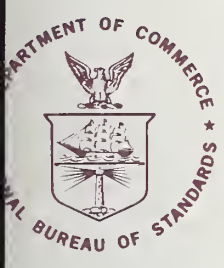

NBS TECHNICAL NOTE 886

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Modification of Fluorescent Luminaires for Energy Conservation

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Modification of Fluorescent Luminaires for Energy Conservation

Robert W. Beausoliel,
William J. Meese and
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Sponsored by

Federal Energy Administration
Washington, D.C. 20402

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Issued October 1975

National Bureau of Standards Technical Note 886

Nat. Bur. Stand. (U.S.), Tech. Note 886, 15 pages (Oct. 1975)

CODEN: NBTNAE

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1975

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C13.46:886). Price 65 cents. (Add 25 percent additional for other than U.S. mailing).

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Modification of Fluorescent Luminaires for Energy Conservation

Robert W. Beausoliel, William J. Meese, and Gary Yonemura

Reducing energy consumption in existing buildings by reducing the number of lamps presents technical problems when more than one fluorescent lamp operates from a single ballast. A preliminary investigation was made whereby capacitors were substituted for one fluorescent lamp in a two-lamp luminaire which operated with a single ballast. Under optimum conditions, lighting efficiency (foot-candles per watt) was nearly as high at reduced power input as it was with two lamps operating normally. No failures in lighting equipment or capacitors occurred and no fire hazards, other safety hazards or other unsatisfactory occurrences were observed. A more thorough investigation involving a number of parameters is needed to ascertain the feasibility of this modification.

Key words: Capacitors; energy conservation; fluorescent lamp; fluorescent luminaire; lighting efficiency; power factor.

1. INTRODUCTION

When two or more fluorescent lamps operate from a single ballast, removing one lamp may not permit the other lamp to operate effectively. This may cause problems in existing buildings when it is desired to conserve energy by reducing the amount of artificial light. At the request of the Federal Energy Administration a preliminary investigation of a possible energy saving procedure involving fluorescent lighting was undertaken by the Building Services Section with cooperation from the Sensory Environment Section of NBS.

1.1 Purpose

The purpose of this investigation was to determine if removing one fluorescent lamp from a two-lamp luminaire with a single ballast and replacing the lamp with various capacitors would permit the luminaire to operate safely, reliably and efficiently. This preliminary investigation was made to determine if it was worthwhile to pursue a more comprehensive investigation of this proposed modification.

1.2 Scope

Appropriate data with a fluorescent luminaire operating both normally with two lamps and with capacitors substituted for one lamp was obtained. This data involved luminous flux output, power consumption, power factor, voltage, current, phase relationships, any observed safety or fire hazards, any observed reliability problems and any other unforeseen occurrences.

1.3 Fluorescent Luminaire Voltages

Most fluorescent luminaires at the National Bureau of Standards which are suspended from ceilings operate from a nominal 277 volt, a-c, 60 hertz supply of electric power to the ballasts. This is a common supply voltage for overhead lighting systems in commercial and industrial buildings. However ballasts which operate from a nominal 120 volt supply are also common.

Conventional rapid start fluorescent lamps of the same wattage are interchangeable in luminaires requiring either nominal 120 volt or nominal 277 volt power supplies. The National Electrical Code [1] prohibits 277 volt power supplies for luminaires in residential occupancies and permits their use in industrial occupancies only under certain specific conditions, including the requirement that such luminaires be mounted at least eight feet above the floor.

2. EQUIPMENT USED IN INVESTIGATIONS

All equipment used in this investigation (luminaires and associated equipment and capacitors) are readily available on the open market.

2.1 Lamps and Associated Equipment

The luminaire used in the investigation contained two four-foot rapid start fluorescent lamps (rated 40 watts each) and a single ballast designed for 120 volt power supply. Marking on the ballast indicated it was for use with two rapid-start 40 watt fluorescent lamps in series.

