watts :	12	18
Incandescent watts :	60	105
LED Total Capital Cost :	\$2,240,000	\$1,800,000
Average power cost (\$/kwh):	\$0.1141	
Prevailing interest rate:	7	
Annual Cost escalation:	3	
Capital reduct.(Rebate/Grant) #:	0	
Annual relamping cost reduction:	\$265,000	
Annual maintenance cost reduct:	\$50,000	
Annual maintenance cost reduct:	\$50,000	
Net capital cost:	\$4,040,000	

\*- use only incremental cost of LED signal if part of signal replacement program  
 #- Enter either unit or lump sum rebate/ grant amounts, not both.

	Environmental impact calculated data		
	8 INCH	12 INCH	TOTAL
LED Annual kwh avoided	3,700,224	3,772,494	7,472,718
LED Ann. Power Cost savings	\$422,196	\$430,442	\$852,637
LED Annual CO2 avoided (tons)	2,960.18	3,018.00	5,978.17
LED Annual SO2 avoided (tons)	34.13	34.80	68.94
LED Annual NOX avoided (tons)	10.82	11.03	21.86

	Life cycle analysis (LED vs. incandescent signals)				
	YEAR				
	1	2	3	4	5
Net Capital cost					
Amortised capital cost	(\$575,205)	(\$575,205)	(\$575,205)	(\$575,205)	(\$575,205)
Annual energy cost reduction:	\$852,637	\$878,216	\$904,563	\$931,700	\$959,651
Annual relamping cost reduct.	\$265,000	\$272,950	\$281,139	\$289,573	\$298,260
Annual maint. cost reduct:	\$50,000	\$51,500	\$53,045	\$54,636	\$56,275
Annual liability cost reduction:	\$50,000	\$51,500	\$53,045	\$54,636	\$56,275
Total Annual Benefit :	(\$2,822,363)	\$1,254,166	\$1,291,791	\$1,330,545	\$1,370,461
Amortized Annual Benefit:	\$642,432	\$678,961	\$716,586	\$755,340	\$795,256
Total Life Benefit	<b>\$8,206,794</b>				
Present worth (annual)	(\$2,822,363)	\$1,172,118	\$1,128,300	\$1,086,121	\$1,045,518
Present worth (cumulative)	(\$2,822,363)	(\$1,650,245)	(\$521,944)	\$564,177	\$1,609,695
<b>Present Worth TOTAL</b>	<b>\$6,279,430</b>				
Internal rate of return (IRR)	<b>0.4545</b>				

Table 4 (cont.)

	YEAR				
	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
Net Capital cost					
Amortised capital cost	(\$575,205)	(\$575,205)	(\$575,205)	(\$575,205)	(\$575,205)
Annual energy cost reduction:	\$988,440	\$1,018,093	\$1,048,636	\$1,080,095	\$1,112,498
Annual relamping cost reduct.	\$307,208	\$316,424	\$325,917	\$335,694	\$345,765
Annual maint. cost reduct:	\$57,964	\$59,703	\$61,494	\$63,339	\$65,239
Annual liability cost reduction:	\$57,964	\$59,703	\$61,494	\$63,339	\$65,239
Total Annual Benefit :	\$1,411,575	\$1,453,922	\$1,497,540	\$1,542,466	\$1,588,740
Amortized Annual Benefit:	\$836,370	\$878,717	\$922,335	\$967,261	\$1,013,535
Present worth (annual)	\$1,006,434	\$968,810	\$932,593	\$897,729	\$864,169
Present worth (cumulative)	\$2,616,129	\$3,584,938	\$4,517,531	\$5,415,261	\$6,279,430

The project consisted of the following major tasks:

1. Monitoring signal performance (burn-outs, string failures, knock downs, etc.)
2. Laboratory testing of relative electrical and optical characteristics of LED vs. incandescent signals
3. Field study of power consumption of LED signal installation under actual operating conditions.
4. Lay observation study of visual impact of LED vs. incandescent signals.
5. Development of spreadsheet software to accurately predict power savings accrued under LED retrofits, and to determine accurate billing data for unmetered traffic signals.

### TASK 1: PERFORMANCE MONITORING

The monitoring period (through 6/30/94) encompasses a total of 807,528 cumulative hours of actual LED signals in service as follows:

**Prototype intersection 17th & Arch St.:** 6 signals, 116,922 hours

**Phase 1 intersections:** 93 signals, 526,056 hours

**Phase 2 intersections:** 119 signals, 281,427 hours

### Findings

Through the study period there were four recorded failures of red LED signals in operation. The first recorded failure occurred in November 1993 at the intersection of 9th and Race Street. The signal was removed and sent to PECO Laboratories for evaluation. It was determined that the design of the unit caused an external bridge rectifier to fail since it was located "upstream" or in advance of a surge protection circuit. An apparent voltage surge caused a grounding condition which destroyed the bridge rectifier. This problem was quickly corrected through a redesign of the surge protector/rectifier circuit. Retrofit surge protectors were provided by Electro-Tech's for installation at the field terminals in the signal controller box. Unfortunately, before the City had an opportunity to install these devices, three additional signals failed for apparently the same reason. In all cases, the LED signals were intact and undamaged; only the external rectifier circuit failed. Installation of the additional upstream surge protectors in previously installed units, and the redesigned rectifier-surge protection circuitry in the new units is expected to eliminate this problem.

To date, there have been no observed failures of the LED arrays in the installed signals, or of series "strings" within the LED arrays. Each 8 inch signal has 5

strings of 85 LEDs, and each 12 inch signal has 7 strings of 85 LEDs each. Since the individual LEDs are arranged in a series circuit, the failure of a single LED results in all the LEDs in that string going dark.

While we have had no opportunity to observe the visual impact of a string failure, the impact of such an event can be easily minimized. By arranging each LED within a string in a uniformly distributed pattern across the face of the signal (interlacing the strings), string failures would be less noticeable. An additional option would be to interlace strings and slightly over-design the signal such that a single string failure would continue to maintain design lumen output. This may significantly increase serviceable life expectancy of the signal.

Performance monitoring of all LED intersections will continue on an on-going basis beyond the study period to maximize statistical validity of the data.

## TASK 2: LABORATORY PERFORMANCE EVALUATION

Comparative tests were performed on each type of LED signal and its incandescent equivalent. This testing was performed at PECO Energy's Corporate Laboratories in Valley Forge, PA. The purpose of these tests was to determine the electrical and relative optical characteristics of both LEDs and standard traffic signal lamps under varying voltage and ambient temperature conditions. These tests were conducted between November 1993 to January 1994.

The test protocol was primarily designed to demonstrate the relative performance of both types of signal displays over varying temperature and voltage ranges. The incandescent optical measurements were made without any reflector or lens system in place; therefore, no conclusions can be drawn from this test regarding the light output of incandescent optical systems vs. LED signals.

A sample of each type of signal display was provided to PECO for testing. This included 8 inch and 12 inch LED displays and 116 watt and 67 watt incandescent traffic signals (12 inch and 8 inch signal lamps). An environmental test chamber was constructed by PECO laboratory personnel to provide a controlled environment for optical and electrical measurements. A total of 60 observations were taken for each permutation of the following conditions:

**Voltage:** Lower than nominal, nominal, and higher than nominal (90 volts to 130 volts in 10 volt increments)

**Temperature:** based on projected operating limits (-10°F, Ambient 64°F, and 120°F)

**Lamp type:** 12 inch LED, 8 inch LED, 67 watt incandescent, 116 watt incandescent

### Findings

The test results indicated that LED signals exhibit a high sensitivity to changes in light output and power consumed for small changes in operating voltage. As a result of this observation, additional tests were conducted for smaller increments (2 volts) of voltage variance between 110 volts and 130 volts.

The results of this testing program is shown in **Appendix A**.

## TASK 3: POWER CONSUMPTION FIELD MEASUREMENTS

All of Philadelphia's traffic signal installations are unmetered, and electric power billing is calculated based on power consumption ratings of signal lamps and other components. In order to verify actual power savings, a field metering analysis was performed. This task involved the installation of a kilowatt-hour meter at a signalized intersection having all red LED signal displays. The intersection selected at 54th and Walnut Streets uses three 12 inch signal heads and nine 8 inch signal heads. The meter was installed and readings recorded on 5/24/94, and cumulative readings taken on 6/23/94.

### Findings

Theoretical power consumed at this intersection is shown in **Table 5**. LED power consumption is based on the results of data obtained from the PECO Energy test report, based on the average ambient temperature range, and measured voltage. Power consumption for incandescent signals is based on manufacturer's design wattage and voltage ratings multiplied by a factor of 0.875, which represents the wattage reduction for 130 volt rated lamps burned at 119 volts measured. The figures in the right column is the theoretical power consumption for the previous (all incandescent) condition:

**TABLE 5: Calculated Power Consumption — 54th & Walnut Sts.**

QTY.	SIGNAL TYPE	BEFORE (ALL INCANDESCENT)			AFTER (RED LEDs)	
		DUTY CYCLE	LAMP WATTS	TOTAL WATTS	LAMP WATTS	TOTAL WATTS
3	12" red incand.	0.38	101.5	115.71	0.0	0.00
3	12" red LED	0.38	0.0	0.00	18.0	20.52
2	8" red incand.	0.38	58.5	44.46	0.0	0.00
2	8" red LED	0.38	0.0	0.00	12.0	9.12
3	12" green incand.	0.57	101.5	173.57	101.5	173.57
2	8" green incand.	0.57	58.5	66.69	58.5	66.69
3	12" yellow incand	0.05	101.5	15.23	101.5	15.23
2	8" yellow incand.	0.05	58.5	5.85	58.5	5.85
4	8" red incand.	0.68	58.5	159.12	0.0	0.00
4	8" red LED	0.68	0.0	0.00	12.0	32.64
4	8" green incand.	0.27	58.5	63.18	58.5	63.18
4	8" yellow incand.	0.05	58.5	11.70	58.5	11.70
1	controller			6.00		6.00
<b>TOTALS:</b>				<b>661.51</b>	<b>404.50</b>	

\*note: unit watts shown based on estimated consumption at average 119 volts.

The test period encompassed 30 days x 24 hours = 720 hours. The signal phasing and timing is in effect 24 hours daily, and no lamp burn-outs were reported during that period. Total theoretical power consumed during this period is then: 720 hours x 404.49 watts (a 257.01 watt savings over the incandescent lamps) = 291.23 kwh.

Actual metered usage for this period was as follows:

**Initial reading:** 5/24/94 12:10 PM: 3,871 kwh

**Progress reading:** 6/23/94 12:07 PM: 4,158 kwh

**Power consumed for period:** 287 kwh.

Due to time constraints, only a single reading at one intersection is available for this study to compare theoretical vs. actual power consumption. However, a variation in these values of only 1.4% provides some confidence in the methodology. Additional metering equipment is being obtained. Additional metering periods and locations will provide a statistically significant sample of metered usage during the balance of 1994 at LED and all incandescent control intersections.

The theoretical calculations for this intersection show a reduction in average load from 661.5 watts to 404.49 watts. This represents a 38.9% reduction in load, power consumed, and power costs at this intersection by replacement of all of the red signals with LEDs. In this case theoretical power cost savings are:

.257 kw saved x 8,760 hrs/yr. x \$.1141/kwh = \$256.88 annual savings

## TASK 5: DRIVER'S OBSERVATIONAL STUDY

One of the concerns regarding LED signals was the visual impact that these signals would have on motorists, and the relative appearance and performance of the LED vs. incandescent signals in actual service. To address this issue, a study program was developed to allow blind comparisons of the visual impact of red LEDs and red incandescent signals randomly interspersed on a fixed route.

This study provides observational trends using relatively small sample sizes. The small sample size is offset somewhat by developing 95% confidence intervals, then comparing low limit "worst case" data for LED signals with high limit "best case" data for incandescent signals.

A "blind" study methodology was chosen. A fixed route, five miles in length and encompassing 33 signalized intersections was selected. This route, located in West Philadelphia includes 22 intersections on a one-way arterial pair (PA. State Route 3- Chestnut and Walnut Streets), and 11 intersections on a parallel two way collector street (Cedar Avenue). The one way arterial street was selected to expedite the data collection process. It was felt that the one way traffic signal progression would enable drivers to proceed through the route at normal traffic speed, observing the red signal when approaching an intersection prior to it "dropping" to green. In theory this would force an instantaneous, and hence unbiased observation of the red signals. Approximately half of the intersections had red LED signals, the remaining intersections had all incandescent signals. The distribution of LED and incandescent signals was random.

Volunteers were not specifically told that they would be observing LED signals; rather they were told that the study involved a “new type of traffic signal.” The volunteers were requested to conduct the studies in groups of two, traversing the route twice. On one trip, one person would drive and make observations; the second person would record the observations. On the second trip, the roles would be reversed. The explanation forms and data observation forms used by the volunteers are shown in **Appendix B**.

The observations were based on two parameters: light intensity and color (chromaticity). Observers were asked to compare a red traffic signal with their normal perception of a red traffic signal. In terms of brightness, did the signal appear less bright (dimmer), normal, or brighter? In terms of color, did the red color appear darker, normal, or lighter? A review of the actual samples obtained indicated that most of the observers had no difficulty in distinguishing differences in relative brightness between signals, but the observations for signal color were very erratic.

The analysis of the data was based on a weighting system. Each of the two factors (brightness and color) was assigned an integer value for each of the three choices. For brightness, values of 0, 1, and 2 were assigned to observations of “dimmer”, “normal”, and “brighter” respectively. For color, the values 0, 1, and 2 were assigned to readings “darker,” “normal,” and “lighter.” A spreadsheet was developed for the purpose of data entry and analysis. A two dimensional data entry format was used for each of the two factors, with the 30 intersections on one axis, and the 24 observations on the other. In each data entry cell the value 0, 1, or 2 was entered based on the recorded observation. For each intersection, the mean, standard deviation, and 95% confidence interval was calculated. A summary of test results is shown in **Table 6**. Actual survey forms, survey instructions and survey data are shown in **Appendix B**.

