LBL-17929

Presented at the Electric Power Research
Institute (EPRI) Lighting and Utility Seminar,
San Francisco, CA, May 21-22, 1984

FLUORESCENT FIXTURES AND BALLASTS

R.R. Verderber

May 1984

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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ABSTRACT

This paper discusses the basic parameters of a fluorescent lighting system that affect the illumination level. The parameters include the thermal performance of the fixture and the ballast factor, voltage regulation, and thermal regulation of the ballast/lamp system. Fixtures determine the minimum lamp-wall temperature of the lamps and are described as hot or cold. That is, the lamp-wall temperatures can vary from 39 to 61^{o}C. In general, cool fixtures tend to provide higher light levels and are more efficacious for a given ballast/lamp system.

Solid-state fluorescent ballast/lamp systems have been measured and show a variation in light output from 6170 to 3780 lumens for the two-lamp, F-40, T-12, rapid-start lamps. Lighting designers must obtain this information in order to accurately predict illumination levels in a space.

INTRODUCTION

The key components of a fluorescent lighting system are the lamp, ballast, and fixture. The lamp is the light source, the ballast conditions the input electrical power to the lamp, and the fixture distributes the light. The fixture also determines the manner in which heat will be dissipated and establishes a minimum lamp-wall temperature (MLWT). The power that the ballast supplies to the lamp is influenced by the MLWT.

The quality of the illumination depends on the light distribution from each fixture and the fixtures' arrangement in the space. The quantity of light depends on the coefficient of utilization of the fixture and the thermal interactions between the fixture and lamp, as well as between the ballast and lamp. This paper describes the thermal factors that affect the quantity of light that a lighting system will supply. Several types of fixtures will be described to illustrate the variation in the lamp-wall temperatures obtained for standard certified ballast manufacturers (CBM) ballasts and F-40, T-12, rapid-start, fluorescent lamps.

The above thermal effects will be related to measurements on several types of solid-state fluorescent ballasts. The ballast/lamp parameters that determine the light output of the system will be presented.

LAMP-WALL TEMPERATURE/LIGHT OUTPUT

The functional dependence of light output on the MLWT of a CBM ballast and F-40 lamp is well documented. Figure 1 shows a curve based on measurements at Lawrence Berkeley Laboratory over a range of MLWTs from 22 to 71°C. The relative light output and efficacy are plotted with respect to the values at 37°C. The figure shows that maximum light output is at 37°C and maximum efficacy occurs at 40°C. These data have been reported (1) for the 35-watt F-40 fluorescent lamp over a range of MLWTs from 32 to 60°C. These curves, along with the ballast factor, permit one to determine the light output of the lamps in a fixture when the MLWT of the lamp is known. From the coefficient of utilization, the lighting designer can then calculate the quantity of light that will reach the workplane.