The luminaire which was used in this investigation originally contained a ballast designed for 277 volt power supply. This ballast was replaced with a ballast designed for 120 volt power supply for reasons of safety and convenience in performing the tests.

2.2 Capacitors

Capacitors used in the investigation were rated for 200 volts d.c. and the tolerance of their capacitance values were $\pm$ 20%. Higher quality, more expensive capacitors, including capacitors designed to withstand higher voltages are available. A 2 ampere fuse was used in series with the capacitors for protection.

3. TEST SET-UPS

Figure 1 illustrates the basic test set-ups for these investigations. The principal instruments used in the tests were:

1) A multi-purpose meter which measured supply voltage, current and power and with which the supply voltage could be regulated. All measurements were made with a supply voltage of 120.

2) An illumination meter with a cosine and color corrected detector. The lamp under test was shaded from other light in the laboratory. The detector was placed six inches from and was centered with respect to the lamp under test. All illumination measurements were made under identical conditions.

3) A volt meter to measure the voltage drops across capacitors in the luminaire.

4) A dual trace oscilloscope to display the current and voltage waves.

Tests were made with the ambient temperature at 23°C. In Figure 2, Item I illustrates two fluorescent lamps in the fixture as they would appear in a normal installation. Items II, III, and IV illustrate methods whereby one or more capacitors were connected when one lamp was removed from the luminaire.

4. PRELIMINARY TESTS

A tests was made to determine if one lamp would operate with the other removed. Referring to Figure 2, Lamp A did not operate if Lamp B was removed. However, when Lamp A was removed, Lamp B would very dimly light. Its illuminance was so low that it would not register on the illumination meter. When capacitors with two microfarads or more were used in either lamp position, the lamp in the other position lit brightly.

Tests were also made to determine the effects of connecting capacitors in different positions as shown in Item II, III and IV in Figure 2. The results were the same with the parallel combination of capacitors between outboard pins (Item II) of the lamp holder or the inboard pins (Item III). However, connecting across pins in each lampholder had no effect (see Item IV); the lamp did not operate.

5. BASIC APPROACH OF INVESTIGATION

The basic approach was to obtain appropriate data with two fluorescent lamps in the fixture (for reference) and with various values of capacitors substituted for one lamp.

