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Reduction of Temperature Rise in High-Speed Photography

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REDUCTION OF TEMPERATURE RISE IN HIGH-SPEED PHOTOGRAPHY

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E-3666

SUMMARY

This report provides information to professional industrial, scientific, and technical photographers as well as research personnel on filtration with glass and infrared-absorbing and -reflecting filters. Glass and infrared filtration is a simple and effective method to reduce the radiation heat transfer associated with continuous high-intensity tungsten lamps. The results of a filtration experiment conducted at the NASA Lewis Research Center in Cleveland, Ohio, are explained. The figures provide starting points for quantifying the effectiveness of various filters and associated light intensities. The combination of a spectrally selective reflector (hot or cold mirror) based on multilayer thin-film principles and heat-absorbing or infrared opaque glass results in the maximum reduction in temperature rise with a minimum of incident light loss. The report recommends use of a voltage regulator to further control temperature rise and incident light values.

INTRODUCTION

Audience and Purpose

This report is for professional industrial, scientific, and technical photographers as well as research personnel who need information on filtration as a method of reducing radiation heat transfer. The purpose is to determine the effectiveness of glass and infrared filtration in reducing temperature rises associated with radiation heat transfer from high-intensity tungsten lamps.

Scope

The report discusses glass and infrared filtration as a simple and effective method to reduce temperature rises associated with continuous high-intensity tungsten lighting in high-speed motion picture photography. The figures provide starting points for quantifying the effectiveness of glass and infrared-absorbing and -reflecting filters in reducing temperature rises. Because of time limitations methods such as vortex generators and water-cooled filters are not discussed.

Research

A filtration experiment with glass and infrared-absorbing and -reflecting filters; interviews with Ernie Walker, A NASA Lewis photographic technologist, and Jerry Ling, a NASA Lewis research engineer; and reports from the library at NASA Lewis provided the major information.

Background

According to Jerry Ling, a continuing problem in high-speed motion picture photography is adequate lighting and the associated radiation heat transfer caused by the high-intensity lights. Large temperature rises above ambient can damage subject matter and create an unsafe working environment. Because of bellows extension and the necessary increase in light the problem is compounded in macrophotography. According to Ernie Walker in high-speed photography the film is generally exhausted in less than 10 sec, with most high-speed work at NASA Lewis requiring 1 to 5 sec (approx. 100 ft at a frame rate of 4000 frames/sec is equal to 1 sec). The greatest temperature rise above ambient occurs in the initial 10 sec with high-intensity tungsten bulbs. Temperature continues to rise at a reduced rate until an elapsed time of 30 sec, when it stabilizes.

FILTRATION METHOD

In a laboratory environment a high-intensity General Electric ELH tungsten bulb (300 W at 120 V) was mounted on an optical bench and attached to a 10-amp Powerstat variable autotransformer. Filter holders were placed in front of a cast aluminum chamber which reduced heat lost by natural convection. The chamber contained an iron-constantan thermocouple that measured temperature in degrees Farenheit through a digital display (fig. 1). A Minolta Auto III F light meter was used to measure incident light values at the thermocouple plane. All filters were manufactured by Melles Griot with the exception of the plain glass filters, which were stock items.

Temperature data were recorded at a given distance of 6 in. with no filtration to establish a constant. The lamp was operating at the maximum of 120 V. In 5 sec the temperature increased 74 percent to 132 °F (fig. 2 and table I). The incident light reading at the thermocouple plane was f/32.5 with ASA 25 and a shutter speed of 1/60th of a second.

Figure 3 and table II represent the spectral performance or transmittance characteristic of the Melles Griot 0° and 45° heat-reflecting mirrors (commonly called hot mirrors) and their respective specifications. The filters were "multilayer dielectric mirrors...operating on the same principles as interference filters (ref. 1)." The visible spectrum was represented from 350 to 700 nm, with the infrared region extending beyond 700 nm. High-intensity tungsten lamps generate extreme heat, approximately one-third to one-half of which is produced by longer infrared wavelengths, according to Ernie Walker.

A single 0° hot mirror passed the visible spectrum and reflected infrared wavelengths back at the normal angle. Figure 4 represents this filter's configuration in the experiment. Table I and figure 5 show the effectiveness of this filter in reducing the rate of radiant heat transfer to the thermocouple. In 10 sec a temperature of 129 °F was achieved with filtration versus 163 °F without filtration. This represents a temperature rise reduction of 26 percent. The incident light value at the thermocouple plane was f/32.3 with ASA 25 at 1/60th of a second.

The 45° hot mirror also passed the visible spectrum and reflected infrared wavelengths away at a 45° angle (fig. 6). This filter allowed only a 55 percent rise above ambient to a temperature of 121 °F (table I and fig. 7) at 10 sec. This represents a temperature rise reduction of 35 percent. The incident light value at the thermocouple plane was f/32.3 with ASA 25 at 1/60th of a second.

Heat-transmitting mirrors, commonly called cold mirrors, "reflect visible light and transmit infrared (heat)(ref. 1)." Figure 8 and table II represent the spectral response of the Melles Griot 0° and 45° cold mirrors and their corresponding specifications. The 0° cold mirror was not tested because the test configuration was not practical. The lamp would have to be aimed directly into the mirror and the visible spectrum reflected back 180° toward the subject plane. The 45° cold mirror reflected visible wavelengths at a 45° angle and allowed infrared wavelengths to pass through (fig. 9). This mirror reduced radiation heat transfer at 10 sec by 54 percent, to 106 °F versus 163 °F (table III and fig. 10). At an elapsed time of 30 sec a 47 percent temperature rise above ambient had occurred versus a 146 percent rise without filtration. The incident light value at the thermocouple plane was f/22.8 with ASA 25 at 1/60th of a second.