## Findings

The results of this study compare red incandescent traffic signals currently in use in the City of Philadelphia with one specific type of LED signal. The City currently uses 116 watt, 130 volt lamps for 12 inch signals, and 67 watt 130 volt lamps for 8 inch signals. A relatively small sample size was used, and no controls were placed upon demographic and environmental conditions. Observations were made on recently installed LED signals, and incandescent signals at various points in the annual relamping cycle. Any inferences drawn from this study should reflect these conditions.

**Brightness**—Values higher than 1 indicate signals perceived overall to be brighter than normal; values less than 1 indicate dimmer than normal signals. Average readings for incandescent signals at 19 intersections range from .63 to 1.33 with an overall average of 1.00. Average brightness readings for LED signals at 14 intersections range from 1.71 to 1.96 with an overall average of 1.85. The results of this analysis indicate a significant perceived increase in brightness of the LED signals vs. the incandescent signals.

To offset the effects of the small sample size, a worst case comparison can be made. This compares the upper limit of the confidence interval for the incandescent signals (the best possible condition within the 95% probability range) to the lower limit of the confidence interval for the LED observations. Under these conditions,

*“Most of the observers had no difficulty in distinguishing differences in relative brightness between signals. . .”*

*“Motorists perceive this type of LED traffic signal to be significantly brighter than standard incandescent signals.”*

the average value for the LED observations (1.67) exceeds the average value for the incandescent observations (1.29) by 1.67 or 29.6%. The results of this analysis are shown in **Table 6** individually for eight inch and twelve inch signals, and as a composite of both.

These results indicate that under the conditions stated, even with statistical data biased in favor of incandescent signals, motorists perceive this type of LED traffic signal to be significantly brighter than standard incandescent signals.

**Color**—The results of this portion of the study are somewhat inconclusive. It is evident from a review of the data, and by interviewing some of the volunteer drivers, that many observers were unable to perceive color differences, or did not understand the intent of this observation.

The purpose of this portion of the study was to determine if observers perceived any noticeable difference in chromicity of the LED signals at a dominant wavelength of 644 nanometers vs. standard signals, which should be in the range of 615 to 620 nanometers. In retrospect this phase of the study probably asked too much of the observers, who were expected to instantly compare the “redness” of a signal as compared to their memory of the color of a normal traffic signal. The data results were erratic, with no clear trends, even within a signal type. The terms “darker” and “lighter” used to describe the color of the signals were probably not appropriate for this study, and, judging from the results obtained may have been interpreted as “brighter” or “dimmer.” Future studies of this type may be more effective by having the observer view a static side-by-side display of various signal types, and make observations of color differences on this basis.

**Table 6** provides a summary of the observational data.

## Conclusions

The results of the brightness study clearly indicate that the volunteer motorists perceived newly installed red LED signals to be significantly brighter than the existing red incandescent signals along this route. By comparing the low limit (worst case) of the 95% confidence interval for the LED signals to the high 95% C.I. limit (best case) of the incandescent signals, the impact of small sample size was mitigated.

No conclusions can be drawn from the color study, as evidenced by erratic data and no significant difference (2.9% overall) between observations.

A compilation of actual sample data is shown in **Appendix B**.

## TASK 6: POWER CALCULATION SOFTWARE DEVELOPMENT

**A**s mentioned previously, none of the signalized intersections in the City of Philadelphia are metered. Billing for traffic signal installations is based on calculated power consumption. Previously, this calculation was simplistic, since all lamps within a signal head were of the same wattage, and the power consumed for each head was assumed to be analogous to a single lamp burning

**TABLE 6: West Philadelphia Observational Study**

Results Summary					
	<u>8" MEAN</u>	<u>12" MEAN</u>	<u>MIN. MEAN (C.I. = .95)</u>	<u>MAX. MEAN (C.I. = .95)</u>	<u>OVERALL MEAN</u>
<b>Brightness:</b>					
LED	1.833874	1.856481	1.675197		1.848407
Incan.	1.152778	0.937088		1.292659	1.005201
<b>Color:</b>					
LED	1.490847	1.443556	1.158134		1.460445
Incan.	0.946479	0.876803		1.185815	0.898806

**"Worst case" data comparison****Brightness Data**

	<u>INCANDESCENT (C.I. UPPER)</u>	<u>LED SIGNAL (C.I. LOWER)</u>	<u>DIFFERENCE (SCORING)</u>	<u>DIFFERENCE (PERCENT)</u>
8 inch signal	1.239	1.382	.1429	11.5 %
12 inch signals	1.135	1.516	.3809	33.6 %
All signals	1.293	1.675	.3823	29.6 %

**"Worst case" data comparison****Color Data**

	<u>INCANDESCENT (C.I. UPPER)</u>	<u>LED SIGNAL (C.I. LOWER)</u>	<u>DIFFERENCE (SCORING)</u>	<u>DIFFERENCE (PERCENT)</u>
8 inch signals	1.047	0.992	-.06	5.5%
12 inch signals	1.086	1.019	-.07	6.6 %
All signals	1.186	1.153	-.03	2.9 %

continuously. However, when various wattage lamps are interspersed in a single head, this method cannot be used. In this case, the calculation, to be accurate, must reflect the burn time (in percent), and wattage of each lamp within the signal head.

In order to develop accurate performance evaluation, and provide a basis for accurate billing, a program was developed in LOTUS 1-2-3 format, which calculates power data based on lamp configuration and signal timing data. This program "Sigcalc" is illustrated in the sample screens reproduced in Appendix C. The program is currently undergoing Beta testing by various agencies, including the Pennsylvania Department of Transportation, City of Phoenix, and PECO Energy Co.

The program has been used to calculate the energy demand and usage reduction, and energy cost savings of the 27 LED installations in the City of Philadelphia. This was accomplished by entering data for each intersection first based on the previous all incandescent condition, then based on installation of LED signals. The difference between the total energy costs for these two calculations represents the energy costs savings which are currently accruing.

The program (labeled SIGCALC.WK1) is contained in the enclosed software diskette. A text version of the program manual (labeled SIGCALC.TXT) is also contained on the diskette.



The demonstration program at 27 intersections in Philadelphia identified a number of factors which should be taken into account when designing or specifying red LED traffic signals

## LIGHT OUTPUT OVER VARYING VOLTAGES:

The study performed by PECO Laboratories indicated a very high sensitivity of the performance of the LED signals to variations in input voltage. For example, in the PECO study, when voltage was reduced from a nominal 120 volts to 114 volts at ambient temperature (a 5% reduction), power consumed was reduced by 39% and light output was reduced by 46.2%. The prototype signals have zero light output below 90 volts.

This wide variation in power consumed and light output over small voltage fluctuations for this type of LED signal produces several potential concerns:

- Power consumption cannot be accurately estimated for unmetered installations with significant voltage fluctuations.
- Light output could drop below required levels under low or fluctuating voltage conditions, such as during summer peaks.
- LED signals exhibit “flicker” due to momentary voltage fluctuations caused by normal load switching.

While these conditions have not caused any observed problems to date at the Philadelphia installations, they are of concern and need to be addressed in future designs. Electro-Tech’s has addressed this problem through the addition of voltage maintenance circuitry. Under this scheme, a device on the LED circuit board samples the incoming voltage, then steps it up or down as required to maintain the optimal voltage to the individual LEDs. The cost of this additional circuit is minimal. The problem can also be addressed by reducing the number of LEDs in a series string, and increasing the number of strings.

## LONG TERM LED BRIGHTNESS DEGRADATION

The second factor affecting the future viability of LED signals is the issue of light degradation over time of the new generation of AlGaAs LEDs, particularly at elevated operating temperatures. This generation of LEDs is the current standard for traffic signal displays, but have insufficient hours in actual operation to determine their long term characteristics. Elevated operating temperature, such as would occur in signals facing direct sunlight for long periods, may accelerate light degradation.

Studies to evaluate this situation are currently being conducted by the National

## Other Considerations

Cooperative Highway Research Program (NCHRP), and by the California Department of Transportation (CalTran). The NCHRP study is part of a 30 month program commissioned by NCHRP (Project 5-12) to evaluate LED signal technology and recommend changes to existing standards for signalized traffic control. One component of this program involves an evaluation of light output of LED signals over time under varying conditions. This study is being performed by LSI Laboratories of Scottsdale, AZ. The final report for this project, including the LSI Laboratories evaluation, is expected to be released in the Fall of 1994.

CalTran is currently evaluating over 2,000 red LED signals installed in that agencies District 6 region, including Fresno, Davis, and Fairfield, CA. As part of this evaluation, CalTran is recording detailed brightness data at six month intervals on a controlled sample of AlGaAs LEDs. This study began in October, 1993 and a six month evaluation was conducted in April, 1994. The six month data indicates a 25% drop in light output over original measurements; however, professional observers were unable to perceive any difference in a side-by-side comparison of new LEDs vs. those in service over six months.

New LED products currently under development tentatively show promise for improved and more predictable light output maintenance over time. However, any problems due to light degradation can likely be mitigated in either of two methods, either of which will result in a minor increase in capital or maintenance costs:

- Over-design the signals to allow for light degradation over time. For example if projected data indicates a 40% reduction in light output at the design life expectancy of 10 years, specify initial light output at 40% in excess of current requirements.
- Increase input current over time in proportion to light degradation, thus maintaining light output level. This could be accomplished by electronic timing circuits which gradually increase power over time, or through occasional (every 3 to 5 years) manual modifications to the signal.

Both of these methods have limitations, however. The required end-of-life brightness, and the allowable maximum initial brightness may severely limit useful life, particularly if brightness degradation is greater than anticipated. Increasing current to maintain brightness over time will be somewhat self-limiting, since this will increase internal heat and power consumed, and accelerate degradation.

## STANDARDS COMPLIANCE

As mentioned above, the study being conducted by NCHRP will evaluate compliance of LED signals with existing standards and recommended changes to the standards based on the results of the study. Standards for traffic signals are established by the Institute of Transportation Engineers based on criteria established for incandescent signals during the 1930's. Many professionals feel that these standards are obsolete and unrealistic when applied to LED technology. Preliminary data indicates that the signals used in this demonstration either meet I.T.E. specifications for incandescent signals, or can do so with minor modifications. However, a revision of the standards to reflect the characteristics and subjective performance of LED signals appears to be

warranted and will result in the availability of a more cost effective product. It is felt that adherence to the I.T.E. incandescent standards will result in a less than optimal design criteria for LED signals, resulting in higher costs, and reduced rate of return.

## FUTURE DEVELOPMENT OF LED SIGNALS

This project has tentatively demonstrated that red LED signals are feasible, cost effective, and tentatively acceptable to the transportation industry and the general public in most applications. These devices will either be marginally acceptable or will achieve their full potential by significantly reducing the cost of traffic signal operations and providing significant environmental benefits. These divergent possibilities will depend on two currently uncertain factors:

- Will a viable, cost effective green LED signal be developed in the foreseeable future?
- Will LED signals provide acceptable performance in all environmental conditions for a significant time period beyond the initial payback period?

The first issue, green LEDs, is not so much an issue of viability as it is a dilemma involving investment in diverging technologies. Most observers within the industry anticipate the development of improved, low cost green LEDs within the near future. The development of the green LED does not just add an additional color to the LED palette, but has the potential to enable a complete revolution in traffic signal technology. Since red and yellow displays are currently feasible, development of a viable green LED signal eliminates the need for incandescent displays and support hardware. Traffic signal heads can then be redesigned to house a significantly lighter, slimmer profile signal head. Support structures, such as foundations, poles, mast arms, span wire, etc. can be similarly downsized to reflect the lighter display units. The three colors could be mounted on a single circuit board with common control circuits for voltage regulation, night dimming, etc. This should significantly reduce capital costs over individual color displays. Signal relamping will be essentially eliminated, except for occasional lens cleaning. The up-to-90% average reduction in power consumption will permit several design efficiencies in the control and power distribution systems:

- Low voltage can be used between the controller and the signal head, resulting in significant safety and tort liability improvement. The use of 24 volt field circuits with an 80% power reduction results in approximately the same current (in amperes) as existing 120 volt incandescent circuits, therefore permitting the use of existing cable.
- Intersection controllers can be significantly downsized, with all low voltage components, and reduced wear on power switching components.
- Battery back-up of signal operations during power outages is feasible due to reduced power requirements. A 24 volt, 10 ampere-hour battery will power full operation of a 12 head intersection with 12 inch signals for about one hour. Flashing operation would be supported for two hours.
- Photovoltaic (solar powered) battery operation at remote locations may be feasible.

*“The development of the green LED . . . has the potential to enable a complete revolution in traffic signal technology.”*

A comparison of the potential advantages and disadvantages of red LED retrofit units vs. three color retrofit vs. completely redesigned three color LED units is shown in the chart below. Data shown is based on 12 inch signal heads.