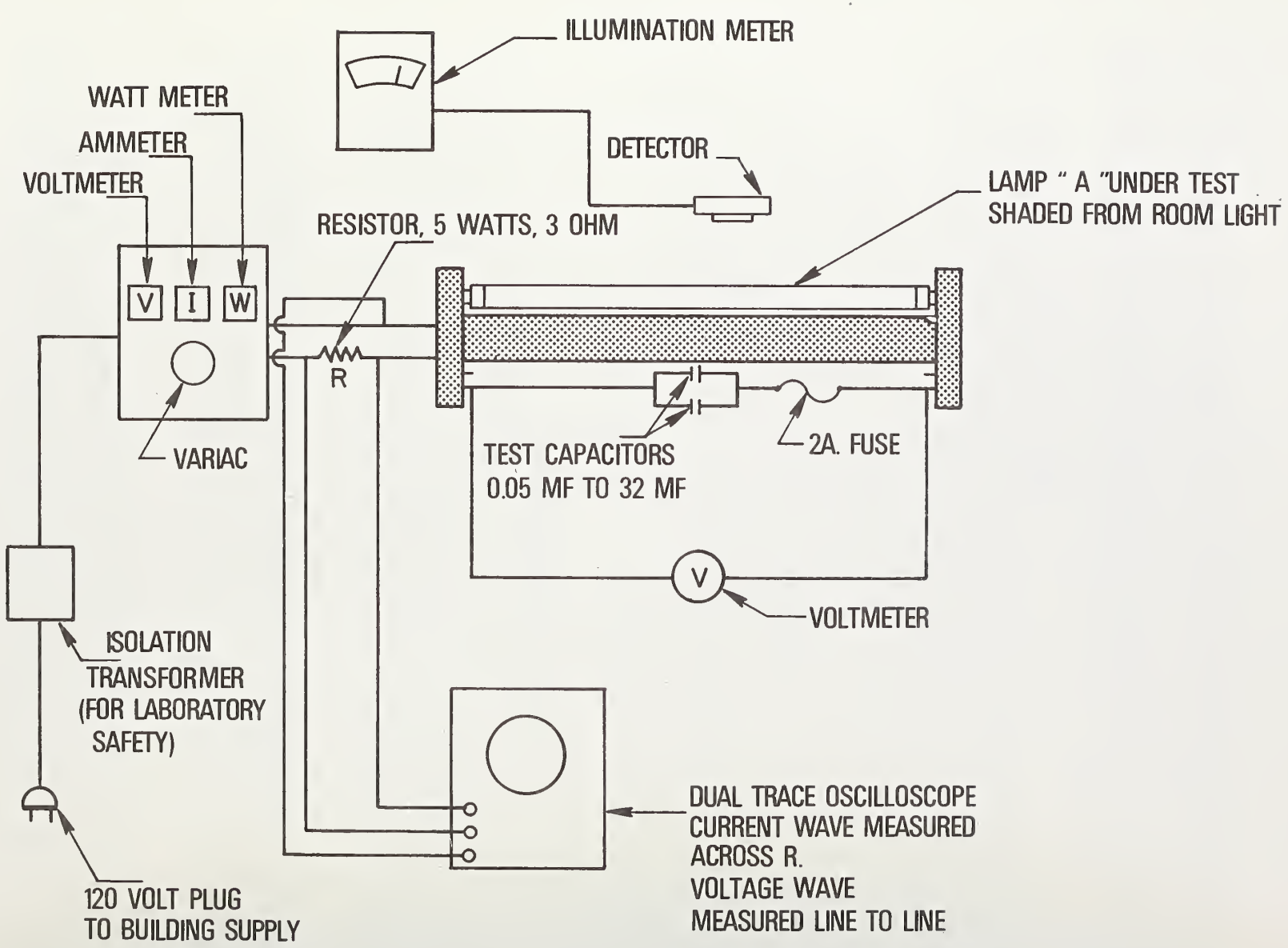


FIGURE 1 - TEST SET UP

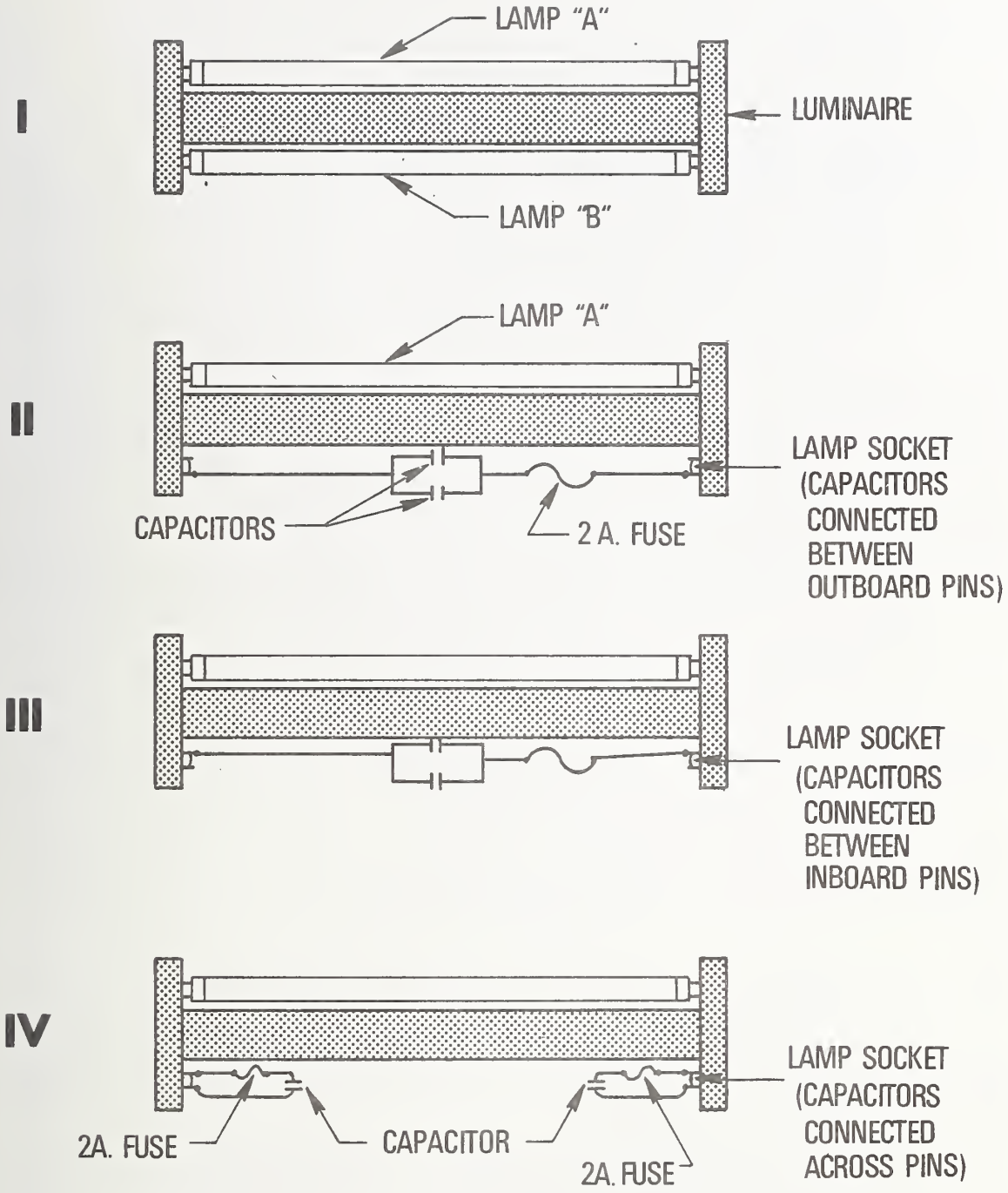


FIGURE 2 - LAMPS AND CAPACITOR CONNECTIONS

5.1 Measurements

The following measurements were made:

(1) Total power input in watts.
(2) Supply voltage - adjust to 120 volts.
(3) Current in amperes.
(4) Whether input current was leading or lagging the supply voltage.
(5) Voltage drop across capacitors.
(6) Luminous flux output of lamp.
With two lamps in the fixture the illuminance of one lamp, which was Lamp A in Figure 1, was measured.

5.2 Calculations

From this information apparent power (volt-amps), power factor and lamp efficiency calculations (foot-candles per watt) were made.

5.3 Tabular Results

Basic measurements and calculations are listed in Table 1. Explanation of symbols is as follows:

C - capacitance (microfarads)
FTC - illuminance (foot-candles)
W - power (watts)
FTC/W - lamp efficiency (foot-candles per watt)
V - supply voltage (volts)
I - current (amperes)
VA - apparent power (volt-amps)
PF - power factor (percent)
Ld/Lg - current leading (Ld) or lagging (Lg)
VD - voltage drop across capacitors (volts)

5.4 Graphic Results

Figure 3 contains plots of (1) illuminance as a function of power input and (2) power factor as a function of power input. Values of capacitances which were substituted for one fluorescent lamp when measurements were made are indicated.

Figure 4 is a plot of lamp efficiency as a function of power input. Values of capacitances used when measurements were made and power factors with each capacitance value are shown.

