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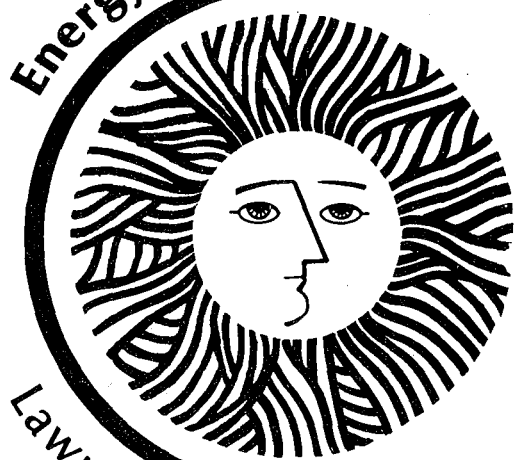
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Testing of Energy Conservation
of Electronic Ballasts for
Fluorescent Lighting
Review of Recent Results and
Recommendations for Design Goals

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TESTING OF ENERGY CONSERVATION OF ELECTRONIC
BALLASTS FOR FLUORESCENT LIGHTING

REVIEW OF RECENT RESULTS & RECOMMENDATIONS FOR
DESIGN GOALS

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ABSTRACT

The performance of two 40-watt T-12 fluorescent lamps driven by both standard core-coil, and electronic ballasts has been measured over a range of temperatures and input voltages that simulate conditions they would experience in typical building installations . When using new energy-efficient lamps and electronic ballasts, an efficiency of 90 lumens/watt has been achieved, which represents an efficiency improvement of over 37% relative to standard lamps and core-coil ballasts. From these results, several design targets are suggested for ballast developers.

Additional features of the electronic ballasts, (low noise, no flicker, and light level control), have potential to increase the use of efficient light sources (gas discharge types) as well as permit less costly luminaire construction. The dimming feature should also conserve energy whenever applied.

I. INTRODUCTION

For the past two years, the Lawrence Berkeley Laboratory (LBL), supported by the Department of Energy (DOE), has managed a program to develop an electronic ballast to operate two 40-watt T-12 fluorescent lamps more efficiently than the core-coil type ballasts that are currently employed. The electronic ballasts used in this program have been developed by Stevens Luminoptics, Danville, California and IOTA Engineering, Inc., Tucson, Arizona, in conjunction with Excel Electronics Systems, Division of Beatrice Foods Co. The performance ^{1,2,3,4} of the first prototype models has been reported and these results have provided evidence to substantiate the claims that these electronic ballasts are more efficient than the core-coil ballasts.

The electronic ballasts have been designed to operate standard fluorescent lamps in standard fixtures, such that they could readily replace the present ballasts, with no wiring changes. In order to assess the reliability of these new ballasts, a large scale demonstration is underway in which three floors of the Pacific Gas and Electric Company (PG&E) office building in San Francisco, California, have been refitted with energy-efficient ballasts. Two floors feature electronic ballasts from the two manufacturers noted above, while the third floor uses new high-efficient core-coil ballasts.

PG&E has metered each of these floors to measure the energy consumption before and after the installation of the new ballasts.

The electronic ballasts for the demonstration have been manufactured by Stevens Luminoptics and Excel Electronic Systems (for IOTA Engineering). Hence, the IOTA ballasts are designated IOTA-EXCEL in this report. The high-efficiency core ballasts are supplied by the Advance Transformer Company.

This report presents the performance data for the prototypical electronic ballasts that have been produced to be installed at the PG&E demonstration site. The measurements have been made at LBL's lighting laboratory. From these measurements, that include measurements with new high-efficient fluorescent lamps that have been recently introduced by the lighting industry, several new design targets are suggested that should be considered by electronic ballast developers.

We will also discuss the implications of additional features of the electronic ballasts, (e.g., low audible noise, no flicker, and the control of the light level) that occur with the use of electronic ballasts, and several additional features leading to other economies.

II. EXPERIMENTAL

The data have been collected at the LBL lighting laboratory using electronic ballasts supplied by the ballast developers, compared with commercially-available standard and high-efficiency core-coil ballasts. The core-coil ballasts include types: GE (8G-1022W), Universal (446-L-SLH-TC-P, 443-L-STF), GE Wattmeiser II (8G1028W), and Advance Mark III (V-2540-1-TP).