<u>FACTOR</u>	<u>RED LED</u>	<u>3 COLOR LED RETROFIT</u>	<u>SYSTEM REDESIGN</u>
Capital cost (per head)	\$180-\$260	\$500-750	\$400-600
Energy savings per head	\$35 to 50	\$75-105	\$80-\$110
Relamping cost reduction	Moderate	Major	Major
Electrical Maint. cost reduct.	Moderate	Major	Major
Liability cost reduction	Moderate	Major	Major
Low voltage field wiring	No	No	Yes
Battery back up	No	w./inverter	Yes
Solar power	No	No	Yes

The choices facing agencies considering major investment in LED signals are these:

- Install red LED retrofit signals in existing signal housings, achieving immediate but less than optimal energy, maintenance, and liability cost savings. Additionally, run the risk of obsolescence if green LEDs become economically feasible in near future.
- Wait for development of cost effective green LEDs (uncertain at this time) to achieve full potential benefits, but lose opportunity for immediate benefit of red LEDs.

Depending on such factors as the capital costs of LED signals, cost of electric power, existing maintenance costs, and prevailing interest rates, it is highly probable that the existing generation of LED signals will provide a 2 to 5 year return on investment. The development of cost effective green LEDs appear to be at least two or more years in the future based on the most optimistic estimates, and a redesign of signal hardware to maximize the benefit of all-color LED displays would likely take several additional years. It is also possible that red LED retrofit units would have considerable salvage value after 3 to 5 years, based on projected useful life of over 10 years.

An additional option would be to utilize red LEDs at this time, purchase green LEDs when they become economically feasible, and continue to use incandescent yellow signals. This would avoid the poor incremental benefit/cost ratio of yellow LEDs, but would preclude the potential benefits of full system redesign.

Based on these factors, investment in red LED retrofit hardware appears to be a good investment at this time.

## ELECTRICAL AND OPTICAL PERFORMANCE

**T**he performance of the LED signals was determined through three sources: the PECO Energy test program, field power measurements, and extrapolation of manufacturer's data. The data developed indicated that:

- Based on a composite of observations at rated optimal voltage (120v.) and ambient temperature, power consumed for the type of LED signal used in this program is nominally 12 watts for 8 inch signals, and 18 watts for 12 inch signals, representing power savings of approximately 83% respectively over incandescent signals. These figures are estimated averages and vary considerably with minor changes in voltage and temperature.
- Power consumption and light output of these LED signals varied moderately with temperature, achieving higher efficiency at lower temperatures.
- For this type of LED signal design, power consumed and light output is extremely sensitive to variations in rated input voltage. A five volt differential was observed to double or halve the power consumption and light output. This problem appears to be correctable through a re-design of the series circuit/resistance configuration, or through the use of voltage maintenance circuitry.
- In subjective observations by lay drivers and transportation professionals, light output of newly installed LED signals was deemed superior to incandescent signals currently used in Philadelphia.

## ECONOMIC VIABILITY

The cost-effectiveness of LED signals is a function of the capital and costs of the signals vs. the benefits derived. Benefits include:

- Electric power cost savings
- Environmental impact of power reduction
- Maintenance cost savings (including relamping)
- Tort liability reduction

Capital costs can be reduced by utility rebates and grant programs. Average unit cost of LED signals is likely to decrease through improvements in LED efficiency and improvements in manufacturing processes. The actual rate of return for a red LED traffic signal will likely vary widely between jurisdictions, due to variations in electric power costs, available rebates and incentives, signal unit costs, current maintenance practices, and other factors. However, based on current economics of this technology, internal rates of return of 25 to 50% should be expected for most applications.

## Summary of Findings and Conclusions

## OUTSTANDING ISSUES

Issues affecting the long term viability of LED signals include:

- Degradation of brightness over time. This is currently being evaluated through other research programs.
- Development of viable green LED signal, with possible impact on overall design of traffic signal systems.
- Compliance of LED signals with standards for traffic signal displays, in particular I.T.E. traffic signal standards.

Significant activities of other agencies including National Highway Transportation Research Board and the California Department of Transportation (CALTRANS) should also be evaluated.

## FUTURE PROGRAMS

The City of Philadelphia is committed to the continued development and use of LED traffic signs as an energy and environmental conservation initiative. The City is currently developing funding sources leading to the installation of red LED signals at over 2700 traffic signal installations. Additionally, the development of green LED signals will be monitored and evaluated on a continuing basis. The City of Philadelphia, with grant funding as part of the UCETF 1995 program, has initiated a program for the development of standard specifications for LED traffic signals. This program will review current development of this technology, including prototype products of four or more manufacturers. This evaluation will consist of "in-service" field tests, and laboratory evaluation of the signals, including accelerated brightness degradation tests. Results of this program should be available in late 1995.

## CONCLUSION

This program demonstrated the viability of red LED traffic signals as means of energy use avoidance with associated environmental benefits, and as a cost effective alternative to standard incandescent traffic signals. The cost effectiveness of these devices, however, is contingent on a number of factors, which can vary significantly between various applications. Life cycle costing of a given application should be performed to determine economic viability.

Regarding existing standards for traffic signal displays, the most prudent approach at this time appears to be a policy of designing red LED signals to comply with these standards. Due to the potential of tort liability, the process of modifying the standards is complex, involving considerable documentation and testing, and the interaction of several agencies. The successful performance over time of a significant population of LED signals vis-à-vis incandescent signals may accelerate a change in current I.T.E. standards.

Current unresolved performance issues, in particular long term brightness degradation should be considered prior to any major investment in this technology. A conservative approach of over-designing the LED signals to allow for a worst case reduction in brightness may be warranted; however, this will increase capital costs.

It is expected that continued development of light emitting diodes for traffic signal use will resolve all of the current performance related issues, will reduce the capital cost of these devices, and will eventually result in the development of viable three color signal display systems.



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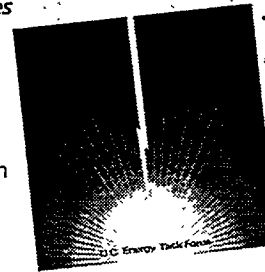
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## ABOUT THESE PUBLICATIONS

These publications were produced through research conducted by the Urban Consortium Energy Task Force (UCETF) of Public

Technology, Inc. Many of the research projects were funded through a grant from the U.S. Department of Energy.

The task force was established to address critical energy needs of urban America. The UCETF acts as a laboratory to develop and test solutions and share the resulting products or management approaches with the wider audience of both large and small local governments, states, and local authorities around the world.

UCETF membership includes elected officials, management, and technical professionals from urban cities and counties. It links through the Urban Consortium and PTI to national organizations, such as the National Association of State Energy Officials (NASEO), the National League of Cities, the National Association of Counties, and the International City/County Management Association to ensure the widespread exchange of information and technology.

For more information about the Urban Consortium Energy Task Force (UCETF) or these guidebooks, contact Jack Werner, PTI Business Director, at 202/626-2421.

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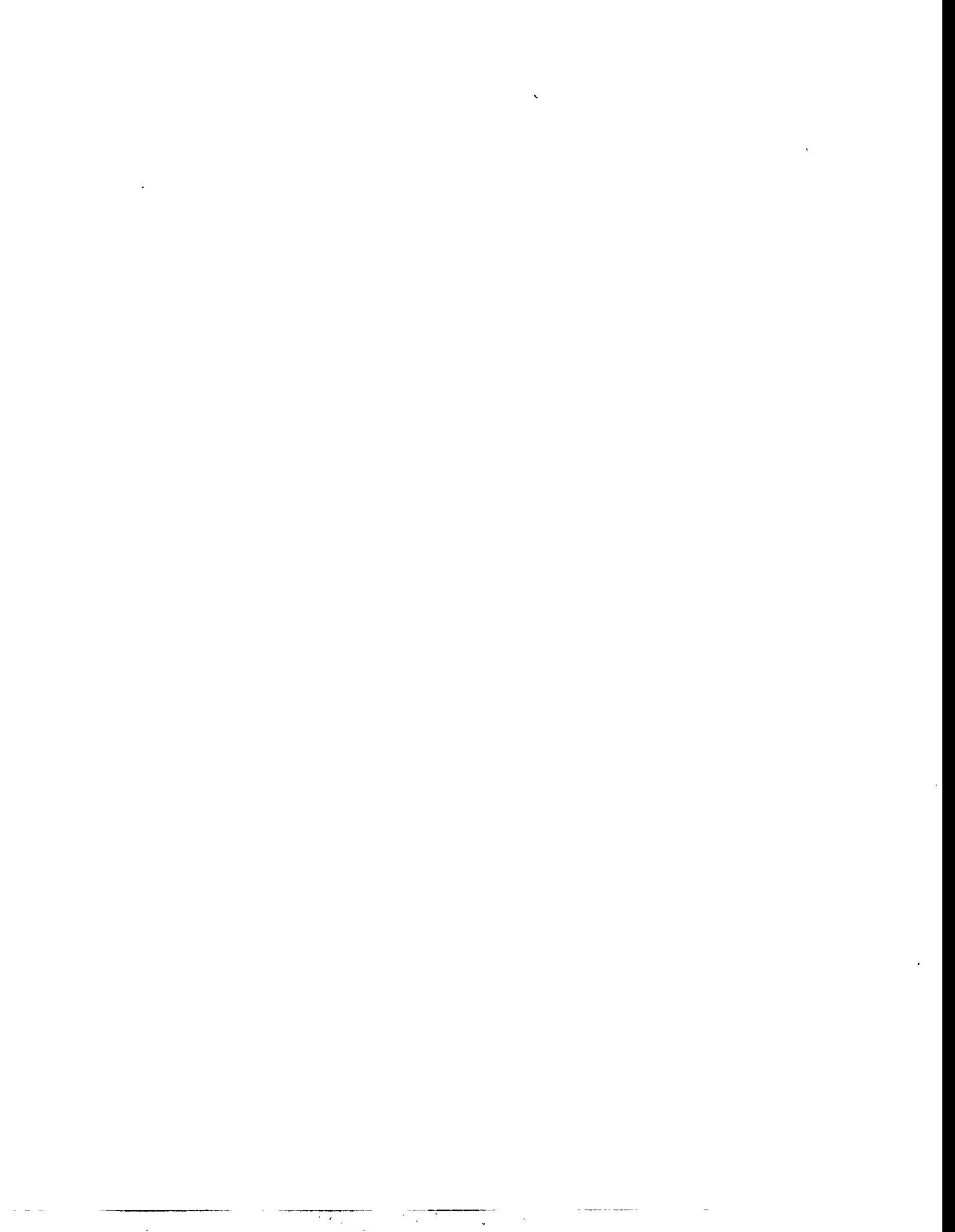
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- Save Money

*The Urban Consortium Energy Task Force of Public Technology, Inc. is chaired by Mike Lindberg, Commissioner, City of Portland, Oregon.*

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## **REPORT AND INFORMATION SOURCES**

Additional copies of this report,

### **LIGHT EMITTING DIODES FOR TRAFFIC SIGNAL DISPLAYS**

as well as reports from other cities, are available from:

**PTI Publications Center  
Tel: 301/490-2188  
Fax: 301/604-0158**

For additional information on the process and the results of the work described in this report or for information on the overall energy management programs in Philadelphia, please contact:

**City of Philadelphia  
Municipal Energy Office  
Judith L. Mondre, Executive Director  
1401 JFK Blvd., Suite 600  
Philadelphia, PA**

**Phone: (215) 686-3904  
Fax: (215) 686-3907**

**Order No: DG/93-312**



# TRAFCALC PROGRAM MANUAL

TRAFCALC -  
Traffic Signal  
Energy Calculation Program

Beta test Version 1.0

Developed by  
City of Philadelphia  
Municipal Energy Office

in cooperation with  
Public Technology Inc.  
Urban Consortium Energy Task Force  
May 1994

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## BACKGROUND

This software product was developed by the City of Philadelphia Municipal Energy Office as part of the "LED Traffic Signal" demonstration project. This project was funded through a grant from Public Technology, Inc., and the Urban Consortium Energy Task Force. The purpose of this project is to demonstrate the feasibility of using light emitting diodes (LED's) for traffic signal displays, as a means of reducing costs associated with energy consumption, maintenance, and liability.

The primary purpose of TRAFCALC is to calculate energy cost savings through the use of LED signals. However, this program can also be used as a means of developing billing data for unmetered traffic signals, as a means of assessing the impact of using various signal lamp types, assessing the energy cost impact of changes to traffic signal systems, or as a verification of metered billing.

## DESCRIPTION

"TRAFCALC" is a spreadsheet developed in "LOTUS 1-2-3" format. The file is a .wk4 version but can be easily translated to or from other versions of 1-2-3 or other compatible spreadsheet programs.

## GETTING STARTED

"TRAFCALC" is started by entering your LOTUS 1-2-3 or compatible spreadsheet program, then loading the file "trafcalc.wk4". "TRAFCALC" calculates the average electrical demand (in kW.) and electrical consumption (in kwh.) for each intersection on a monthly and annual basis. The program also calculates actual monthly electric costs when billing is based solely on consumption. The program can be easily modified to calculate electrical costs based on other factors such as peak demand and facilities costs. The program is designed primarily for fixed time traffic signal installations, but can be adapted for use on traffic actuated flexible timing systems.

The following types of traffic signal operations are supported in "TRAFCALC":

Multiple signal head and lamp types on individual signal heads

Flashing signal intervals

Leading/lagging green intervals

Multiple daily timing programs

Simultaneous lamps lit on one head

Unlimited number of phases/intervals.

The maximum number of intersections that can be entered is dependent upon the memory constraints of your computer system. A minimum of 2 megabytes of internal memory is recommended.

## PROGRAM ELEMENTS

The "TRAFCALC" program consists of the following major elements:

**INTERSECTION GRAPHIC-** (Top left portion of spreadsheet) This is a representation of an intersection or portion of an intersection showing all possible locations where a traffic signal head may be located. This is to assist in identifying the location of each signal head, and insure that all signal heads are accounted in the tabulation. This is not a scale drawing or an inventory of signal hardware. If additional internal memory is needed for your application, the graphic can be printed, then deleted.