The spectral response of Melles Griot's heat-absorbing glass filters is represented in figure 11. The filters are "made of heat-absorbing or infrared opaque glass (ref. 1)." Table III and figure 12 show the effectiveness of the Schott heat-absorbing filter. At 10 sec a temperature of 105 °F was achieved versus 163° without filtration. This represents a temperature increase above ambient of only 36 percent, or a reduction in temperature rise of 55 percent. The incident light value at the thermocouple plane was f/22.9 with ASA 25 at 1/60th of a second.

The effectiveness of infrared-absorbing and -reflecting filters was further demonstrated when they were compared with plain glass filters. Table IV represents the data for 1/4-in.-thick plain glass acting as a heat-reducing filter. A low 11 percent reduction in temperature rise was attained at 10 sec versus a 55 percent reduction for the Schott heat-absorbing filter. Combining three 0.083-in.-thick pieces of plain glass reduced heat conduction through the filter and accordingly allowed lower temperature readings. Table IV shows that the combination of three thin layers of glass reduced temperature rise by 18 percent to a temperature of 138 °F. This is still much less than the temperature reduction achieved with the infrared-absorbing and -reflecting filters. The incident light value at the thermocouple plane was f/32.2 with ASA 25 at 1/60th of a second.

A single 45° hot or cold mirror in combination with the Schott heat-absorbing glass (fig. 13) produced the greatest reduction in temperature rise. At 10 sec a temperature of 98 °F was attained, only 26 to 27 percent above ambient. This represents a temperature rise reduction of 66 percent as compared with the temperature without filtration at 10 sec (table V). The incident light value was f/22.3 with ASA 25 at 1/60th of a second. This corresponds to a 1-1/3-stop reduction in light intensity at the thermocouple plane as compared with the intensity required without filtration.

Replacing the Schott heat-absorbing filter with 1/4-in.-thick plain glass was ineffective in reducing temperature rise (fig. 14). At 10 sec a temperature of 116 °F was attained with this combination (table VI) while a single Schott filter controlled temperature to 105 °F and a 45° cold mirror to 106 °F, respectively.

Another method of controlling temperature rise in conjunction with the filters is to use a voltage regulator. If distance from the light source cannot vary and only a limited temperature rise is tolerable, a voltage regulator in combination with the filters is effective in reducing the rate of radiation heat transfer (table VII). There was significant light loss at lower voltages.

SUMMARY AND RECOMMENDATIONS

Filtration of high-intensity tungsten bulbs with infrared-absorbing and -reflecting filters is a simple and effective method of reducing temperature rises with minimum incident light loss. Because high-speed motion picture photography generally requires less than 10 sec to exhaust the film and the major temperature rise of tungsten bulbs occurs in the first 10 sec, it is critical to control or delay this initial rate of temperature rise. Single filters cause negligible incident light loss but are less effective in reducing temperature rise than filter combinations. Because of contact resistance between surfaces a single filter composed of thin glass layers results in greater temperature reductions than a normal glass filter of equal thickness. These data indicate that infrared-absorbing or -reflecting filters and mirrors reduce the rate of radiation heat transfer (heat rise) more effectively than plain glass filters. The combination of a 45° hot or cold mirror with a heat-absorbing filter results in a 66 percent reduction in temperature rise at a distance of 6 in. Incident light loss is kept to a minimum - a 1-1/3-stop increase in exposure. The figures provide professional photographers flexibility in the completion of photographic assignments that require temperature rise control with minimum light loss.

Because every photographic situation is unique, photographers should use the figures only as a starting point for determining temperature rises and associated incident light values. ASA 25 and the shutter speed of 1/60th of a second should be converted to actual photographic needs. Because of extreme temperature rises and possible shattering, glass filters less than 0.083 in. thick should not be used. Because many photographic applications cannot vary light to subject distances and only a limited temperature rise is tolerable, photographers should use a voltage regulator with the designated filter combination to reduce temperature rises.

REFERENCES

1. Optics Guide 3, Melles Griot, 1985 p. 244.

2. Walker, E.D. and Slater, H.A., Method of Reducing Temperature in High-Speed Photography. NASA TM-83620, 1984.

TABLE I. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND PERCENT RISE ABOVE AMBIENT FOR NO FILTER AND 0° AND 45° HOT MIRRORS

Time, sec	Filter					
	None		0° Hot mirror		45° Hot mirror	
	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent
0	76	---	76	--	78	--
5	132	74	109	43	105	35
10	163	114	129	70	121	55
15	177	133	140	84	129	65
20	184	142	144	89	132	69
25	186	145	146	92	133	71
30	187	146	147	93	134	72

TABLE II. - SPECIFICATIONS OF HEAT-REFLECTING FLAT MIRRORS

Angle of incidence, deg	Normal (0) or 45
Flatness, λ/25 mm (at 546 nm)	1
Dimensions, mm (±0.2 mm)	50 x 50 x 3
Substrate	Polished pyrex
Cosmetic surface quality	80-50 Scratch and dig
Coating	Multilayer dielectric

TABLE III. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND PERCENT RISE ABOVE AMBIENT FOR NO FILTER, 45° HOT MIRROR, AND HEAT-ABSORBING GLASS

Time, sec	Filter					
	None		45° Cold mirror		Heat-absorbing glass	
	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent
0	76	---	78	--	77	--
5	132	74	95	22	94	22
10	163	114	106	36	105	36
15	177	133	110	41	111	44
20	184	142	113	45	114	48
25	186	145	115	47	116	51
30	187	146	115	47	117	52