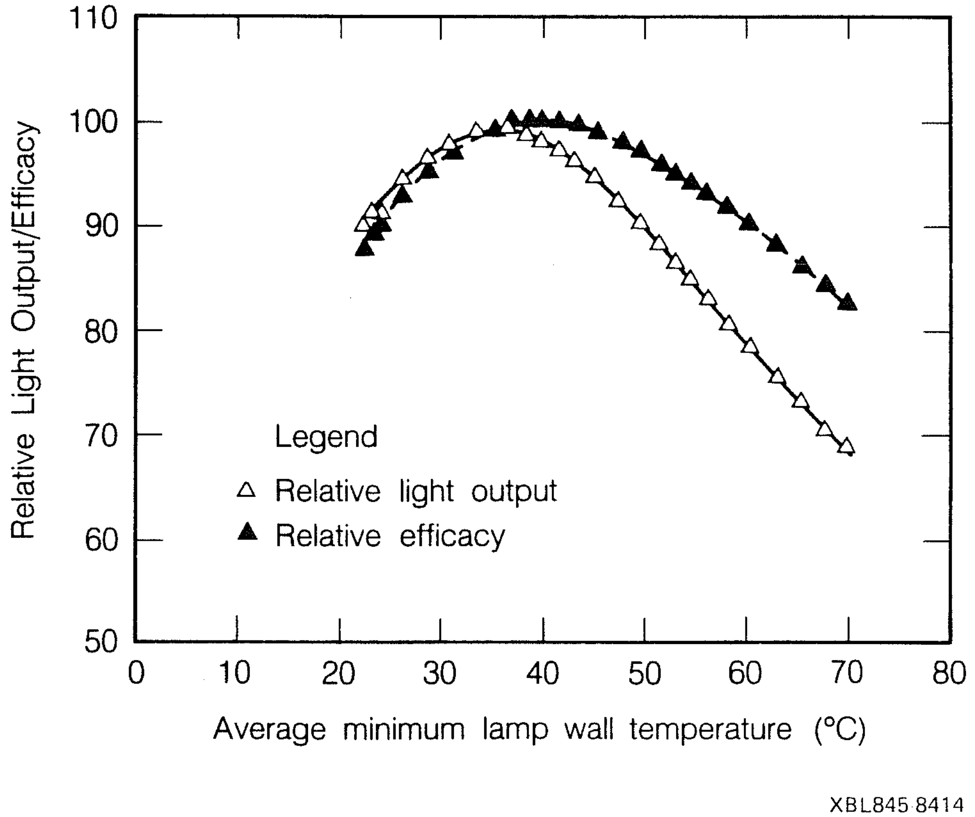

Figure 1 Relative light output and efficacy of CBM-Ballast/F-40 lamps as a function of minimum lamp-wall temperature (22 to 70°C).

THERMAL PERFORMANCE OF FIXTURES

The thermal performance of a fixture is one of several design criteria that the fixture designer must consider. For a standard ballasted F-40 lamp system, the lamps should operate at an MLWT of 38°C for maximum light output, or at 40°C to obtain optimum system efficacy. Achieving either goal depends on the designer's estimate of the ambient environment in which the fixture will be used. Many fixture designs place a low priority on the effects of thermal performance and may primarily consider cost or total light flux. With regard to our present concern, fixtures can be classified as hot or cold based on the MLWT of the lamps.

Hot Fixtures

Lamps having an MLWT that exceeds 40°C are considered hot fixtures. Figure 2 presents schematic illustrations of three hot fixtures: a two-lamp wrap-around, a two-lamp enclosed, and a multi-lamp enclosed ceiling system. In the course of our on-site demonstrations, we have measured the MLWTs of lamps in these types of fixtures.