Since the performance of these core-coil ballasts are well documented, and of CBM rating, they provide a reference that allows one to assess the relative performance of the electronic ballasts.

The power input, RMS voltage, RMS current, the arc power to the lamps is measured as well as the light output from the two 40-watt lamps. The light output from a portion of the two lamps is determined by measuring the illumination of a ground glass plate positioned above the lamps. This value is assumed to be proportional to the total lumen output of the lamps. The light output of the lamps measured in the above set up have been calibrated with our integrating cylinder and we have found that the illumination measurement of one foot-candle is equivalent to a light flux of 128 lumens. The electrical characteristics are measured with a Data Precision Model 248 voltmeter, General Electric Model G0-91 ammeter, a Weston Model 432 wattmeter, and a Clark-Hess Model 255 high

frequency Volt-Amp-Wattmeter. The lumination is measured with a Tektronic J16 photometer with a J6511 probe. The lamp wall temperature is measured with a Type T thermocouple.

All of the lamps used in this experiment have been operated for at least 100 hours, but otherwise were new at the start of the tests.

III. SYSTEM PERFORMANCE

A. Lamp Wall Temperature

Figure 1 (a, b, and c) shows the relative change in the input power, light output, and system efficiency for a two-lamp fixture operated with core and electronic ballasts over a range of minimum wall temperatures from 30°C to 50°C.

The lighting system with core ballasts shows a monotonic decrease in both power and light above 30°C. Note the different functional dependence between the IOTA-EXCEL and Steven ballasts. This difference reflects the different circuit design concepts employed by the two ballasts.

The light output from these two R-40 type lamps is specified at a 25°C ambient to be 6300-5% lumens, see American National Standards Institute (ANSI) C82.1, Sec. 5.3.2.1. The lamp wall temperature is near 30°C. Fixture manufacturers generally design their units to operate at 40°C, as evidenced by

the data presented in Figure 1. And while the fixture designers attempt to achieve this condition, where there is inadequate ventilation, lamps will exceed this temperature. Thus, lamp wall temperatures typically operate between 40°C and 50°C , and sometimes greater.

B. Ballast Temperature

In the measurements described in the preceeding section, although the lamp wall temperature was increased, the ballast was fixed at a free air ambient of about 25°C . Since, in a fixture, the lamp and ballast are in the same ambient temperature, an experiment was conducted to measure the lighting system performance for increasing ballast temperature with the lamp at 40°C . The results shown in Figure 2 (a,b, and c) indicate that the ballast temperature, 30°C greater than its temperature in a free air (25°C ambient), has little effect upon power input, light output, and system efficiency (less than 1%). Thus, the predominant change in the lighting systems performance, for both core and electronic ballasts, can be attributed to the temperature of the lamp. However, continuous operation of ballasts in a high temperature environment will adversely affect the operating life of the ballast.

C. Voltage Regulation

Table I lists the values of the lighting systems performance for a variation of $\pm 10\%$ of the rated voltage, as specified

by the American National Standards Institute (ANSI), C82.1 (Sec. 5.5.1). The specification requires that reference lamps driven by ballasts with a $\pm 10\%$ change in rated voltage must supply $\pm 25\%$ of the rated lumen output. All systems are well within this requirement; however, the .2% regulation exhibited by the Stevens ballast demonstrates the excellent regulation that can be obtained for electronic systems.

D. Effect of Heater Power

It is useful to determine the energy savings that can be realized by the removal of electrical power to the heaters of a conventional fluorescent lamp and ballast system during operation, but after start-up. Both the Stevens and the IOTA-EXCEL ballasts take advantage of this savings. The results of the study are listed in Table II, where the results for a standard core ballast, an IOTA-EXCEL ballast, and a ballast supplied to LBL by the Data Power Corporation are shown. The core-coil and the Data Power ballast, in their normal operating mode, do not remove the filament power. The input power to these two ballasts is reduced by one to two watts, and the system efficacy is improved by 1% to 2%. These results are not obtained by IOTA ballasts, since most of the savings has already been achieved by the existing circuitry. The savings for the conventional lamp-ballast are much less than the nominal 5 watts expected. (Five watts of power is supplied to the filaments).