TABLE IV. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND PERCENT RISE ABOVE AMBIENT FOR NO FILTER, 1/4-INCH-THICK GLASS, AND THREE LAYERS OF 0.083-INCH-THICK GLASS

Time, sec	Filter					
	None		1/4-Inch-thick glass		Three layers of 0.083-inch-thick glass	
	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent
0	76	---	79	---	79	---
5	132	74	122	54	116	47
10	163	114	147	86	138	75
15	177	133	159	101	148	87
20	184	142	164	108	153	94
25	186	145	167	111	156	97
30	187	146	168	113	158	100

TABLE V. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND PERCENT RISE ABOVE AMBIENT FOR NO FILTER AND 45° HOT AND COLD MIRRORS - BOTH MIRRORS IN COMBINATION WITH SCHOTT HEAT-ABSORBING GLASS

Time, sec	Filter					
	None		45° Hot mirror with Schott heat-absorbing glass		45° Cold mirror with Schott heat-absorbing glass	
	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent
0	76	---	78	--	77	--
5	132	74	90	15	90	14
10	163	114	98	26	98	27
15	177	133	101	29	103	34
20	184	142	103	32	105	36
25	186	145	104	33	106	38
30	187	146	105	35	107	39

TABLE VI. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND PERCENT RISE ABOVE AMBIENT FOR NO FILTER AND 45° HOT MIRRORS WITH 1/4-INCH-THICK OR THREE LAYERS OF 0.083-INCH-THICK GLASS

Time, sec	Filter					
	None		45° Hot mirror with 1/4-inch-thick glass		45° Hot mirror with three layers of 0.083-inch-thick glass	
	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent	Temperature, °F	Rise, percent
0	76	---	78	--	78	--
5	132	74	101	29	98	27
10	163	114	116	49	111	42
15	177	133	122	56	116	49
20	184	142	125	60	119	52
25	186	145	126	62	120	54
30	187	146	126	62	121	55

TABLE VII. - TEMPERATURE RISE AT 6 INCHES FROM LIGHT AND INCIDENT LIGHT FOR VOLTAGE REGULATOR WITH NO FILTER AND FOR 45° COLD MIRROR AND 45° HOT MIRROR WITH SCHOTT HEAT-ABSORBING GLASS

[Ambient temperature, 78 °F.]

Voltage, V	Voltage regulator in combination with filter-					
	None		45° Cold mirror		45° Hot mirror with Schott heat-absorbing glass	
	Temperature, °F	Incident light, f-stop[a]	Temperature, °F	Incident light, f-stop[a]	Temperature, °F	Incident light, f-stop[a]
60	108	11.2	89	8.6	84	8.5
70	119	16.2	92	11.6	86	11.2
80	129	16.6	96	16.3	89	11.7
90	142	22.4	100	16.8	93	11.9
100	156	22.9	105	22.3	96	16.5
110	172	32.1	112	22.7	100	16.8
120	189	32.5	118	32.0	105	22.3

[a]For ASA 25 at 1/60th of a second.

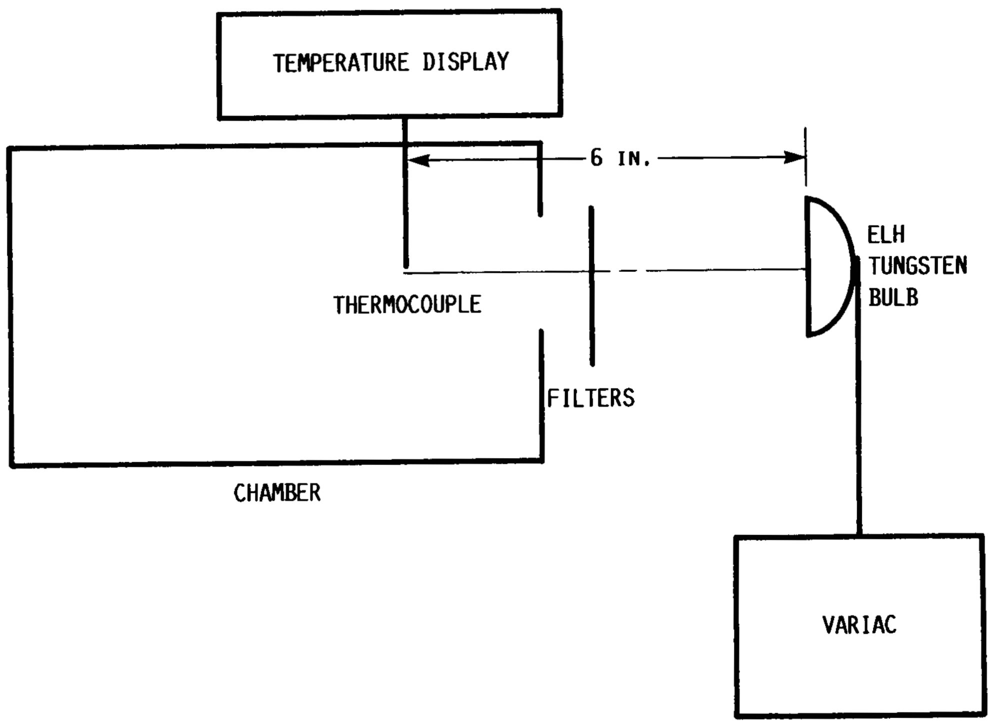


FIGURE 1. - TEST CONFIGURATION.