5.5 Observed Results

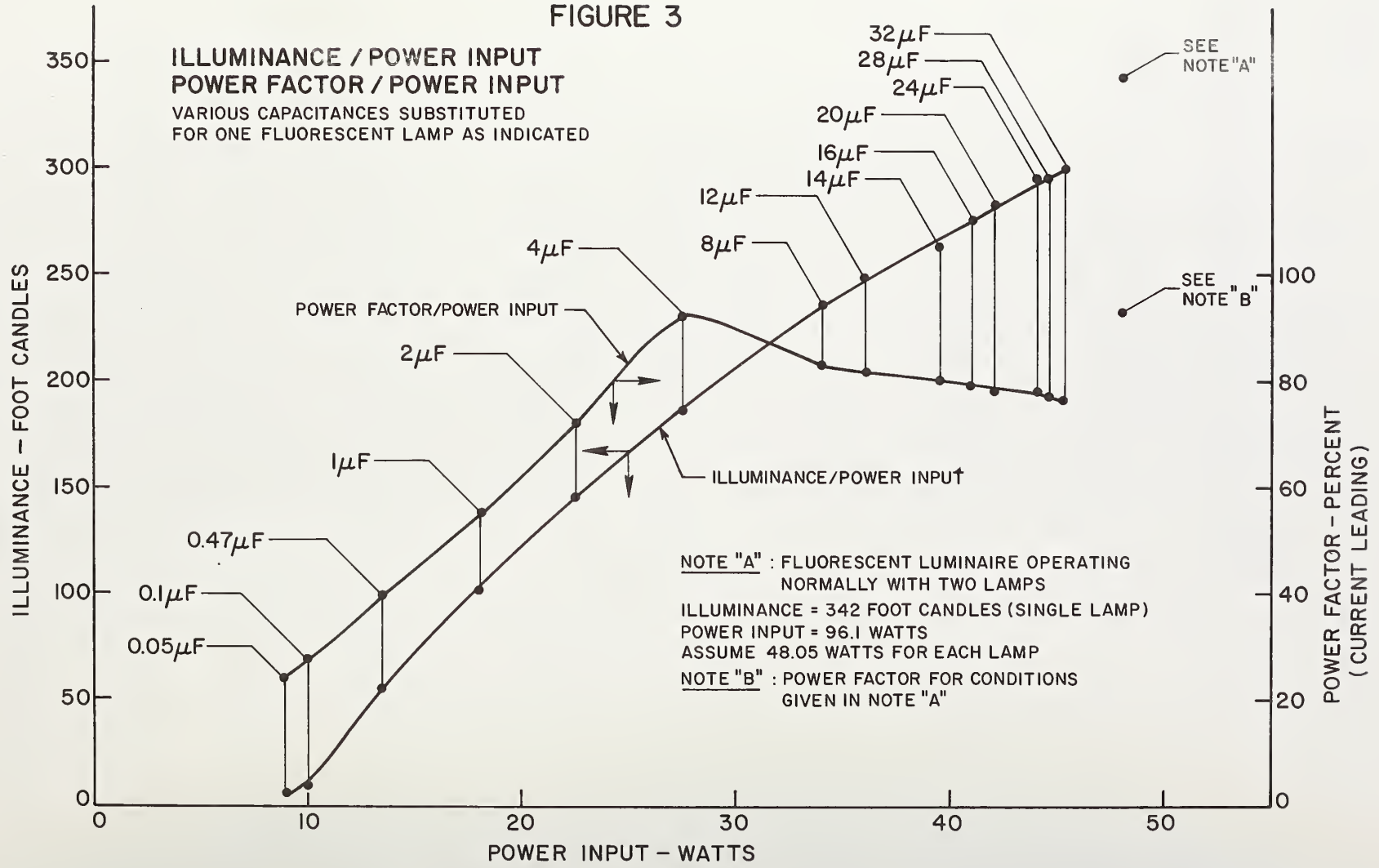
No obvious fire or safety hazards were observed by the investigators. There were no failures with lamps, associated equipment or with any capacitors used. No unforeseen events occurred. There were no events, happenings or other observations which would indicate that any reliability or durability aspects would be unsatisfactory in the brief period of testing.