**LOOK-UP TABLES** (located to right of graphic) The first lookup table (LT) indicates the electrical load (in watts) associated with each type of signal head. The table holds up to 20 entries, but can be expanded to hold more. The table is pre-loaded with signal lamp types that are in use in Philadelphia. The table should be customized to reflect the lamps or LED's used in your jurisdiction.

**Flashing lamps:** The table lists each type of lamp twice; the lamps or LED's that are listed in codes 1 through 10 are repeated in codes 11 through 20. The only difference is that the second group shows power consumption at one-half the value of the first group; this is to calculate power consumed for that lamp type under flashing operation. This assumes flasher units with standard 50% on-off operation; if your values are different they can be reflected in the power consumption value.

**Lamp codes:** This is the value shown in the first column, and is the value entered in the program under each signal head and head display to indicate the type of lamp in use. The value "1" is the default value used in the data entry section, therefore when you develop your customized table use code "1" for your

most common lamp type. For instance, if the majority of your signals use 150 watt 130 volt lamps use this type for code #1.

**Lamp type:** This is a text description of the various lamps and LED's shown in the table. For incandescent lamps, indicate both rated wattage and voltage; for LED's, watts consumed at the design voltage.

**WATTS:** This column shows the wattage consumed by the lamp or LED at the average operating voltage at the intersection. When using over-rated incandescent lamps be sure to use the actual wattage consumed at the operating voltage. For example, a 150 watt 130 volt lamp operated at 120 volts consumes only 88.4% of rated power, or 132.6 watts. Tables and charts indicating the performance of your lamps under various rated vs. operating voltage conditions are available from your lamp supplier.

**MAKING CHANGES TO THE LOAD TABLE:** If you are not exceeding 10 lamp types, simply type of new information into the table. Type the lamp description next to codes 1 through 10, using code #1 as the default (most common) lamp. Under the "WATT" column type in the watts consumed at the operating voltage for that lamp. Under codes 11 through 20 repeat the lamp description (or just copy it from above using the copy commands). In the "WATT" column place the value for flashing operating; generally 50% of the values used in Items 1 through 10.

If more than 10 lamp types are used, you must expand the size of the table. This involves the following steps:

1. Insert two additional rows into the spreadsheet for each additional lamp type, immediately below the last row of the table. For example for three additional lamps insert 6 rows. To insert rows, type "/ W I R", move cursor down to highlight number of rows to be inserted, then press <ENTER> key.

2. Type in additional code numbers in the "CODE" column in the newly created rows.

3. Move flashing operation data (description and load data) downward one row for each lamp type added, so that there are an equal number of rows for normal lamp data and flashing lamp data. To move data put cursor on first cell (top left of data), type "/ M", then move cursor to highlight data to be moved, press <ENTER> key, move cursor to top left cell of new location, then press <ENTER> again.

4. The table is found in a range named "LT". This range must be changed to incorporate the new rows. Type "/ R N C", then select the range name "LT". The program will display the old range. Change the range to include the new rows then press <ENTER>.

The new range and its data is now incorporated into the program.

The second lookup table, "PH" is located to the right of table "LT". This table is used to determine the columns associated with timings for various phases. This table should never be changed. The only exception is if you desire to customize the program by adding any additional columns between columns A and AD, such as to add a comment column. In this case all of the column letters should be incremented by the number of columns added (AA becomes AB, etc.).

**DATA ENTRY-** Data for each intersection is contained in one or more rows beginning with row 32. Data entry consists of four sections from left to right: 1. intersection indexing data, 2. phasing and timing data, 3. phase association and lamp types for standard locations, and 4. phase association and lamp types for special locations.

**1. INTERSECTION INDEX-** This is a numeric or alpha-numeric code used to identify an intersection. The names of the intersecting streets is contained in the phasing data. This number can be any existing code used to identify signal installations, or a newly assigned code, whatever you prefer. In cases where intersections occupy multiple rows, the number should be repeated for each row, with a sequential letter designation added. For example, if an intersection designated D-738 occupies two rows the row indexes are D-738a and D-738b.

**Hours daily-** For time-of-day variations, the number of daily hours that a timing schedule is in effect is entered in this column. There must be at least one line for each timing schedule, and the duration of the individual timing schedules must add up to 24 hours: The default value for this column is 24. This column is displayed to two decimal places.

**2. PHASING/TIMING DATA -** Note: this program uses only phasing and timing information needed to calculate electric consumption; it does not track actual timings in seconds, nor it concerned with the actual sequence of multiple phase intersections. The program allows for two to four phases per line. For the purposes of this program, a phase is defined as a set of red /yellow /green and auxiliary circuits emanating from a designated set of terminals in the controller and feeding a given group of signal heads. Two sets of terminals producing identical, coincident timing can be considered as one phase. Phasing and timing information consists of the following:

**PHASE IDENTIFICATION:** The convention established is that Phase #1 is the north-south street, and Phase 2 is the east-west street. If the north-south street (in our examples its "Main Street") has identical timings in both directions, Phase 1 can be labeled "Main St." If the northbound and southbound timings are different, Phase 1 is labeled "MAIN ST. NB" and Phase 3 is labeled "MAIN ST. SB". Phase 2 is always assigned to the east-west street. Special phases should be identified by their purpose:

- MAIN NB/SB LEFT for a left turn phase in both directions
- MAIN PED. for all pedestrian movements parallel to Main
- MAIN WS PED. for pedestrian signals on west crosswalk
- MAIN SB for signals facing southbound traffic on Main

The above convention can be changed to suit your preferences, provided that it is consistent throughout the spreadsheet.

**PHASE TIMINGS:** The numbers shown for all timings are expressed as a percentage of the signal cycle. If timing records are in seconds they must be converted to percentages by dividing the interval time by the signal cycle. Timings for electromechanical signal controllers are, by design, always expressed in integral numbers. Timings for electronic controllers can be expressed to any number of decimal places, but are displayed to one decimal place. Timings are generally entered for four values: green (g), yellow (y), arrow (<) and all red (ar) intervals. Data in shaded columns is not entered but is calculated by the program. Minimum data entry is for Phase 1 green and yellow, and for Phase 2

yellow. Entry of all-red and turn arrow interval times, or any data for phases 3 and 4 is optional; otherwise the default values are used. Red intervals and the Phase 2 green interval are never entered; these are automatically calculated values shown in shaded cells.

Phases 3 and 4 have an additional column labeled "cm" for "complementary phase". This column is a flag indicating whether the phase is "coincident", running simultaneously with Phases 1 or 2, or if it is "complementary", that is it an exclusive phase in the signal cycle, not running concurrent with phases 1 or 2 (or 3 in the case of Phase 4). If the phase is coincident enter a "0" in this column; if complementary enter a "1".

All of the timing cells are pre-loaded with default timings. This speeds data entry particularly if you have standardized timings for yellow and all-red intervals. If your standard values are different than the default values given, simply put your value in the first intersection, then copy the value to all cells in that column. Individual values differing from the defaults are entered as each intersection row is completed.

Column "Cntl" - This column allows entry of the electrical load associated with the intersection controller, and any auxiliary devices such as illuminated signs. The default value is 6 watts.

#### SIGNAL HEAD DATA ENTRY

A maximum of 24 signal heads can be entered on each line. This includes 16 "standard" locations (four each for north, south, east, and west intersection approaches) and 8 special locations. Each signal head at an intersection must be accounted for.

The data for each signal head at an intersection is entered into one of the 24 available data entry blocks. Primary locations are entered first; for instance if there are four signals for northbound traffic they are entered into locations N1, N2, N3, and N4. A suggested convention is to number vehicular indications from right to left, then pedestrian indications in the same manner. If there are three vehicular and two pedestrian indications northbound, the far right vehicle signal is N1, the middle indication is N2, and the far left vehicular is N3. The far right pedestrian signal is N4. The second (far left) pedestrian signal would be listed as a special signal, at location X1.

Data entry for each signal head includes the following columns: Column "L"- Enter the location from the intersection graphic that best describes the head location. This is optional, and may be omitted. The location codes and intersection graphic is simply a method to keep track of all the signal heads at a complex location.

Column "ph"- Enter number (from 1 to 4) of phase associated with signal head. Unused head locations should have the default value of "0" in this column.

Column "G"- Enter code (from table LT) for green indication lamp.

Column "Y"- Enter code for yellow lamp

Column "R"- Enter code for red lamp (or LED)

Column "<"- Enter code for turn arrow lamp



## **Appendix A**

**Peco Energy Laboratories**

**LED Signal Tests**





PECO ENERGY

PECO Energy Company  
1111 Old Eagle School Road  
Wayne, PA 19087-1453

January 20, 1994

Mr. John M. O'Connell, P.E.  
Chief Engineer  
Municipal Energy Office  
City of Philadelphia  
1600 Arch Street, 7th Floor  
Philadelphia, PA 19103

Dear Mr. O'Connell:

As requested per your letter dated October 28, 1993, PECO Energy Laboratories has completed the evaluation of the 8- and 12-inch LED traffic signals. Please see the attached data sheets and diagrams for laboratory data of these evaluations. Your request asked for the power factor of the LED signals. Analysis of the current waveforms showed the current waveshape to be that of a switching/transient nature, typical of semiconductor devices when they "fire" or turn on. This current waveshape is not the usual sinusoidal current waveshape as found in typical power circuits, thus the determination of a power factor for these voltage/current relationships has no real meaning or significance.

A failure analysis was performed on the supplied inoperable 8-inch LED signal. The review of the failed signal found a full wave bridge rectifier chip "blown apart" from an apparent short circuit downstream of the rectifier. Located downstream of the rectifier is a surge protection device that is designed to turn on and "crowbar" in conditions of circuit overvoltage. This crowbar action protects the signal LEDs from high voltage damage but, in doing so, draws excessive current through the rectifier bridge thus destroying the bridge. As per your request, I contacted the signal manufacturer (Ray Deese) and informed him of our findings. His response was a positive acknowledgement of the problem and he has initiated a circuit redesign that you will be made aware of. The circuit redesign is to install another surge protection device in front of the rectifier bridge.

We are thankful for being able to provide our laboratory services to you. If you have any questions or need any future testing services, please call me at 971-7241.

Thank you,

Raymond M. Connolly, III, P.E.  
Attachment

RMC/wsm

WP5.1 (rmc-jmo.ltr)



**PECO ENERGY LABORATORIES  
SPECIAL TEST SECTION**

PROJECT NUMBER: 9301446

TYPE OF RECORD: SPECIAL TEST

DESCRIPTION: PERFORM POWER CONSUMPTION TESTS OF NEW "DIODE" TRAFFIC SIGNAL LENSES.

<b>8 IN. LED</b>					
TEMP. NOMINAL -10 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
-6.6 (ACTUAL)	130	130.4	0.1331	13.53	91.6
	120	119.7	0.1000	8.897	56.0
	110	110.2	0.0517	4.201	22.0
	100	100.5	0.0155	1.400	1.0
	90	89.98	0.0117	1.003	0

<b>12 IN. LED</b>					
TEMP. NOMINAL -10 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
-6.6 (ACTUAL)	130	129.8	0.2671	24.08	107.3
	120	120.1	0.1783	14.29	65.6
	110	109.9	0.0822	5.681	24.7
	100	99.83	0.0169	1.409	0.8
	90	89.65	0.0121	0.997	0

<b>67 WATT INCANDESCENT LAMP</b>					
TEMP. NOMINAL -10 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
-6.6 (ACTUAL)	130	130.2	0.5283	68.78	23.0
	120	119.9	0.5063	60.70	16.6
	110	110.1	0.4849	53.39	11.6
	100	99.99	0.4618	46.16	7.6
	90	89.84	0.4376	39.30	4.7

<b>116 WATT INCANDESCENT LAMP</b>					
TEMP. NOMINAL -10 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
-6.6 (ACTUAL)	130	130.1	0.9165	119.2	46.4
	120	120.3	0.8784	105.7	34.8
	110	110.1	0.8378	92.23	24.8
	100	100.5	0.7976	80.14	17.2
	90	89.85	0.7514	67.50	10.8

8 IN. LED					
TEMP. NOMINAL AMBIENT (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
64.0 (ACTUAL)	130	129.8	0.2242	22.18	96.7
	120	120.0	0.1672	14.78	58.7
	110	110.0	0.0966	7.246	27.4
	100	100.2	0.0381	2.451	6.0
	90	90.18	0.0129	1.035	0.04

12 IN. LED					
TEMP. NOMINAL AMBIENT (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
64.0 (ACTUAL)	130	130.4	0.3524	32.02	105
	120	120.1	0.2487	19.65	68.2
	110	110.0	0.1417	9.134	32.0
	100	100.2	0.0450	2.552	6.1
	90	89.46	0.0127	1.010	0.04

67 WATT INCANDESCENT LAMP					
TEMP. NOMINAL AMBIENT (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
64.0 (ACTUAL)	130	130.4	0.5291	69.00	25.0
	120	119.7	0.5061	60.58	18.1
	110	109.9	0.4843	53.22	12.5
	100	99.73	0.4608	45.95	8.3
	90	90.13	0.4379	39.46	5.3

116 WATT INCANDESCENT LAMP					
TEMP. NOMINAL AMBIENT (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
64.0 (ACTUAL)	130	130.6	0.9226	120.4	47.5
	120	120.4	0.8869	106.8	34.4
	110	109.6	0.8462	92.73	23.9
	100	99.78	0.8089	80.70	16.1
	90	90.04	0.7726	69.55	10.2

8 IN. LED					
TEMP. NOMINAL 120 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
121.0 (ACTUAL)	130	130.2	0.2601	26.33	75.0
	120	119.8	0.1873	16.77	49.0
	110	110.0	0.1098	8.516	25.6
	100	100.3	0.0463	3.057	7.0
	90	89.69	0.0136	1.059	0.01