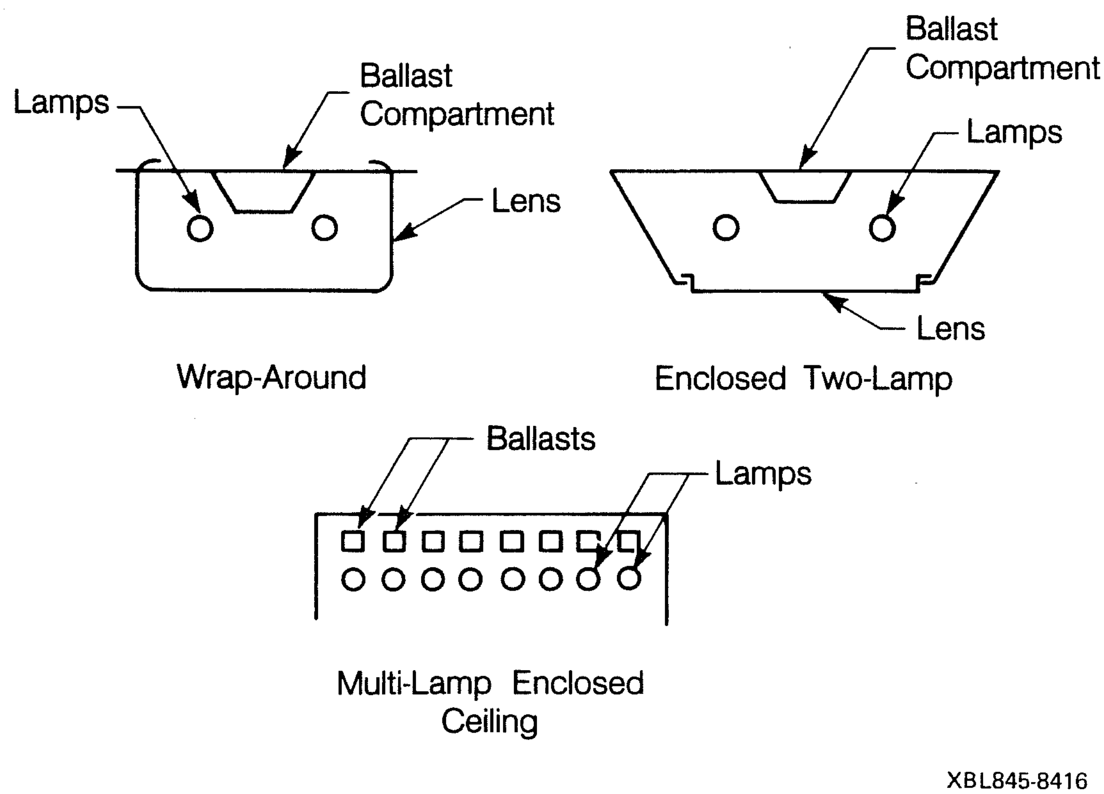

Figure 2 Three schematics of hot fixtures, lamps having high minimum lamp-wall temperatures.

The wrap-around two-lamp fixture was measured in a room having an ambient temperature of 25°C (77°F). The MLWT was 55°C, which lowered the lamp's light output by 15% (see Fig. 1).

Lamps in enclosed two-lamp and multi-lamp (≃ 128) ceiling fixtures were measured at a demonstration site (2). The two-lamp fixture was ceiling-mounted, and both systems operated in an ambient temperature of about 20°C (68°F). The MLWTs of the lamps were 50 and 61°C, respectively. The reduction in light output in the multi-lamp ceiling fixture approached 25%.

Cool Fixtures

Figure 3 shows schematics of two types of cool fixtures that operate lamps at an MLWT about the maximum efficacy (or light output). Both fixtures create an air flow over the lamps. The air-handling fixture acts as a return-air conduit for the HVAC system feeding into a low-pressure plenum.

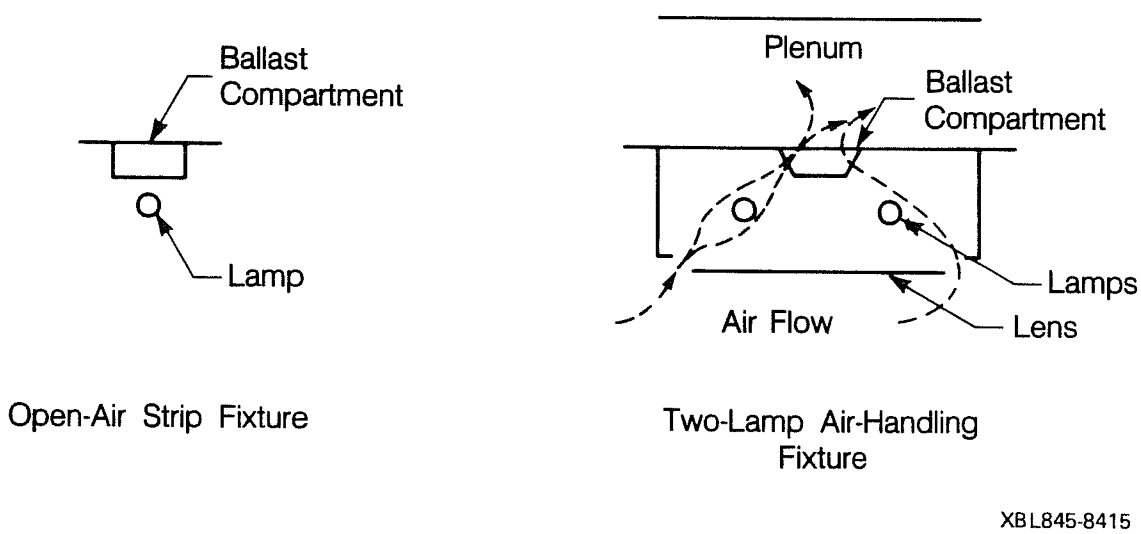

Figure 3 Two schematics of cool fixtures that operate lamps about the optimum efficacy and light output.

The single-lamp open-air strip fixture simulates the ANSI environmental condition used for the standard measurement of fluorescent lamps. The MLWT in a 25°C (77°F) ambient is 37°C.