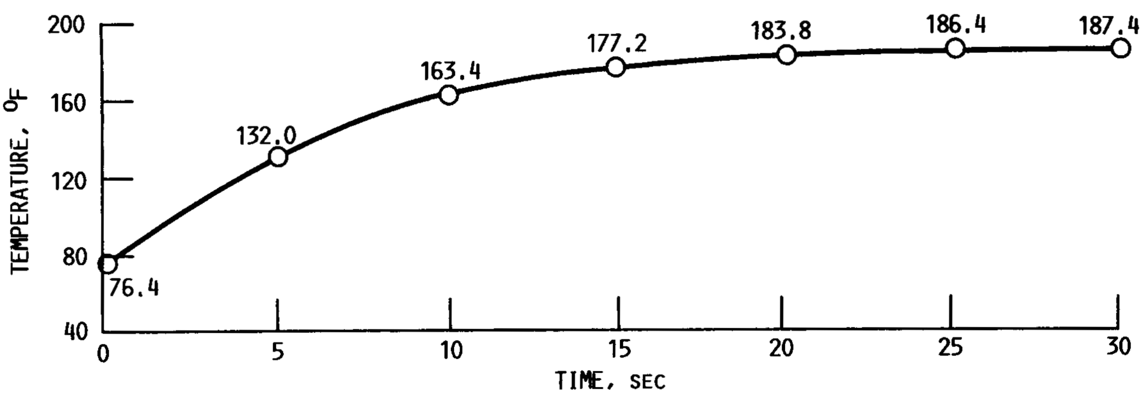


FIGURE 2. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT WITH NO FILTRATION.

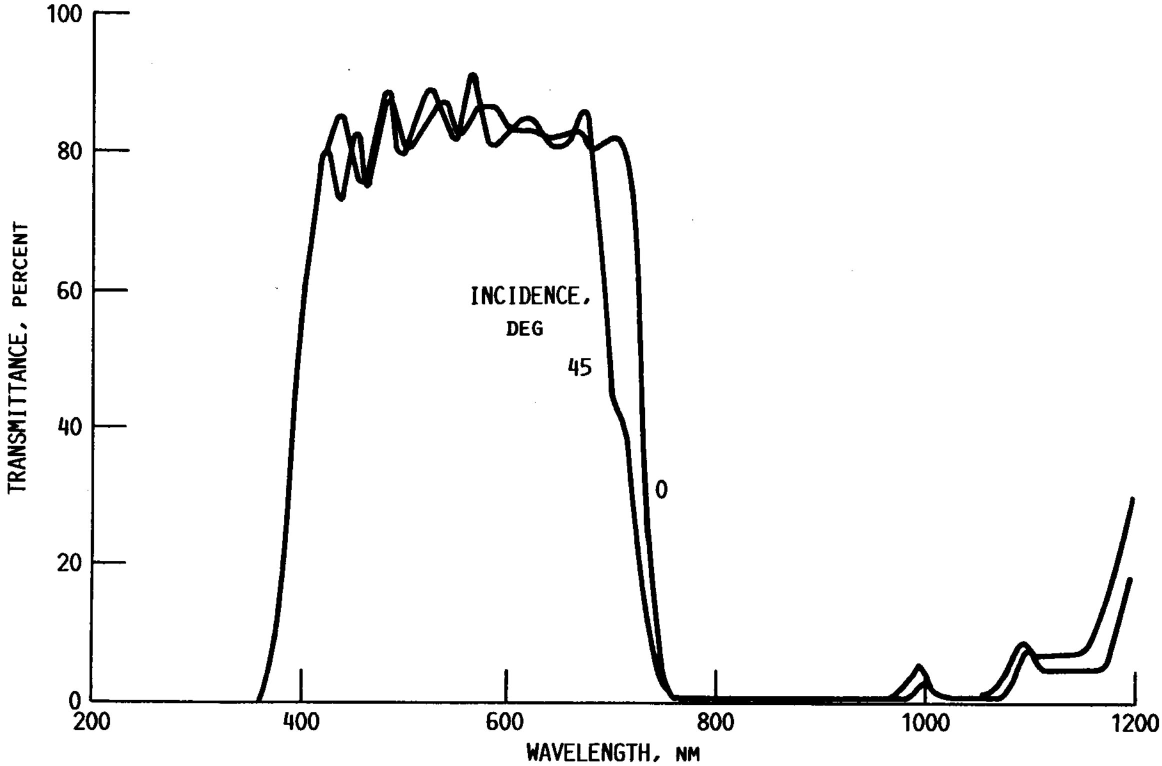


FIGURE 3. - SPECTRAL PERFORMANCE OF 0^{o} AND 45^{o} HEAT-REFLECTING (HOT) FLAT MIRRORS. (DATA FROM REF. 1.)

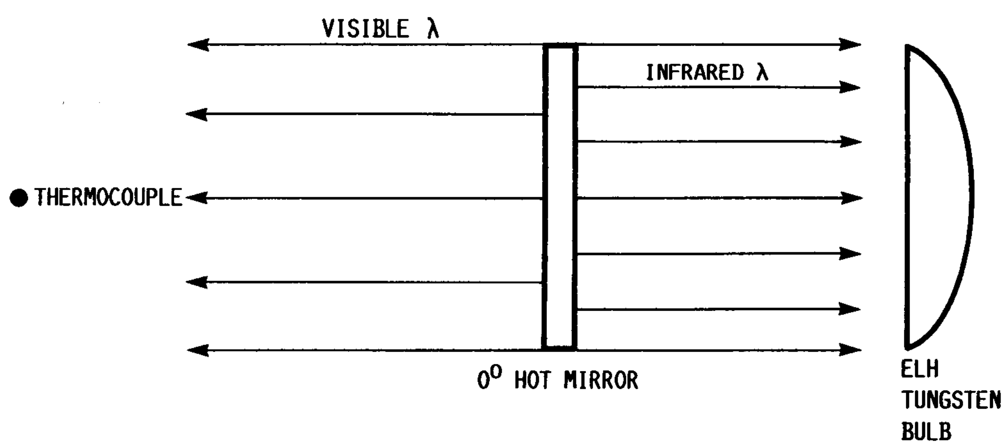


FIGURE 4. - 0^{o} HOT MIRROR CONFIGURATION.