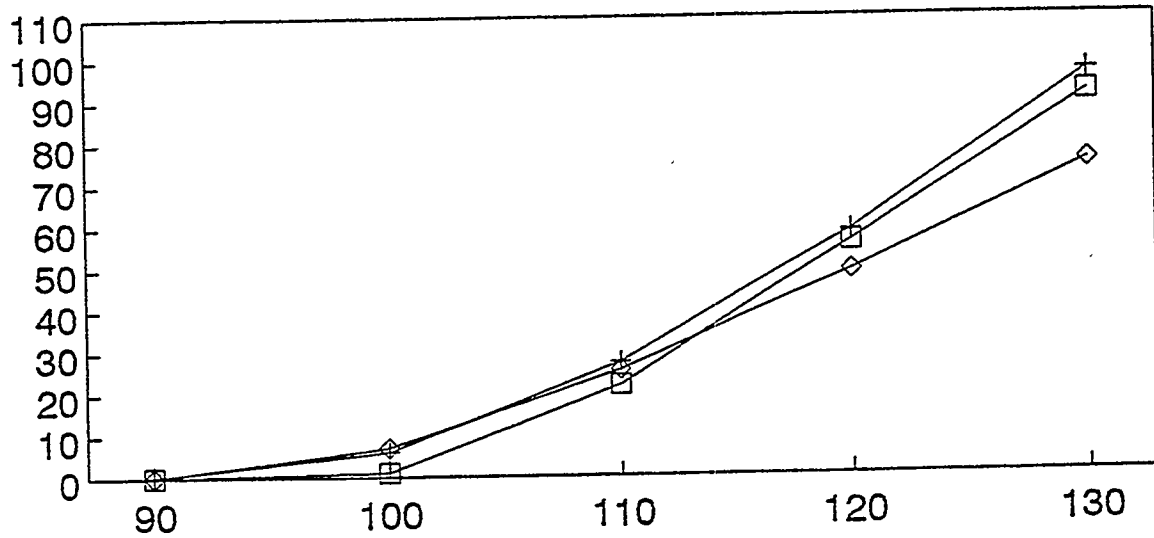
12 IN. LED					
TEMP. NOMINAL 120 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
121.0 (ACTUAL)	130	130.0	0.3696	33.60	85.0
	120	119.8	0.2625	21.08	56.0
	110	109.7	0.1491	10.16	27.0
	100	99.96	0.0549	3.038	5.9
	90	89.70	0.0136	1.054	0.06

67 WATT INCANDESCENT LAMP					
TEMP. NOMINAL 120 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
121.0 (ACTUAL)	130	130.0	0.5275	68.56	26.2
	120	119.4	0.5047	60.24	18.7
	110	109.7	0.4836	53.06	13.3
	100	100.3	0.4617	46.29	9.2
	90	89.63	0.4363	39.10	5.6

116 WATT INCANDESCENT LAMP					
TEMP. NOMINAL 120 °F (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)
121.0 (ACTUAL)	130	130.2	0.9173	119.4	48.8
	120	120.0	0.8771	105.2	36.2
	110	110.3	0.8377	92.37	26.7
	100	100.1	0.7953	79.60	18.0
	90	89.67	0.7498	67.22	11.6