During a ballast demonstration in a PG&E building in San Francisco (3), MLWTs were measured in two- and four-lamp air-handling fixtures. The MLWTs of the lamps having CBM ballasts were 39.5°C and 44°C for two- and four-lamp fixtures, respectively. The room ambient temperature was about 22°C (71°F). In this demonstration, these fixtures were refitted with solid-state ballasts, which reduced the MLWT by 2 to 4°C. This illustrates the effect on the minimum lamp-wall temperature of reducing the input power to the lamps.

The few on-site measurements of the MLWTs of several types of fixtures show the possible wide ranges of temperatures that occur in practice (37 to 61°C). For standard CBM ballasts and two F-40 lamps, the variation in the light output at the two temperatures is 23%, from the manufacturer's rated output of 5990 lumens to as low as 4160 lumens.

SOLID-STATE BALLASTS

There are no voluntary standards by which to measure the performance of solid-state fluorescent ballasts because of their recent entry into the market. The American National Standards Institute (ANSI) Fluorescent Lamp and Ballast Committee is preparing the groundwork for these specifications. In order to contribute to the better understanding of the solid-state ballasts on the market, the Electric Power Research Institute sponsored a study to measure their characteristics. One set of measurements included the design factors, i.e., characteristics that affect the light output of the ballast/lamp system. Table 1 lists the design factors that were measured for nine types of solid-state ballasts from five different manufacturers. Three ballasts of each type were purchased and three values for each parameter averaged. The results for one type of ballast are listed in Table 2. The input electrical power and the light output were measured at the central design voltage (120 volts) and ± 10% about this voltage (108 and 132 volts). The change in light output at the design voltage (1200) was measured at an MLWT of 39 and 50°C. The system efficacy with the F-40 lamps was 77.4 lumens per watt (lm/W), an increase of 21% above standard core-coil ballast (≃ 64 lm/W). In Table II, the values for relative system efficacy are with respect to a standard core-coil CBM ballast/lamp system operating at the same input voltages.

The range of design factors for all the solid-state fluorescent ballasts is presented below. The factors include ballast factor, voltage regulation, and thermal regulations.

Table 1 Fluorescent Ballast/Lamp Design Factors.

Input Power (watts)
Light Output (lumens)
Ballast Factor
System Efficacy (lumens/watt)
Light Regulation at ± 10% of Design Voltage
Light Regulation between 40 and 50°C MLWT

Table 2 Data for One Solid-State Ballast (120 volts).

Used For: Two F40 lamps
Rated Voltage: 120 volts

	Percent design voltage		
	90	100	110
Ballast Input			
Current (amps)	0.655	0.665	0.667
Power (watts)	64.7	72.2	79.5
Power factor	0.915	0.909	0.903
Output			
Initial light output	5048	5585	6081
Ballast factor		0.887	
Light output regulation	-9.6		+8.9
Thermal light regulation for 10°C increase		-4.2%	
Flicker (%)	5.5	5.3	4.6
System Performance			
Initial system efficacy (lumens/watt)	78.0	77.4	76.5
Relative system efficacy (CBM core)	1.20	1.21	1.23
System efficacy change at 50°C		-5.5	

Ballast Factor

The ballast factor indicates the light output that a ballast/lamp system will provide relative to the manufacturer's light output rating measured under standard ANSI conditions and procedures. Ballast/lamp systems (two-lamp, F40) that meet ANSI standards will provide 95± 2 1/2% of the manufacturer's rated light output.

Figure 4 shows the range of ballast factors measured for the different solid-state ballasts. The solid line is the minimum ballast factor for a CBM ballast (92.5%). The ballast factor for the solid-state ballasts ranged from 97.5 to 81%. These factors were 5% greater and 11% less than for the CBM ballast.