Capacitance (C)	Illuminance (FTC)	Power (W)	Lamp Efficiency (FTC/W)	Supply Voltage (V)	Current (I)	Apparent Power (VA)	Power Factor (PF)	Current Ld/Lg	Voltage Drop (VD)
0.05	11	9.0	1.2	120	0.325	39.0	0.23	Ld	-
0.1	17	10.0	1.70	120	0.32	38.4	0.26	Ld	-
0.47	53	13.5	3.92	120	0.29	34.8	0.39	Ld	-
1	101	18.0	5.61	120	0.30	36	0.50	Ld	-
2	144	22.5	6.40	120	0.26	31.2	0.72	Ld	175
4	185	27.5	6.72	120	0.25	30.0	0.92	Ld	140
8	236	34.0	6.94	120	0.34	40.8	0.83	Ld	105
12	249	36.0	6.91	120	0.37	44.4	0.81	Ld	80
14	265	39.5	6.71	120	0.41	49.2	0.80	Ld	-
16	275	41.0	6.70	120	0.43	51.6	0.79	Ld	70
20	284	42.0	6.76	120	0.45	54.0	0.78	Ld	60
24	293	44.0	6.66	120	0.47	56.4	0.78	Ld	55
28	293	44.5	6.58	120	0.48	57.6	0.77	Ld	36
32	297	45.0	6.60	120	0.49	58.8	0.76	Ld	33
			WITH TWO LAMPS INSTALLED						
-	342*	96.1	7.11	120	0.86	103.2	0.93	Ld	-

TABLE 1

* For the one lamp under test

FIGURE 3


ILLUMINANCE / POWER INPUT
POWER FACTOR / POWER INPUT
VARIOUS CAPACITANCES SUBSTITUTED
FOR ONE FLUORESCENT LAMP AS INDICATED
32μF
28μF
24μF
20μF
16μF
14μF
12μF
8μF
4μF
2μF
1μF
0.47μF
0.1μF
0.05μF
SEE NOTE "A"
SEE NOTE "B"
POWER FACTOR/POWER INPUT
ILLUMINANCE/POWER INPUT
NOTE "A" : FLUORESCENT LUMINAIRE OPERATING NORMALLY WITH TWO LAMPS
ILLUMINANCE = 342 FOOT CANDLES (SINGLE LAMP)
POWER INPUT = 96.1 WATTS
ASSUME 48.05 WATTS FOR EACH LAMP
NOTE "B" : POWER FACTOR FOR CONDITIONS GIVEN IN NOTE "A"
ILLUMINANCE – FOOT CANDLES
0
50
100
150
200
250
300
350
POWER INPUT – WATTS
0
10
20
30
40
50
POWER FACTOR – PERCENT (CURRENT LEADING)
0
20
40
60
80
100