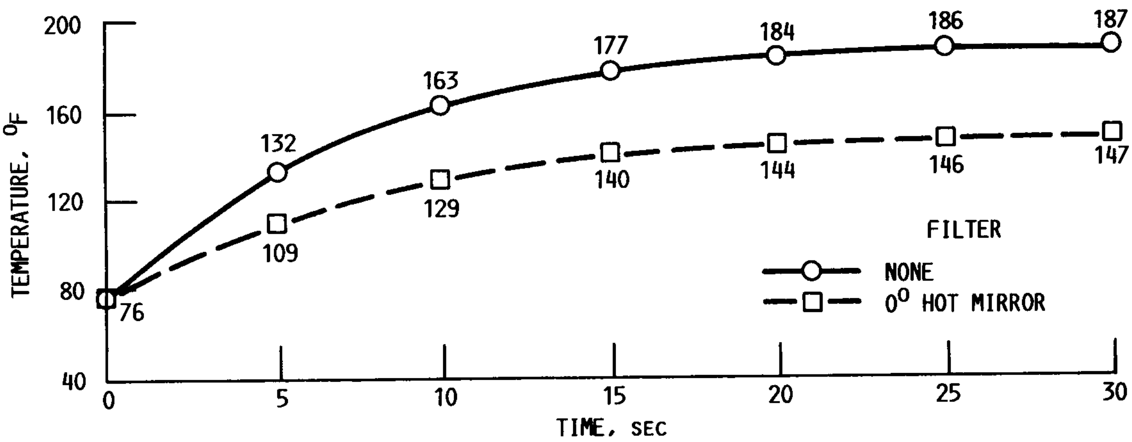


FIGURE 5. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR A 0° HOT MIRROR.

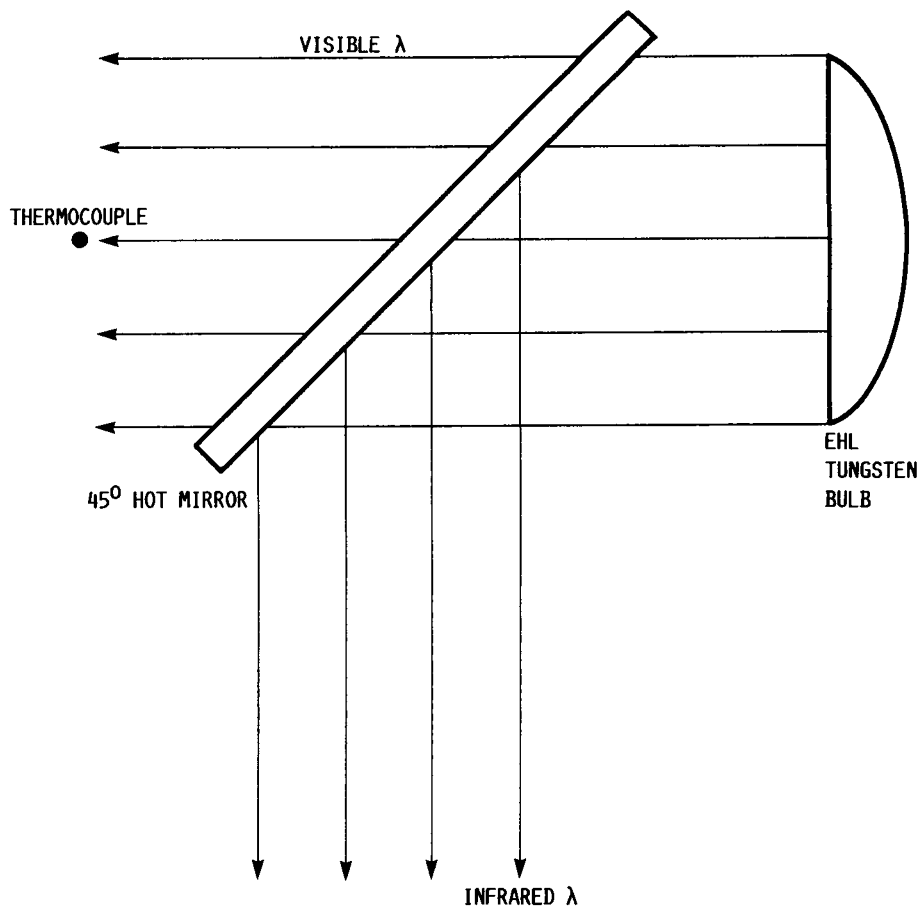


FIGURE 6. - 45° HOT MIRROR CONFIGURATION.