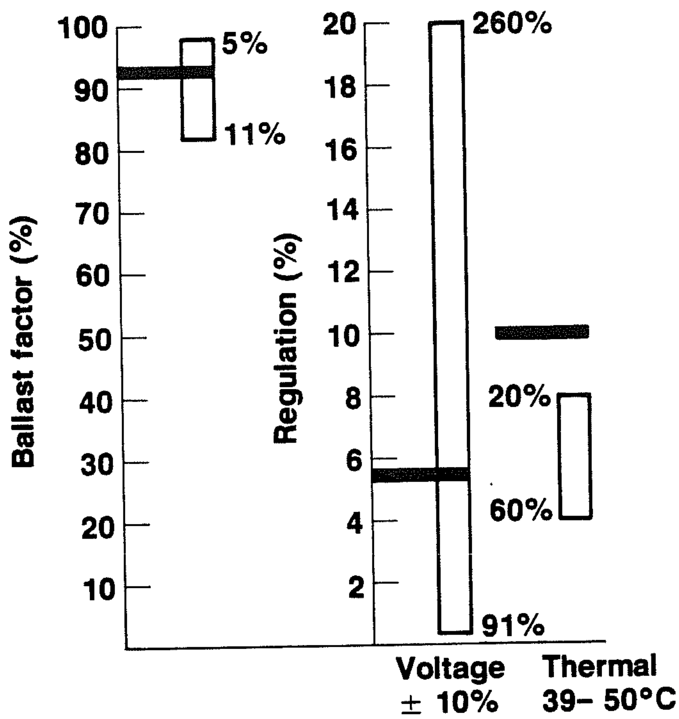

Figure 4 Range of design factors (ballast factor, voltage regulation, and thermal regulation) for nine solid-state ballasts compared with a CBM core-coil ballast.

Voltage Regulation

The changes in light output for a 10% change in input voltage to the various solid-state ballasts are shown in Figure 4. Some solid-state ballasts are very loosely regulated, varying the light output by 20%, while some ballasts are highly regulated, showing changes less than 0.5%. The CBM ballast produced a ± 5.5% change over the 10% voltage change. The ANSI standard for the permissible light output change is ± 25%.

Thermal Regulation

When the MLWT is increased from 39 to 50^{o}C, the light ouput decreases by 10% for a standard CBM F-40 lamp system. The range of changes for solid-state ballasts for the same MLWTs is less for all types of solid-state ballasts, as shown in Figure 4. The changes for the different types of ballasts ranged from 4 to 8%. All the changes were sufficiently large to warrant consideration in designs of "hot" fixtures.

Input/Output

Figure 5 shows that input power to two F-40 lamps ranged from 65 to 90 watts, i.e., from 5 to 33% less. Since the maximum relative system efficacy is 22%, solid-state ballasted systems are sometimes designed to provide low light levels. It is clear that a ballast/lamp system should not be assessed only on input power. In retrofit applications, where spaces may be over-illuminated, a solid-state ballast having a low ballast factor may be an appropriate choice. In new construction and renovation, the system providing the greatest light output may be the judicious choice.