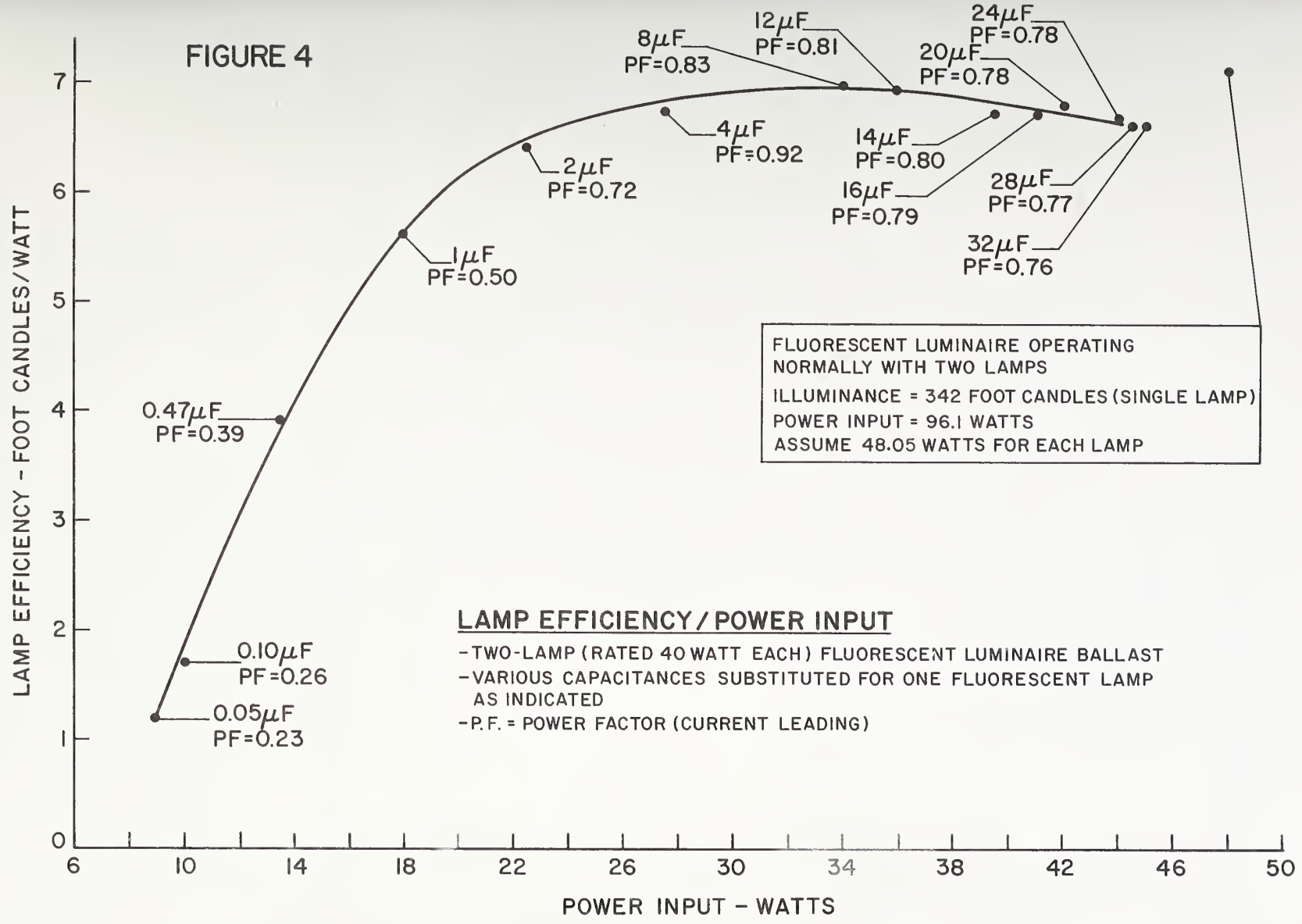


FIGURE 4
LAMP EFFICIENCY - FOOT CANDLES/WATT
POWER INPUT - WATTS
0
1
2
3
4
5
6
7
6
10
14
18
22
26
30
34
38
42
46
50
0.05μF PF=0.23
0.10μF PF=0.26
0.47μF PF=0.39
1μF PF=0.50
2μF PF=0.72
4μF PF=0.92
8μF PF=0.83
12μF PF=0.81
14μF PF=0.80
16μF PF=0.79
20μF PF=0.78
24μF PF=0.78
28μF PF=0.77
32μF PF=0.76
FLUORESCENT LUMINAIRE OPERATING NORMALLY WITH TWO LAMPS
ILLUMINANCE = 342 FOOT CANDLES (SINGLE LAMP)
POWER INPUT = 96.1 WATTS
ASSUME 48.05 WATTS FOR EACH LAMP
LAMP EFFICIENCY / POWER INPUT
-TWO-LAMP (RATED 40 WATT EACH) FLUORESCENT LUMINAIRE BALLAST
-VARIOUS CAPACITANCES SUBSTITUTED FOR ONE FLUORESCENT LAMP AS INDICATED
-P.F. = POWER FACTOR (CURRENT LEADING)