8 INCH L.E.D.

FOOT-CANDELES

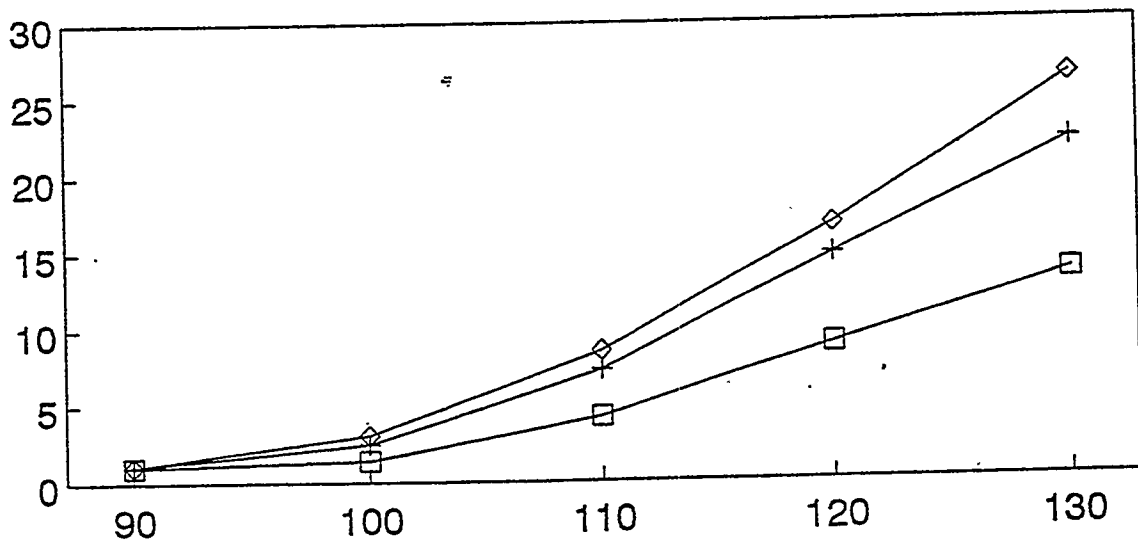


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F ◇ 121.0 °F

8 INCH L.E.D.

WATTS

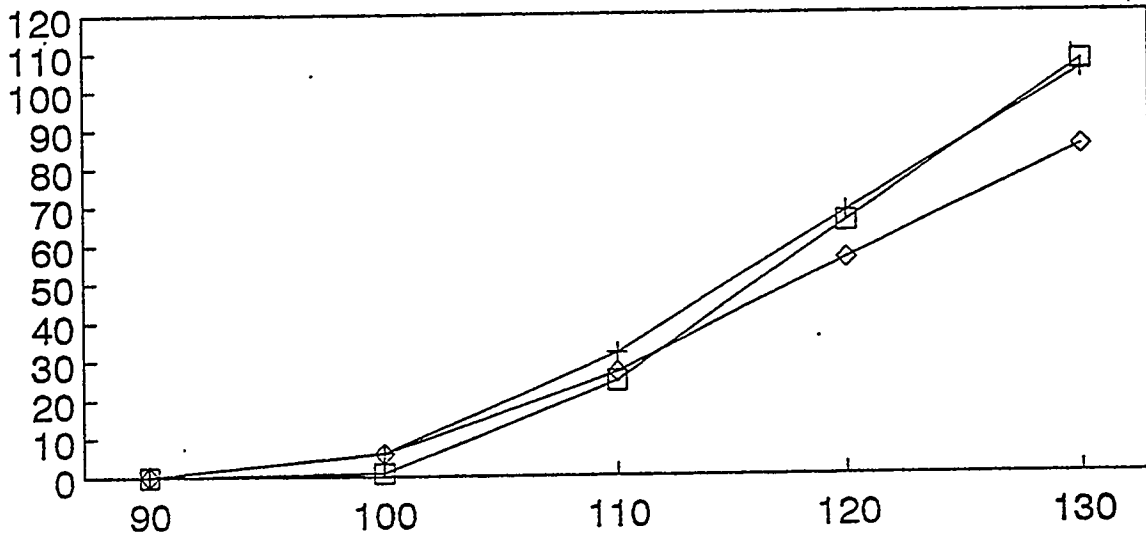


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F ◇ 121.0 °F

12 INCH L.E.D.

FOOT-CANDLES

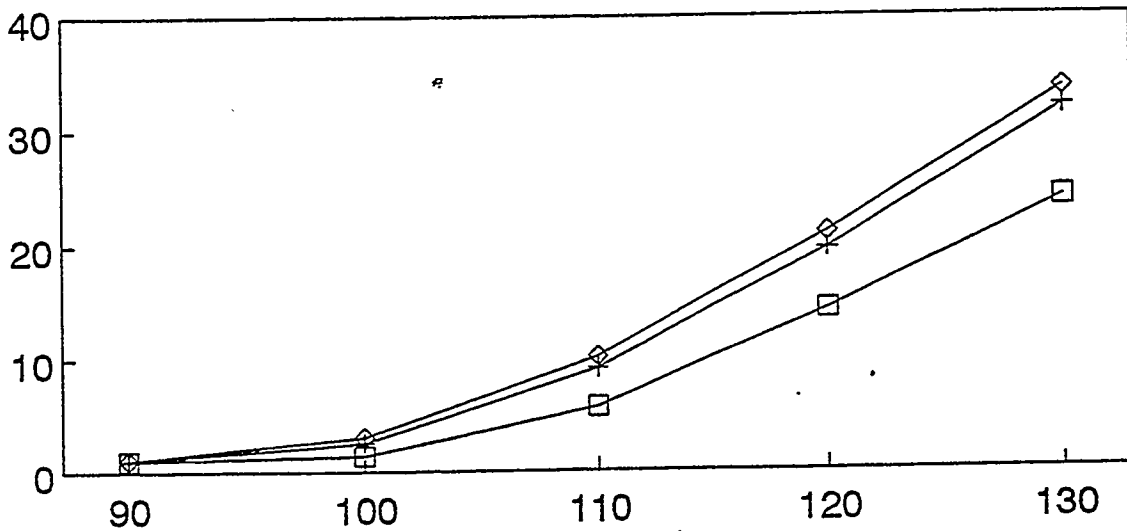


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F    ◇ 121.0 °F

12 INCH L.E.D.

WATTS

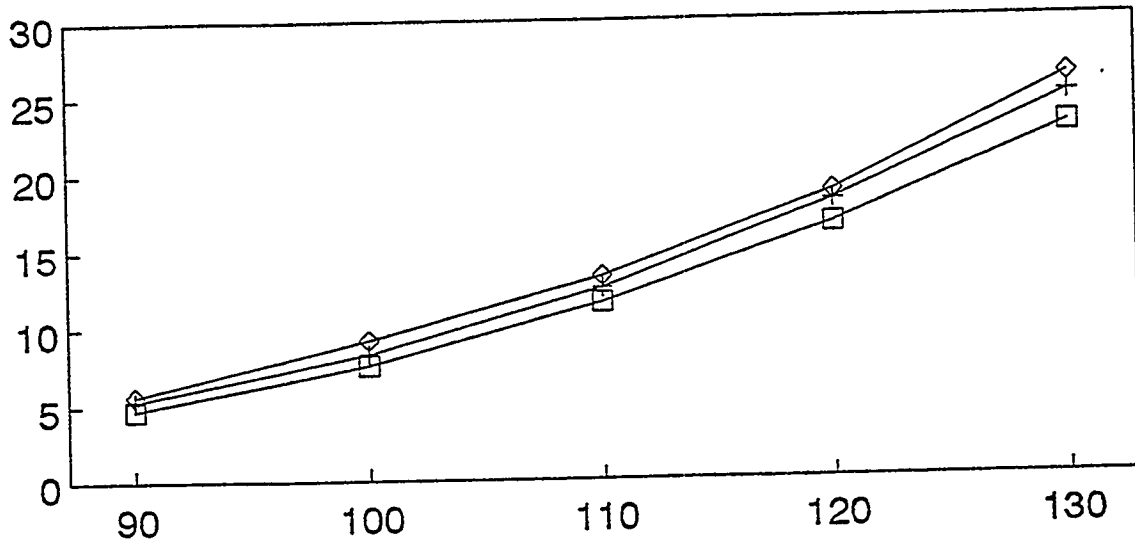


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F    ◇ 121.0 °F

67 WATT INCANDESCENT LAMP

FOOT-CANDLES

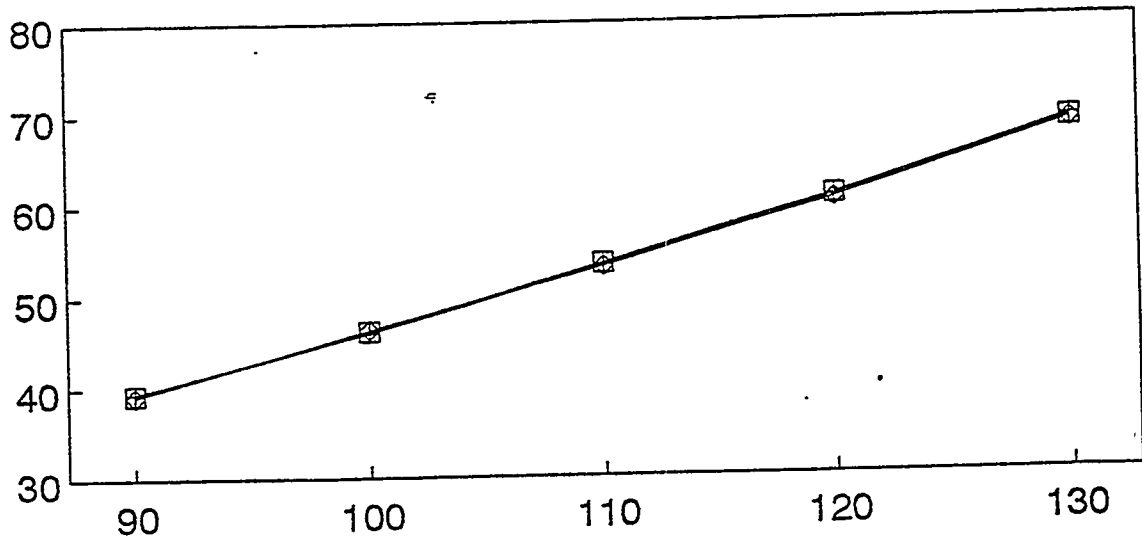


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F ◇ 121.0 °F

67 WATT INCANDESCENT LAMP

WATTS

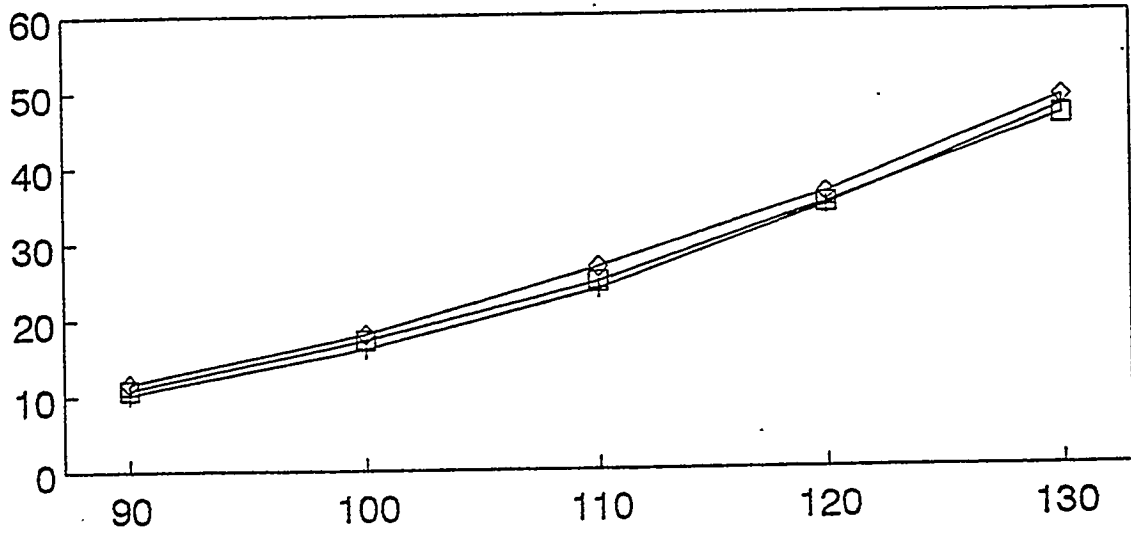


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F ◇ 121.0 °F

116 WATT INCANDESCENT LAMP

FOOT-CANDLES

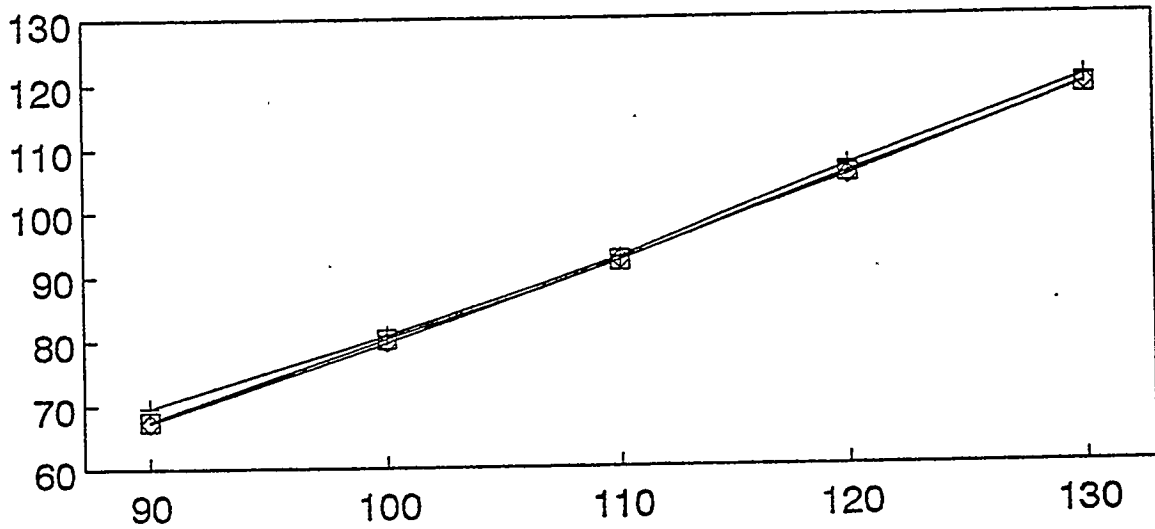


A.C. INPUT VOLTS (NOMINAL)

□ -6.6 °F + 64.0 °F ◇ 121.0 °F

116 WATT INCANDESCENT LAMP

WATTS

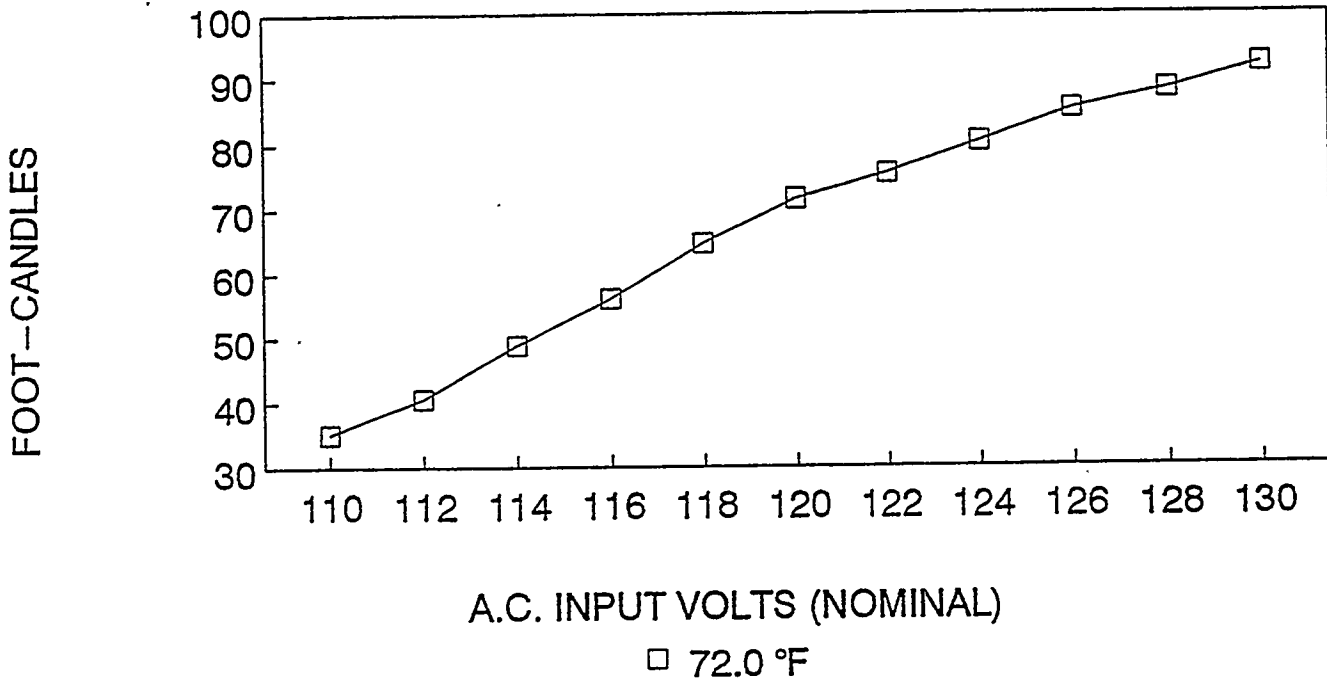


A.C. INPUT VOLTS (NOMINAL)

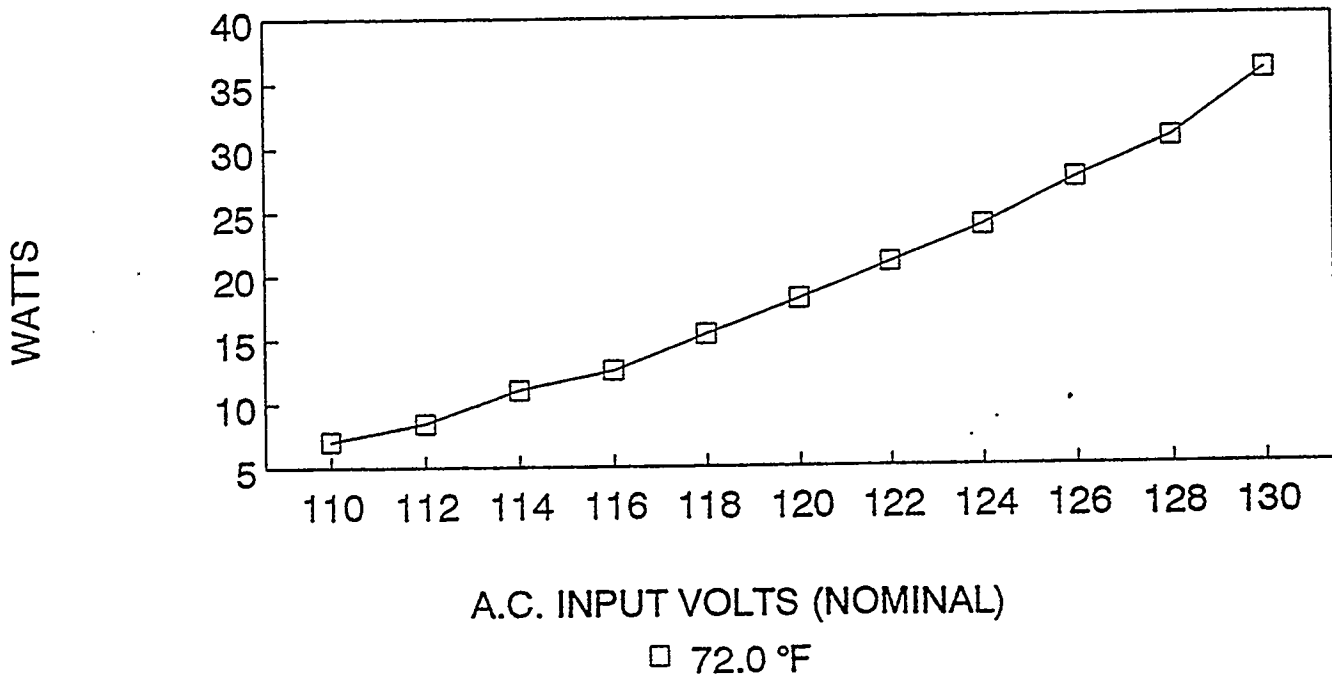
□ -6.6 °F + 64.0 °F ◇ 121.0 °F

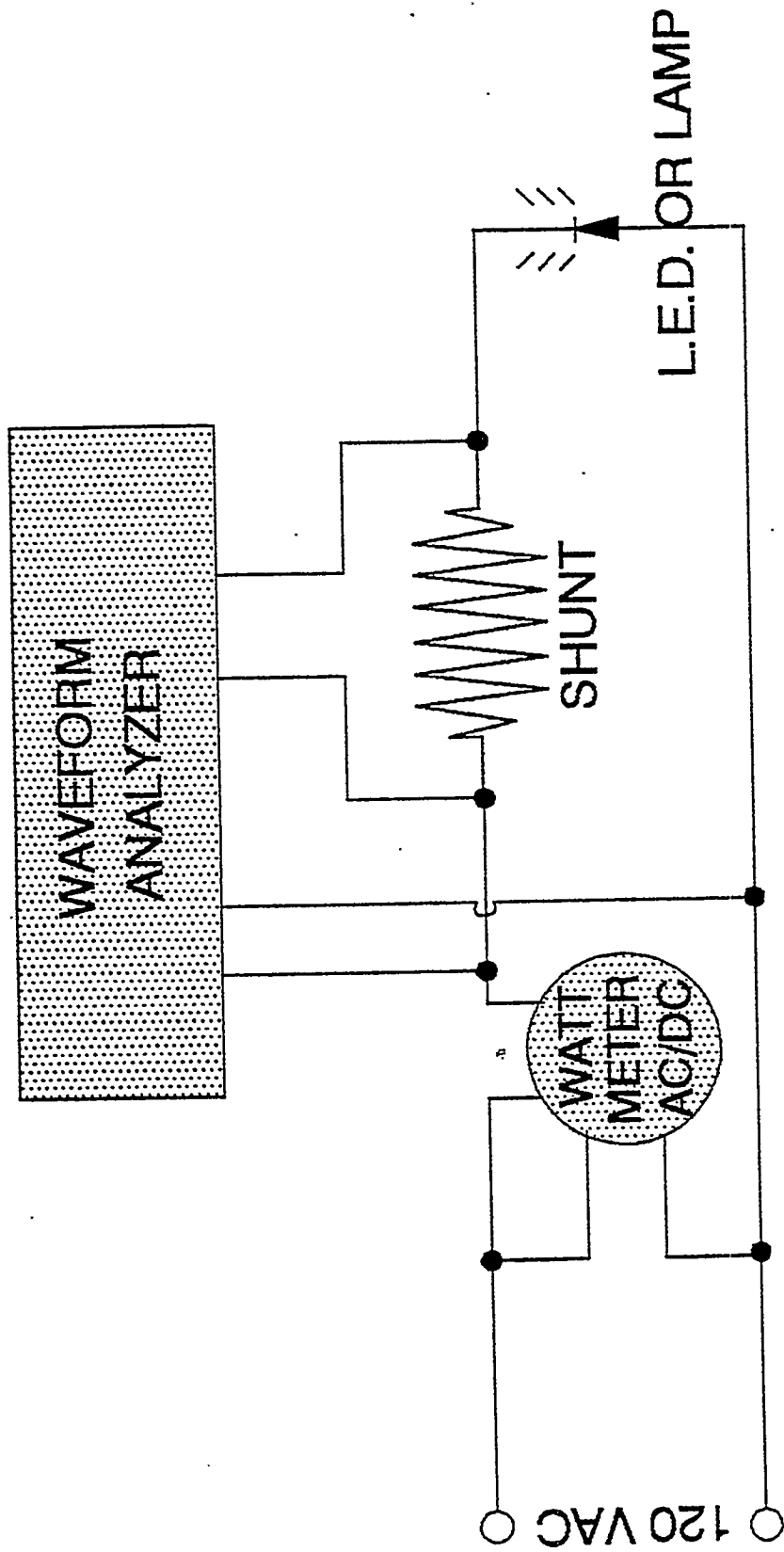
12 IN. LED						
TEMP. NOMINAL AMBIENT (°F)	INPUT VOLTAGE NOMINAL (ACV)	INPUT VOLTAGE ACTUAL (ACV rms)	INPUT CURRENT ACTUAL (ACA rms)	INPUT POWER ACTUAL (AC WATTS)	OUTPUT ILLUMINANCE ACTUAL (FT-CANDLES)	
72.0	130	131.0	0.4000	35.74	92.1	
(ACTUAL)	128	128.2	0.3569	30.56	88.2	
	126	126.5	0.3296	27.47	85.1	
	124	124.2	0.2972	23.80	80.2	
	122	122.4	0.2703	20.94	75.3	
	120	120.5	0.2424	18.07	71.5	
	118	118.4	0.2151	15.35	64.7	
	116	116.0	0.1850	12.53	56.1	
	114	114.6	0.1686	11.03	48.9	
	112	111.9	0.1375	8.45	40.6	
	110	110.2	0.1207	7.07	35.1	