E. New Energy Efficient Lamps

The lamp industry is presently marketing new fluorescent lamps that have a reduced power rating. The Type I lamps employ a new gas fill, while the Type II lamps also have a new gas fill and, in addition, coat the tube with a more efficient phosphor. Table III shows the performance of both the core-coil and the electronic ballasts with the standard, Type I, and Type II fluorescent lamps .

For all ballasts with Type I lamps, both the input power and the light output is reduced, compared to standard lamps; still the system efficiency is improved 1% to 2%. The power input is the same for all ballasts with the Type I and Type II lamps; however, the light output is increased for Type II lamps. This is reflected in another increase in efficiency of 4% to 6%, or a total of 5% to 8% increase with respect to the ballast operating a standard lamp.

Comparing the most efficient system (the Stevens with Type II lamps) to a standard core and standard lamp system, one finds an efficiency increase of 37.5%. The system efficacy of 90 lumens per watt is in the range of efficacies of the high pressure sodium lamp systems.

At LBL, we only measure a portion of the light from the lamps and have calibrated its proportionally to the total light output.

In order to confirm our measurement relating illumination, as measured for these and the total light flux, the performance of these fluorescent systems have been measured by an independent lighting laboratory⁵ that measures the total light flux from the lamps calibrated with NBS standard lamps. The measurements between the two laboratories are in agreement.

IV. ELECTRONIC BALLAST DESIGN TARGETS

A. Light Output

Table IV lists the light output of the lighting system with the core ballasts based upon the data presented in Figure 1a. To be consistent with design practice of the recent past, the electronic ballasts should be designed to achieve the same light output as standard lamps operating at their actual operating temperatures.

Thus, ballasts should be designed to obtain equivalent light output as the core-ballasts with the lamp wall temperature at 40°C to 50°C. This corresponds to a 10% decrease in lumen output, such that ballasts to be equivalent should provide approximately 2,800 lumens, initially, from a lamp. The input power for the Stevens and IOTA-EXCEL ballasts are shown in Table IV. The power savings for the electronic ballasts at 40°C operating temperature are 16.7 to 21.2 watts per ballast and in a more severe environment can be as high as 17.7 to

23.3 watts per ballast.

B. Heating Power

With proper design, the removal of the heater power does not adversely affect the lamp life with the electronic ballasts. Incorporating this design should be based upon the cost of the added components. Since the efficiency improvement is 2%, or about 10% of the energy savings, the parts should be less than 10% of the ballasts cost.

Dimming ballasts require power to the filaments at the lower light levels. It would probably not be cost-effective for dimming ballast to incorporate a means for reducing heater power. At least not for present-day lamp designs.

Both the Stevens and the IOTA-EXCEL ballasts reapply the filament power in the dimming mode, and the results obtained here question the economic justification of the need to switch the power down at all.

C. Lamps

The electronic ballasts in this report were designed to operate standard two 40-watt T-12 rapid-start lamps. System efficacies approaching 90 lumens per watt have been achieved with electronic ballasts and the new Type II energy-efficient lamps. It is very likely that these lamps will be in general use, thus, electronic ballast designers should design their ballasts to operate these new lamps. It is projected that new lamp designs optimized for high frequency operation permitted

by electronic ballasts can be even more efficient.

D. Pricing

Table IV shows that 21 to 23 watts per ballast can be saved operating conventional lamps having the same light output under typical operating conditions. With new energy-efficient lamps, it can approach 28 watts per two-lamp ballast. (For the electronic ballast compared with efficient core-coil two-lamp ballasts, the savings approach 11 watts for both the conventional lamps and energy-saving lamps.) For the conventional fluorescent lamp and ballast, using an annual operation of 4,000 hours, at five cents per kilowatt-hour, the annual energy savings is \$4.60 to \$5.60 per ballast (two-lamps) supplying the equivalent light output. Using the maximum savings, and based upon a two-year payback, a \$11.20 premium cost to the user can probably be justified.

V. OTHER FEATURES OF ELECTRONIC BALLASTS

In addition to the energy savings associated with the use of electronic ballasts, there are three additional features that fluorescent lighting systems possess when operated by these electronic ballasts. These are: low audible noise, no flicker, and dimming control.