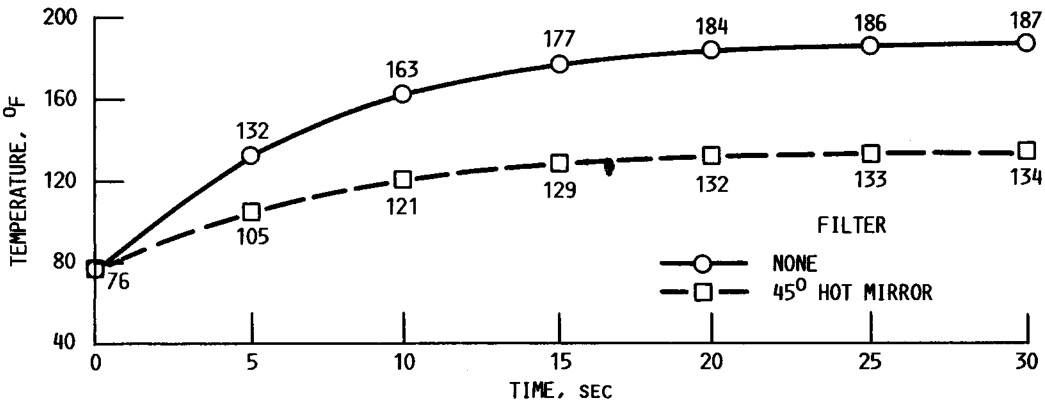


FIGURE 7. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR 45° HOT MIRROR.

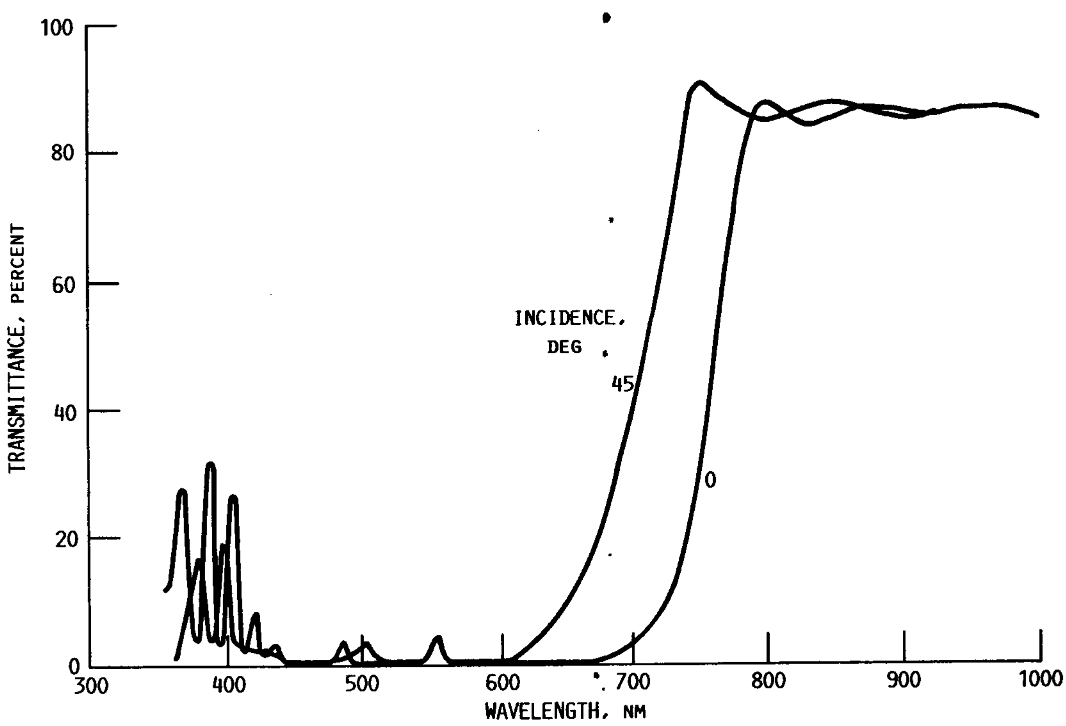


FIGURE 8. - SPECTRAL PERFORMANCE OF 0° AND 45° HEAT-TRANSMITTING (COLD) FLAT MIRRORS. (DATA FROM REF. 1.)