Voltage drop measurements across capacitors are listed in the table. Data on transient voltage "spikes" when the lamp is turned on was not obtained. Static and transient voltages had no observable effect on capacitor life during these limited experiments.

5.6 Reversing Lamps and Capacitors

Measurements listed in this report are with Lamp A (see Figure 2) in place and with capacitors substituted for Lamp B. With Lamp B in place and with capacitors substituted for Lamp A, measurements involving power input, voltage and current were made with each value of capacitance. These measurements were substantially the same when capacitors and the lamps were in the reversed positions.

6. CONCLUSIONS

1. The preliminary investigations indicated quite promising results. Luminous output in relation to power consumption (ft. candles/watt) under optimum conditions was nearly as high, with one fluorescent lamp and capacitors as it was when two lamps operated normally. Power factors under optimum conditions were also substantially as they were when the lamps operated normally.

2. No hazards, equipment failures or other unfavorable results were observed during the preliminary investigations. It appears that dummy tubes with capacitors could be manufactured and installed and would satisfactorily operate with less power.

3. A more comprehensive investigation of this proposed energy saving measure should be undertaken to address parameters listed in Section 7 of this report on Recommendations.

7. RECOMMENDATIONS

Before any widespread use is made of this proposed energy conservation measure, an investigation should be made to determine:

- designs and types of fluorescent luminaires most common in government and other office buildings
- effects on different designs of fluorescent lighting systems (there are many)
- effects on lighting quality
- noise and interference with radio and t.v., if any
- durability of capacitors
- durability of fluorescent lamps in this mode
- durability of ballasts in this mode
- effects of high ambient temperature, humidity or other environmental conditions
- effects with 277 volt supply
- effects of transient voltages
- effects on different sizes of fluorescent lamps
- optimum capacitance and types of capacitors for various loads and designs
- costs and projected energy savings
- data which approaches "statistical significance"
- thorough assessments of any long term effects, including potential safety or fire hazards.

8. REFERENCES

[1] National Electrical Code, 1975 edition, NFPA #70-75, published by the National Fire Protection Association.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS TN-886	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

MODIFICATION OF FLUORESCENT LUMINAIRES FOR ENERGY CONSERVATION

5. Publication Date: October 1975

6. Performing Organization Code

7. AUTHOR(S) Robert W. Beausoliel, William J. Meese, and Gary Yonemura

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 462-4193

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address (*Street, City, State, ZIP*)

SAME AS ABOVE

13. Type of Report & Period Covered: 3/1/75 - 4/30/75

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

Reducing energy consumption in existing buildings by reducing the number of lamps presents technical problems when more than one fluorescent lamp operates from a single ballast. A preliminary investigation was made whereby capacitors were substituted for one fluorescent lamp in a two-lamp luminaire which operated with a single ballast. Under optimum conditions, lighting efficiency (foot-candles per watt) was nearly as high at reduced power input as it was with two lamps operating normally. No failures in lighting equipment or capacitors occurred and no fire hazards, other safety hazards or other unsatisfactory occurrences were observed. A more thorough investigation involving a number of parameters is needed to ascertain the feasibility of this modification.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Capacitors; energy conservation; fluorescent lamp; fluorescent luminaire; lighting efficiency; power factor.

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[X] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13. 46:886

[ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT): UNCLASSIFIED

21. NO. OF PAGES: 15

20. SECURITY CLASS (THIS PAGE): UNCLASSIFIED

22. Price: 65 cents

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