The first two features, low audible noise and no flicker, can be important for extensions of the electronic ballast concept

to other types of gas discharge lamps such as HID lamps. The indoor use of HID lamps, where certain visual tasks would find the normal flicker and noise disturbing, could readily benefit. For example, reading and studying tasks in libraries and school classrooms, as well as delicate and precise manufacturing tasks in industrial areas, are two possible extensive applications of this efficient light source operated at the higher frequencies with electronic ballasts.

The dimming feature of these electronic ballasts are generally obtained at very little extra cost. This light level control is achieved with low voltage signals to the ballast. Manual controls can be incorporated into the ballast design to permit the adjustment of the light level after installation to accommodate the particular needs in an area. The cost of this occasional light adjustment would be minimal.

Automatic controls are available that can be integrated with those electronic ballasts to control light levels after installation to the needs of the area. In addition, these controls can be made such that the light levels will respond to the more immediate lighting needs of the area, e.g., daylighting, lamp lumen depreciation, changes in visual task, evening cleaning tasks, daily changes in work periods, and peak demand requirements.

It is virtually impossible for a lighting designer to achieve

optimum lighting efficiency for all the visual tasks that may occur in a commercial or industrial building over time, without occasional costly renovation and movement of lighting systems. The electronic ballasts, with controls that permit dimming of gas discharge tubes, will not only improve the operation efficiency of the light source, but will permit economic adjustments of the lighting system to achieve the most efficient light levels and light distribution to execute the tasks that are required.

Several additional features of the ballast derive from the very light weight (about one-fifth of the core-coil ballast) and the smaller size (about one-half or less). These features make retrofit easy, and permit new fixtures to be designed for substantially less cost.

Another benefit of the high-frequency operation is that no metal (grounding) starting aid is required, permitting fixtures to be made of plastic if desired. The electronic ballast also permits starting at low temperatures not permitted by conventional core-coil ballasts.

VI. ACKNOWLEDGEMENT

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5. B. Jones, Lighting Research Laboratory, Orange, New Jersey, (To Be Published), August 1978.

LIST OF FIGURES

- Figure 1 Affect of lamp wall temperature upon input power, light output and efficacy of 2 lamp 40 watt T-12 fluorescent lamp system with (a) core coil ballast, (b) IOTA-EXCEL ballasts and (c) Stevens ballast.
- Figure 2 Affect of ballast temperature upon input power, light output and efficacy of 2 lamp 40 watt T-12 fluorescent lamp system for (a) core-coil ballast, (b) IOTA-EXCEL ballast and (c) Stevens ballast.

TABLE I

VOLTAGE REGULATION

Ballast	Standard Core			IOTA-EXCEL 60-5			STEVENS 07-136C		
Lamp Temperature ($^{\circ}\text{C}$)	40 $^{\circ}\text{C}$			40 $^{\circ}\text{C}$			40 $^{\circ}\text{C}$		
Input Voltage (volts)	132	120	108	132	120	108	305	277	249
Input Power (watts)	102	94	87	81	75	68	73	72	71
Light Flux (lumens)	6016	5837	5581	6067	5619	5171	5760	5773	5747
System Efficacy (lumens/watt)	59	63	64	76	76	76	82	83	84

Standard T-12-F40 RS Lamps

TABLE II

EFFECT OF FILAMENT POWER ON EFFICIENCY

	Standard Core		IOTA-EXCEL #60-5D1		DATA POWER	
	Normal	Open-Filament	Normal	Open-Filament	Normal	Open-Filament
Power Input (Watts)	97	95	67.5	68	83	82
Power Lamp (Watts)	72	73.2	56.4	57.4	57.6	61.4
Ballast Efficiency	.74	.77	.83	.84	.69	.75
Lamp Efficacy (1/watt)	82	81	95	93	106	101
System Efficacy (1/watt)	61	63	78	79	74	76
Lamp Wall Temperature (°C)	40°C		40°C		40°C	