12 INCH L.E.D.



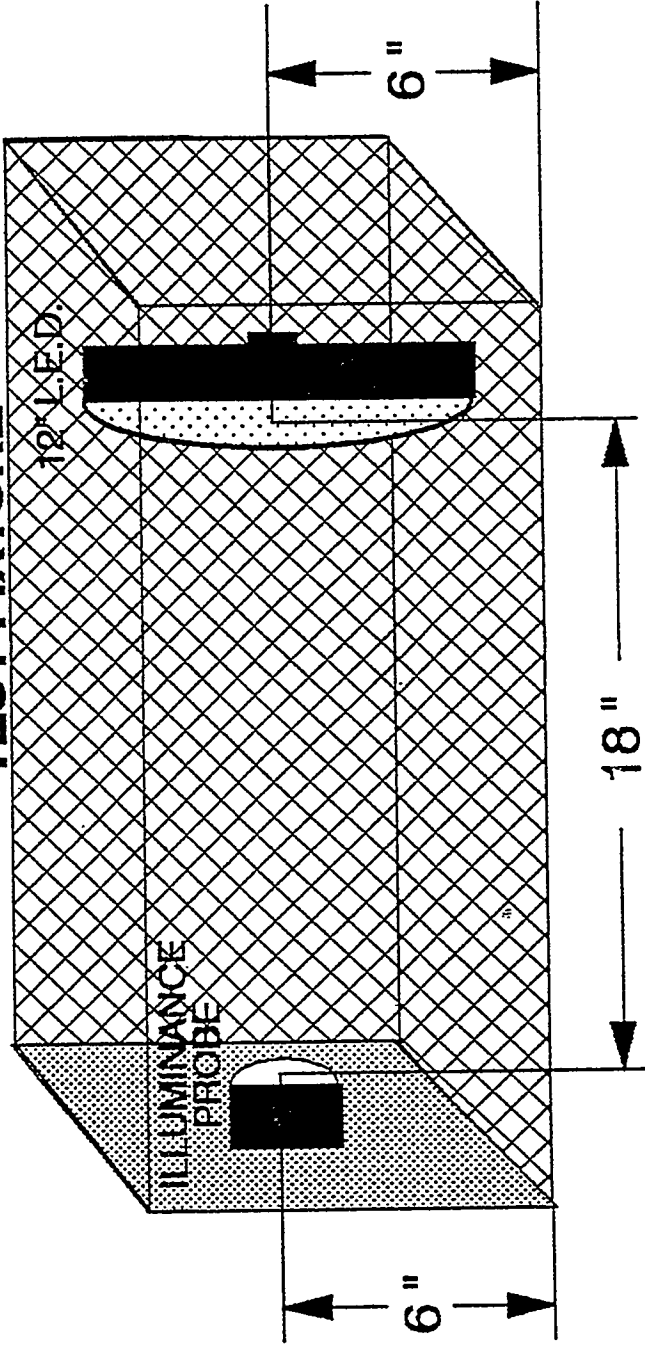
12 INCH L.E.D.





SCHEMATIC OF TEST SETUP FOR THE 8" LED,  
12" LED, & INCANDESCENT LAMPS.

**TEST FIXTURE**





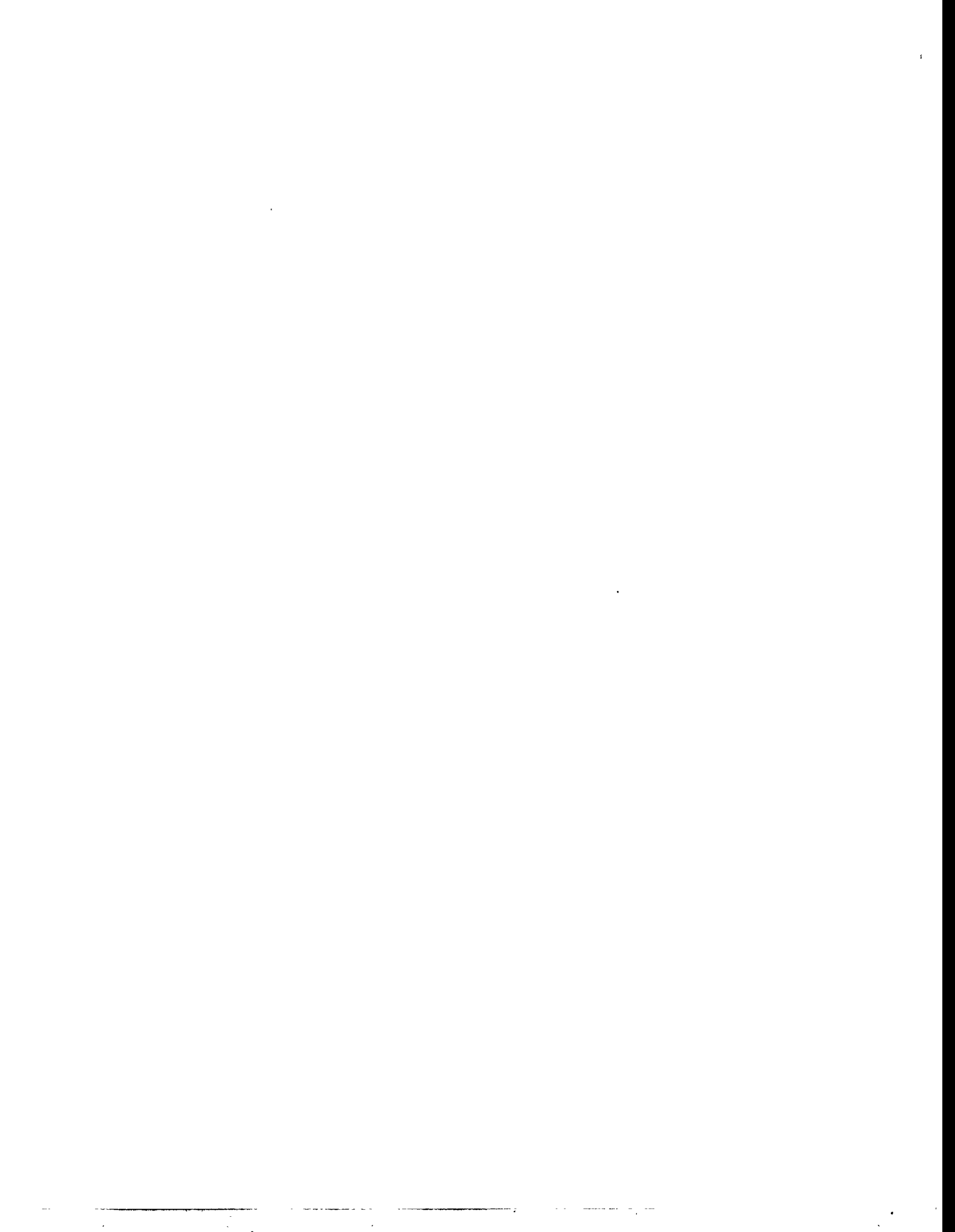
**Appendix B**

**LED Signal Evaluation**

**West Philadelphia Study**

**Forms & Data**

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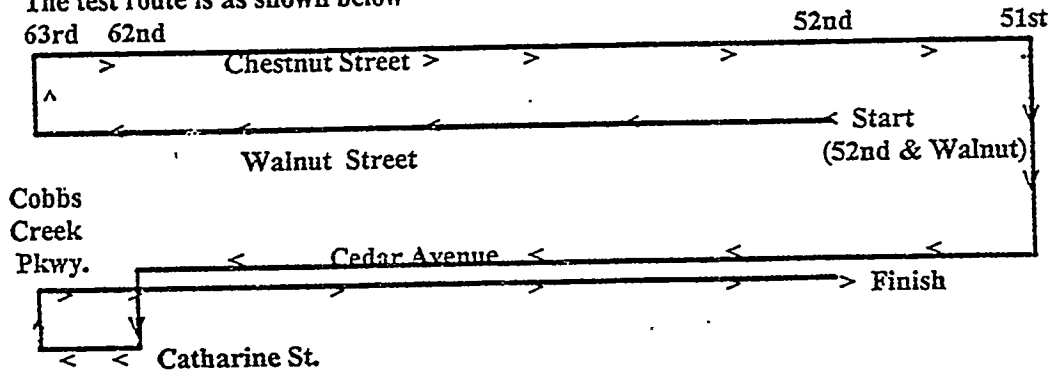


CITY OF PHILADELPHIA  
MUNICIPAL ENERGY OFFICE  
TRAFFIC SIGNAL EVALUATION STUDY

Thank you for participating in this evaluation program. The purpose of this study is to determine motorists' perception of a new type of energy efficient traffic signal. The results of the study will be used to make any needed changes or improvements to the signal, and to obtain approval from state and federal transportation agencies for expanded use. Only red traffic signals are being evaluated at this time.

Each participant will be asked to make two trips accompanied by a partner through a pre-determined route in West Philadelphia. While driving, you will make observations of the red signals (and only the red signals) that you observe while approaching the intersection. You will announce your observations to your partner, who will record your observations on the attached form. On one trip you will drive, and your partner will record your observations. On the other trip, the roles will be reversed. The entire process should take less than one hour from Center City.

The test route is as shown below



The actual observations take place only on the east-west streets between 52nd Street and 62nd Street. The signals on these streets are coordinated so that signals at an intersection should be red as you approach the intersection, then change to green. This should give you an opportunity to observe the red signals as you approach the intersection.

**TEST PROCEDURE:**

If possible, trips should be made during off-peak hours (between 10 A.M. and 2 P.M., when traffic is light. It will be easier for you to keep up with the signal system speed on Walnut and Chestnut Streets of 30 m.p.h. and observe the red signals during these times.

You must have an opportunity to observe the red signals on your approach to each intersection prior to the signals turning green. This is easier to do if you start each segment (at 52nd & Walnut and 62nd & Chestnut) by dropping out of the flow of traffic, then positioning yourself at the head of the next "platoon" of traffic so that you are at the head of the platoon when the first signal turns green. If you then drive at the system speed of 28 to 30 m.p.h. you should have no problem observing the red signals as you approach the intersection. If local traffic congestion or some other reason causes you to move back in the stream of traffic, then drop out of the platoon, and position yourself at the head of the following platoon. If you miss an observation at one or two intersections, don't start over or drive the route again. Just record that intersection as "No Observation".

Your observation at an intersection is based on your general impression of all of the red signals (generally two or three) that you observe approaching the intersection.

**THANKS FOR YOUR PARTICIPATION !**

Compared to your normal perception of a traffic signal were the red signals at this intersection:

Compared to your normal perception of red traffic signals were the red signals at this intersection:

If you did not make an observation, check block below:

	DIMMER	NORMAL	BRIGHTER	DARKER RED	NORMAL RED	LIGHTER RED	NO OBSERVATION
52nd & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
53rd & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
54th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
55th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
56th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
57th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
58th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
59th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
60th & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
61st & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
62nd & Walnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

(PROCEED WEST ON WALNUT, RIGHT ONTO 63RD, THEN RIGHT ON CHESTNUT TO 62ND ST.)