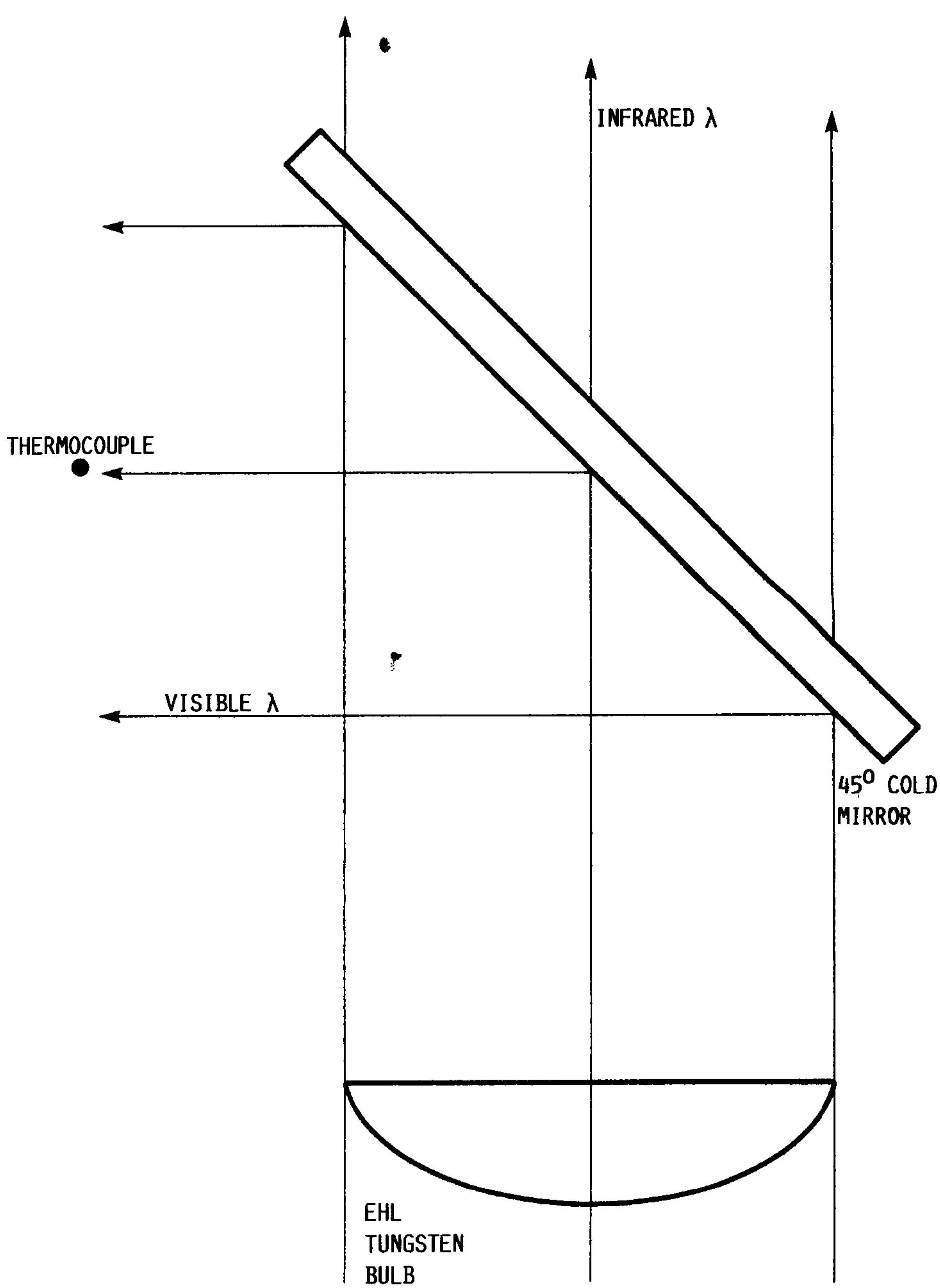


FIGURE 9. - 45° COLD MIRROR CONFIGURATION.

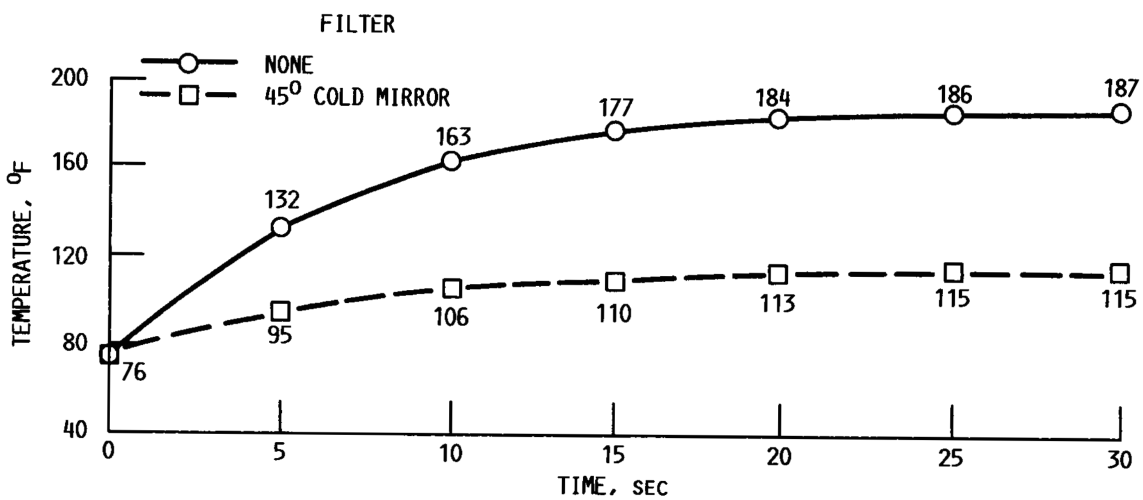
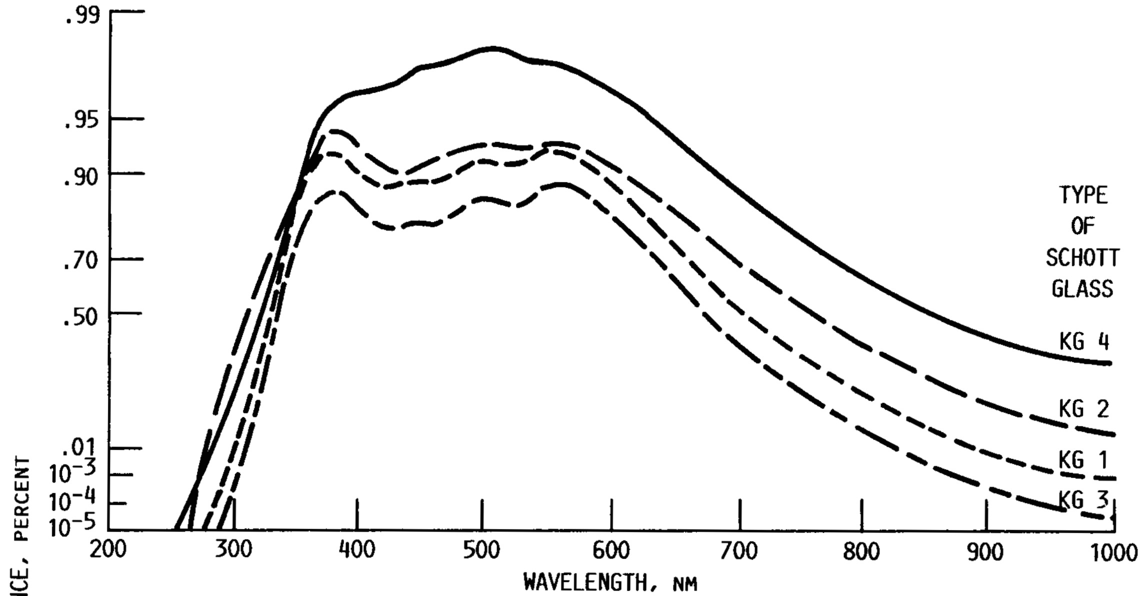
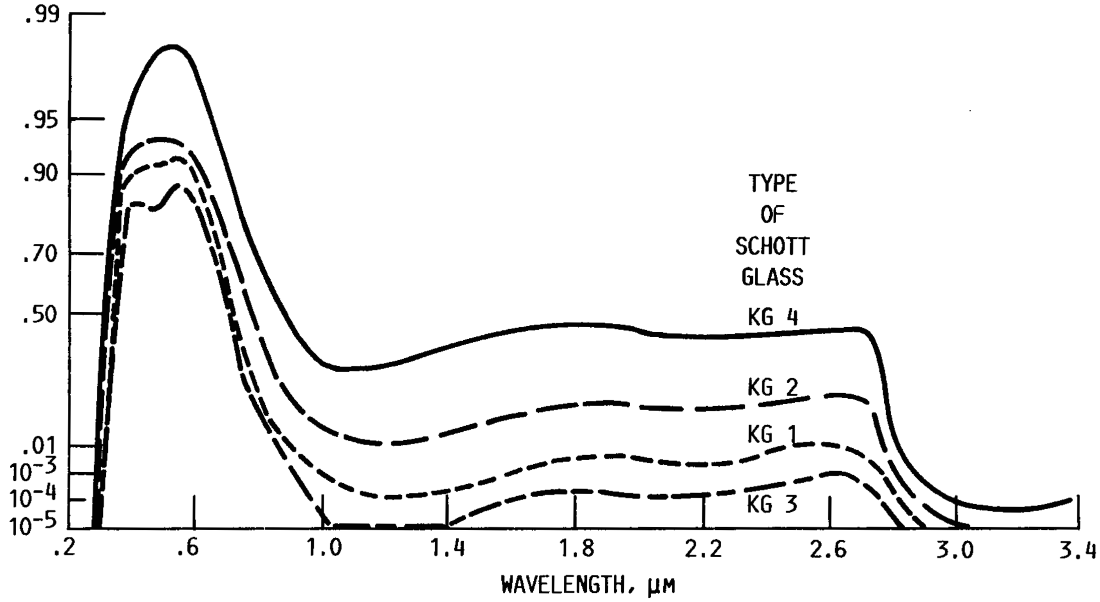