Standard T-12-F40 RS Lamps

TABLE III
BALLAST PERFORMANCE WITH DIFFERENT FLUORESCENT
T-12 RAPID START LAMPS

BALLAST	STANDARD CORE			EFFICIENT CORE*			IOTA-EXCEL 64P-9			STEVENS 803-017		
Lamp Type	1	2	3	1	2	3	1	2	3	1	2 ⁺	3 ⁺
Lamp Temperature (°C)	40°	40°	40°	40°	40°	40°	40°	40°C	40°	40°	40°C	40°
Input Power (watts)	93.5	81	81.5	84	73.1	73	74.5	67	67	77	70	69.9
Power Factor	98.5	.94	.93	.98	.98	.97	.91	.89	.89	.93	.90	.90
Power to Lamp (watts)	71	58.3	57.4	71	58.4	57.3	60.6	54	53.6	65	60.1	58.3
Light Flux	6093	5350	5606	6080	5402	5645	5862	5466	5760	6400	5952	6272
Ballast Efficiency	.759	.720	.704	.845	.800	.785	.813	.806	.800	.844	.858	.830
Lamp Efficacy (l/w)	86	92	98	86	92	98	97	101	108	98	99	108
System Efficacy (l/watt)	65	66	69	72	74	77	79	82	86	83	85	90

Lamp 1 - Standard T-12 RS F40

2 - Efficient Type I T-12 RS F-35 (Mfg. A)

3 - Efficient Type II T-12 RS F-35 (Mfg. B)

*Average of 3 Ballasts from different manufacturers

+Lamps dimmed with ballast to appropriate light levels

TABLE IV

LIGHT OUTPUT DESIGN TARGETS**

Lamp Wall Temp (°C)	30°C		40°C		50°C	
	Light Flux Lumens	Power Watts	Light Flux Lumens	Power Watts	Light Flux Lumens	Power Watts
Standard Core	6208	99	5837	94	5338	89.5
IOTA-EXCEL	6208	86.6	5837	77.3	5338	71.8
Stevens	6208	79.1	5837	72.8	5338	66.2