62nd & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
61st & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
60th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
59th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
58th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
57th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
56th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
55th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
54th & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
53rd & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
52nd & Chestnut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

(PROCEED EAST ON CHESTNUT, RIGHT ONTO 51ST, 5 BLOCKS TO CEDAR AVE, RIGHT ON CEDAR TO 52ND)

52nd & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
54th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
56th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
58th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
60th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
62nd & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

(PROCEED LEFT ONTO 62nd, 1 BLOCK TO CATHARINE, RIGHT TO 63RD, RIGHT TO CEDAR, RIGHT TO 62)

61st & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
59th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
57th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
65th & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
63rd & Cedar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

(FOR 2ND RUN, PROCEED EAST ON CEDAR, LEFT ON 51ST, 4 BLOCKS TO WALNUT, LEFT ON WALNUT)

NAME: \_\_\_\_\_

ORGANIZATION: \_\_\_\_\_

DATE: \_\_\_\_\_ TIME: \_\_\_\_\_

WEATHER:

fair cloudy rain/snow

COMMENTS: \_\_\_\_\_



EVALUATION OF TRAFFIC SIGNAL COLOR

OBSERVATION #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	ISUM	COUNT	MEAN	STD DEV	CIT DIST	MINIMUM	MAXIMUM	
52 & Walnut	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	0	0	0	0	0	0	2	1	2	17	23	0.7391	0.6887	0.2973	0.4419	1.0364
53 & Walnut *	0	2	1	1	2	1	2	1	2	2	0	1	2	2	0	2	2	2	2	1	2	1	1	2	31	23	1.3478	0.7751	0.3346	1.0133	1.6824	
54 & Walnut *	2	2	1	2	2	1	2	0	2	2	2	1	2	2	0	2	0	1	2	2	1	0	1	2	30	23	1.3043	0.7648	0.3301	0.9742	1.6345	
55 & Walnut	0	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	2	12	21	0.5714	0.2726	0.2989	0.2989	0.8440	
56 & Walnut	1	2	1	1	2	1	2	1	2	2	0	2	2	2	0	1	1	1	1	1	1	0	1	2	25	21	1.1905	0.6016	0.2744	0.9161	1.4648	
57 & Walnut	1	2	0	0	1	1	1	1	1	2	0	2	2	2	0	0	1	1	1	1	1	1	1	2	26	22	1.0000	0.6901	0.3060	0.6940	1.3060	
58 & Walnut	2	2	1	1	2	1	2	1	2	2	2	2	2	2	1	1	0	1	1	1	2	2	1	2	32	21	1.2381	0.7584	0.3505	0.8876	1.5886	
59 & Walnut *	2	2	1	1	2	1	2	2	2	2	2	0	2	2	1	2	0	2	2	2	2	2	2	2	34	22	1.4545	0.7385	0.3275	1.1270	1.7821	
60 & Walnut *	2	2	1	1	2	1	2	2	2	2	2	1	2	2	1	2	0	2	2	2	2	2	2	2	19	21	1.5455	0.5958	0.2642	1.2812	1.8097	
61 & Walnut	2	1	1	1	2	1	2	2	2	2	0	1	0	1	1	0	0	0	0	0	0	0	1	2	19	21	0.9048	0.7684	0.3605	0.5543	1.2552	
62 & Walnut *	2	1	1	1	2	1	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	2	1	2	31	21	1.4762	0.7496	0.3419	1.1343	1.8181	
62 & Chestnut	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	2	18	22	0.8182	0.5011	0.2222	0.5960	1.0404	
61 & Chestnut *	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	36	22	1.6364	0.5811	0.2577	1.3787	1.8941	
60 & Chestnut	0	0	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	10	22	0.4545	0.5958	0.2976	0.1903	0.7188	
59 & Chestnut *	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	0	1	1	2	2	1	2	2	32	22	1.4545	0.7341	0.3256	1.0835	1.7347	
58 & Chestnut *	2	1	1	1	2	1	2	2	2	2	2	1	2	2	2	0	1	1	1	1	1	1	1	2	19	22	0.8636	0.6396	0.2836	0.5800	1.1473	
57 & Chestnut	1	0	0	2	1	1	1	1	1	2	0	1	0	1	1	1	1	1	2	2	2	1	1	2	21	22	0.9545	0.7222	0.3203	0.6343	1.2748	
56 & Chestnut	0	0	2	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	2	0	2	2	1	2	16	20	0.8000	0.6156	0.2877	0.5123	1.0877	
55 & Chestnut	1	0	0	2	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	21	21	1.0000	0.4472	0.2040	0.7960	1.2040	
54 & Chestnut	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	2	1	2	2	30	22	1.3636	0.7267	0.3223	1.0414	1.6859	
53 & Chestnut *	2	1	1	2	1	2	2	2	2	2	2	1	1	0	2	0	1	0	0	2	2	0	1	2	19	22	0.8636	0.8335	0.3696	0.4940	1.2333	
52 & Chestnut	1	0	0	2	1	2	2	2	2	2	2	1	1	0	0	1	0	0	0	0	2	0	1	2	29	20	1.4500	0.6048	0.2826	1.1674	1.7326	
52 & Cedar	2	2	1	1	2	1	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2	1	2	2	33	23	1.0000	0.5222	0.2254	0.7746	1.2254	
54 & Cedar	0	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	2	23	23	1.4783	0.5931	0.2560	1.2223	1.7343	
56 & Cedar	2	1	1	2	1	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2	1	1	2	34	23	1.0000	0.6742	0.2910	0.7090	1.2910	
58 & Cedar	2	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	2	2	2	2	1	0	2	23	23	1.0000	0.5976	0.2726	1.2989	1.8440	
60 & Cedar	2	2	1	1	2	1	2	2	2	2	2	2	2	2	2	2	0	1	1	1	2	2	1	2	33	21	1.5714	0.5976	0.2726	1.2989	1.8440	
62 & Cedar	0	2	0	0	1	1	1	1	1	0	0	2	0	1	1	0	0	0	0	1	1	0	1	1	14	23	0.6087	0.7223	0.3116	0.2989	0.9205	
61 & Cedar *	2	2	1	1	1	1	1	1	1	0	0	2	0	1	1	0	0	2	2	2	2	1	1	1	32	22	1.4545	0.5958	0.2642	1.1903	1.7188	
59 & Cedar	2	0	0	1	1	1	1	1	1	2	2	2	1	1	1	2	0	2	2	2	1	1	1	1	25	21	1.1905	0.7496	0.3419	0.8486	1.5324	
57 & Cedar *	1	1	1	1	2	1	2	2	2	2	2	2	1	1	1	2	0	2	2	2	2	2	2	2	30	20	1.5000	0.7609	0.3556	1.1444	1.8556	
55 & Cedar	1	1	1	1	2	1	2	2	2	2	2	2	1	1	2	2	0	2	2	2	2	2	2	2	16	14	1.1429	0.3631	0.2096	0.9332	1.3525	
53 & Cedar	1	1	0	0	2	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	14	19	0.7368	0.5620	0.2707	0.4661	1.0076	

1 = NORMAL 2 = LIGHTER 0 = DARKER

\* L.E.D. Lamps

**Appendix C**

**'SigCalc'**

**Energy Calculation Program**

**Data Screens**





LOCAT.	DATE	I	HOURS DAILY (AVER)	PHASE DESCRIPTION		G% < Y	ar	R	E - W (PHASE2)	G% < Y	ar	R	OTHER (PHASE3)	cm/G% <	Y	ar	R	OTHER (PHASE4)	cm/G% <	
				N - S (PHASE1)	DELAVARE(COLUMBUS)NB															
001	29-Oct-92	1	24	17TH ST.		50	0	5	0	45	ARCH ST.									
002	15-Sep-93	1	24	9TH ST.		45	0	5	0	50	RACE ST.									
003	15-Sep-93	1	24	DELAVARE(COLUMBUS)NB		63	0	4	2	33	DOCK ST									
004	10-Dec-93	1	24	25TH ST		40	0	5	0	55	COLUMBIA (CB MOORE)									
005	10-Dec-93	1	24	28TH ST		40	0	5	0	55	COLUMBIA (CB MOORE)									
006	10-Dec-93	1	24	5TH ST		43	0	5	0	52	SNYDER AV									
007	10-Dec-93	1	24	6TH ST		43	0	5	0	52	SNYDER AV									
008	28-Dec-93	1	24	65TH		40	0	5	0	55	WOODLAND AVE									
009	28-Dec-93	1	24	66TH ST.		40	0	5	0	55	WOODLAND AVE									
010A	04-Nov-93	1	24	ROOSEVELT BLVD (NB)		57	9	4	0	39	PRATT (INNER)									
010B	04-Nov-93	0	24	ROOSEVELT BLVD (SB)		43	0	4	2	53	(OMIT)									
011A	08-Dec-93	1	24	ROOSEVELT BLVD (SB)		57	0	4	2	39	BRIDGE (INNER)									
011B	08-Dec-93	0	24	ROOSEVELT BLVD (NB)		43	0	4	2	53	(OMIT)									
012	26-Apr-94	1	24	TORRESDALE AVE		60	0	5	2	35	MEGARGEE ST									
013	27-Apr-94	1	24	TORRESDALE AVE		60	0	5	2	35	TOLBUT ST									
014	22-Mar-94	1	24	52ND ST		53	0	5	0	47	CEDAR AVE									
015	22-Mar-94	1	24	56TH ST		40	0	5	0	55	CEDAR AVE									
016	22-Mar-94	1	24	57TH ST		40	0	5	0	55	CEDAR AVE									
017	23-Mar-94	1	24	60TH ST		40	0	5	0	55	CEDAR AVE									
018	23-Mar-94	1	24	61ST ST		40	0	5	0	55	CEDAR AVE									
019	24-Mar-94	1	24	53RD ST		27	0	5	3	68	WALNUT ST									
020	24-Mar-94	1	24	54TH ST		27	0	5	3	68	WALNUT ST									
021	24-Mar-94	1	24	59TH ST		27	0	5	3	68	WALNUT ST									
022	25-Mar-94	1	24	60TH ST		30	0	5	3	65	WALNUT ST									
023	25-Mar-94	1	24	62ND ST		27	0	5	3	68	WALNUT ST									
024	23-Mar-94	1	24	61ST ST		27	0	5	3	68	CHESTNUT ST									
025	23-Mar-94	1	24	59TH ST		27	0	5	3	68	CHESTNUT ST									
026	24-Mar-94	1	24	58TH ST		27	0	5	3	68	CHESTNUT ST									
027	24-Mar-94	1	24	53RD ST		27	0	5	3	68	CHESTNUT ST									



LOCAT.	E4	W1	W2	W3	W4	X1	X2	X3	X4	X5
	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia	Philadelphia
001	2933029330									
002	2811028110									
003	28110									
004	2333023330									
005	2333023330									
006	2933029330									
007	2333023330									
008	2933029330									
009	2333023330									
010A	4333029330	4333043330	4333043330	4333043330	4333043330	433302143330	28110223330	28110223330	28110223330	28110223330
010B	0000000000									
011A	2933029330	2933029330	2933029330	2933029330	2933029330	29330213330	28110223330	28110223330	28110223330	28110223330
011B	0000000000									
012	2111021110									
013	2811028110									
014	2811028110									
015	2811028110									
016	2811028110									
017	2811028110									
018	2811028110									
019	2933029330	2933029330	2933029330	2933029330	2933029330	2933029330				
020	2933029330	2933029330	2933029330	2933029330	2933029330	2933029330				
021	2933029330	2933029330	2933029330	2933029330	2933029330	2933029330				
022	2933029330	2933029330	2933029330	2933029330	2933029330	2933029330				
023	2933029330	2933029330	2933029330	2933029330	2933029330	2933029330				
024	2811028110									
025	2811028110									
026	2811028110									
027	2811028110									

LOCAT.	X6	X7	X8	ANNUAL KWH	N1	N2	N3	N4	S1	S2	S3	S4	E1	E2	E3	E4	W1	W2
001	a L p h r y g a L p h r y g a L p h r y g a			329	329	0	0	0	577	577	0	0	0	285	285	0	0	501
002				307	307	0	0	0	307	307	0	0	0	307	307	0	0	307
003				289	171	668	668	668	508	508	0	0	0	379	379	0	0	215
004				526	285	0	0	0	285	526	0	0	0	920	920	0	0	920
005				285	526	0	0	0	526	285	0	0	0	920	920	0	0	920
006				298	298	0	0	0	298	298	0	0	0	554	554	0	0	554
007				298	298	0	0	0	298	298	0	0	0	920	920	0	0	920
008				920	920	0	0	0	920	920	0	0	0	577	577	0	0	577
009				285	285	0	0	0	285	285	0	0	0	920	920	0	0	920
010A				623	623	623	705	355	355	0	0	0	0	348	348	348	920	348
010B				293	0	0	0	0	516	516	516	516	516	0	0	0	0	0
011A				623	98	355	623	355	355	0	0	0	0	333	333	546	920	333
011B				293	0	0	0	0	516	516	516	516	516	0	0	0	0	0
012				653	653	0	0	0	653	653	0	0	0	219	219	0	0	526
013				920	920	0	0	0	920	920	0	0	0	219	219	0	0	219
014				342	342	0	0	0	342	342	0	0	0	272	272	0	0	272
015				285	285	0	0	0	285	285	0	0	0	329	329	0	0	329
016				285	285	0	0	0	285	285	0	0	0	329	329	0	0	329
017				285	285	0	0	0	285	285	0	0	0	329	329	0	0	329
018				285	285	0	0	0	285	285	0	0	0	329	329	0	0	329
019				285	285	0	0	0	285	285	0	0	0	329	329	0	0	329
020				228	228	0	0	0	228	228	0	0	0	359	359	0	0	630
021				228	228	0	0	0	228	228	0	0	0	359	359	0	0	630
022				241	241	0	0	0	241	241	0	0	0	346	346	0	0	607
023				228	228	0	0	0	228	228	0	0	0	359	359	0	0	630
024				228	228	0	0	0	228	228	0	0	0	630	630	630	0	359
025				228	228	0	0	0	402	228	0	0	0	359	630	630	0	359
026				402	402	0	0	0	228	228	0	0	0	630	630	630	0	359
027				228	228	0	0	0	228	228	0	0	0	630	630	630	0	359



## REPORT AND INFORMATION SOURCES

Additional copies "*Light Emitting Diodes for Traffic Signal Displays*" from the City of Philadelphia's Municipal Energy Office, are available from:

PTI Publications Center  
Tel: 301/490-2188  
Fax: 301/604-0158

For additional information on the process and the results of the work described in this report or for information on the overall energy management programs in the City of Philadelphia, PA, please contact:

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