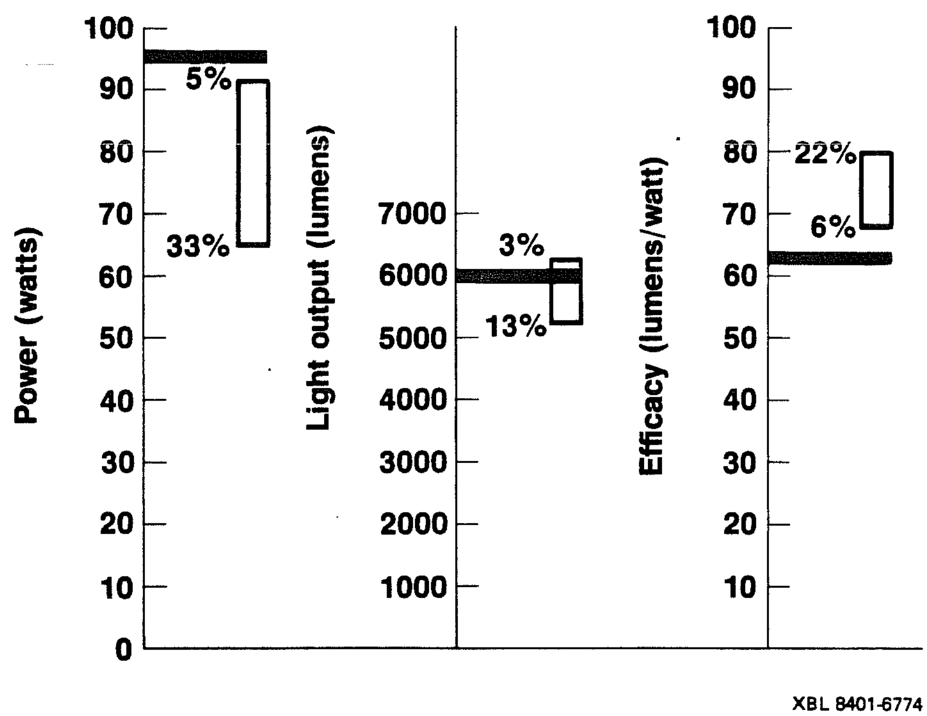

Figure 5 Range of design factors (input power, light output, and efficacy) for nine solid-state ballasts compared with a CBM core-coil ballast.

SUMMARY

In order to preserve productivity it is important for the lighting designer to meet recommended levels of illumination. Providing excess illumination, however, is no longer a suitable option because of the significant increase in operating costs for electrical energy. This paper has illustrated the problems facing a lighting designer in meeting both these aims. The lighting designer can no longer use a single factor for the change in the manufacturer's rated light output for the coefficient of utilization of the lighting system. It has been shown that there are various fixtures in which the MLWTs ranges from 37 to more than 60°C. These large changes in lamp temperature appear as changes in the electrical load to the ballasts, resulting in large changes in the light output of the lamp. The factors that create these changes must be determined and must include the thermal performance of the fixture and ballast/lamp system (5). In addition, other factors that must be supplied by ballast developers include the ballast factors and the input voltage regulation. The need for this information is illustrated by the wide range of light output for two F-40, T-12, rapid-start, cool-white lamps, for a CBM ballast, one particular solid-state ballast (Table 3), and the best and worst cases for various solid-state ballasts.

Table 3 shows that rated light output of lamps (6300 lm) for standard systems, can be lowered to 4910 lm, or by 22%. This change is due to the ballast factor, input voltage variation, and use of a hot fixture. Considering all the available solid-state ballasts listed in Table 4, light output can be as high as 7370 lm or as low as 3760 lm--variations of +17% and -40%, respectively, from the lamp's rated output. While these ranges are extremes, they illustrate the need for the lighting designer or end-user to collect the necessary information on the lighting system thermal performance and regulation, and ballast factor, in order to provide the illumination needed for the required tasks.

Table 3 Light Output of CBM Solid-State Ballast System in Response to Changes in Input Voltage and Temperature.

Ballast Type	Lamp Wall Temp. (°C)	Light Output for ±10% Voltage (%)	Light Output from 39 to 50°C (%)	Ballast Factor	Light Output (lm) ±10% Volt	Light Output (lm) 120 Volt
CBM Core-Coil	39	+5.5/-5.5	0	92.5	6170/5480	5830
	50	+5.5/-5.5	-10	92.5	5540/4910	5240
Solid-State (Table 4-2)	39	+8.9/-9.6	0	88.7	6110/5040	5590
	50	+8.9/-9.6	-4.2	88.7	5860/4850	5360

Table 4 Light Output, Best and Worst Case for Solid-State Ballasts in Response to Changes in Input Voltage and Temperature.

Lamp Wall Temp (°C)	Light Output Change for ±10% Voltage (%)	Light Output Change from 39 to 50°C (%)	Ballast Factor (%)	Light Output (lm) ±10% Voltage	Light Output (lm) Design Voltage
39	+20/-20	0	97.5	7370/4910	6140
39	+0.5/-0.5	0	97.5	6170/6110	6140
39	+20/-20	0	81	6050/4080	5100
39	+0.5/-0.5	0	81	5130/5080	5100
50	+20/-20	-8	97.5	6780/4520	5650
50	+0.5/-0.5	-8	97.5	5680/5620	5650
50	+20/-20	-8	81	5630/3760	4690
50	+0.5/-0.5	-8	81	4720/4670	4690
50	+20/-20	-4	97.5	7080/4720	5900
50	+0.5/-0.5	-4	97.5	5930/5870	5900
50	+20/-20	-4	81	5880/3920	4900
50	+0.5/-0.5	-4	81	4920/4870	4900

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and the Electric Power Research Institute, Project RP 225-4.

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