**Based upon data from ballast shown in figure 1.

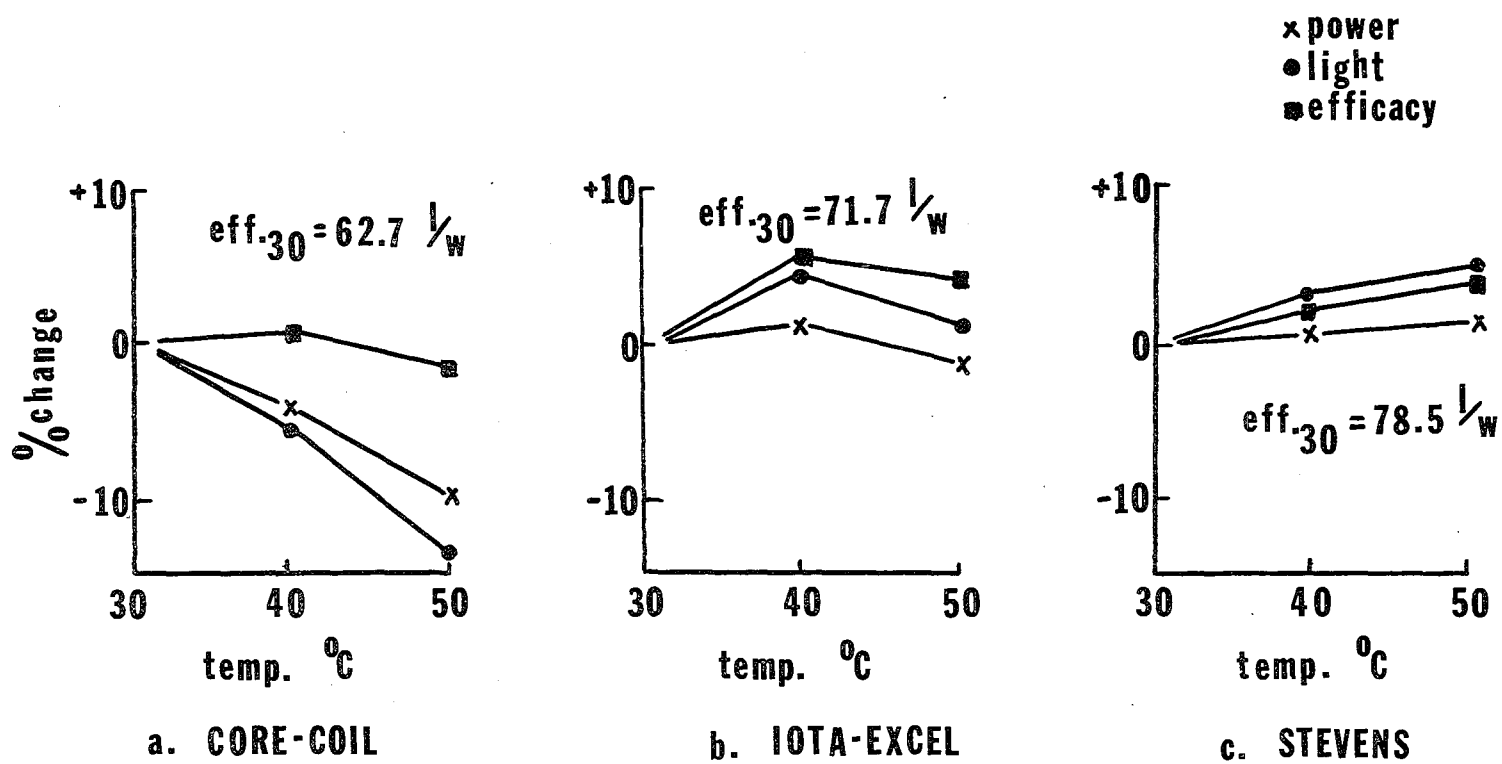
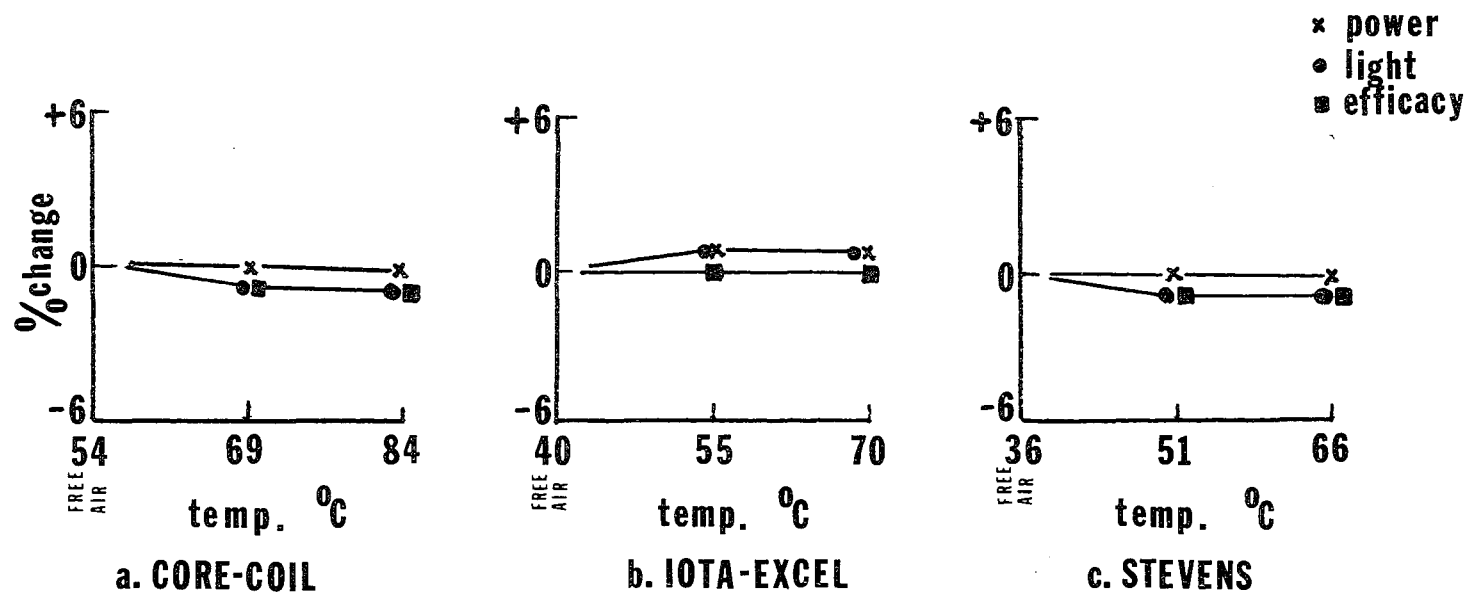


Figure 1



XBL 7812-13212

Figure 2

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