FIGURE 10. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR 45° COLD MIRROR.



(A) VISIBLE RANGE.



(B) EXTENDED RANGE.

CORRECTION FACTOR t_1t_2 . . . . 0.92
DIMENSIONS, MM (±0.25 MM) 50x50x3
PARALLELISM, ARC-MIN 2
MATERIAL. . . . . SCHOTT KG GLASS
COSMETIC SURFACE QUALITY. . . . . PITCH POLISHED, 8-50 SCRATCH AND DIG
SUGGESTED MAXIMUM OPERATING TEMPERATURE, ^{o}C (^{o}F) 250 (482)

(C) SPECIFICATIONS.

FIGURE 11. - SPECTRAL PERFORMANCE AND SPECIFICATIONS OF MELLES GRIOT HEAT-ABSORBING GLASS FILTERS.

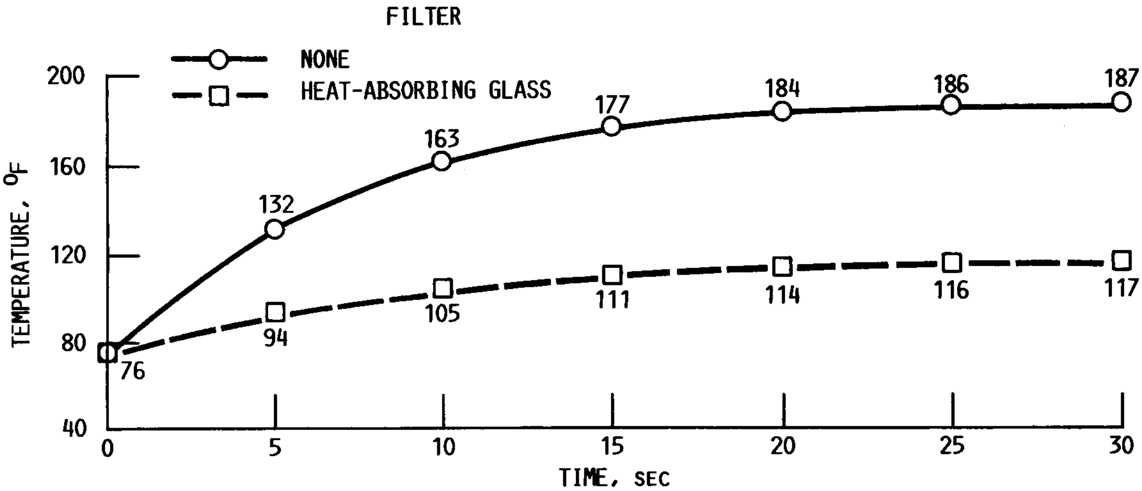


FIGURE 12. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR SCHOTT HEAT-ABSORBING GLASS FILTER.

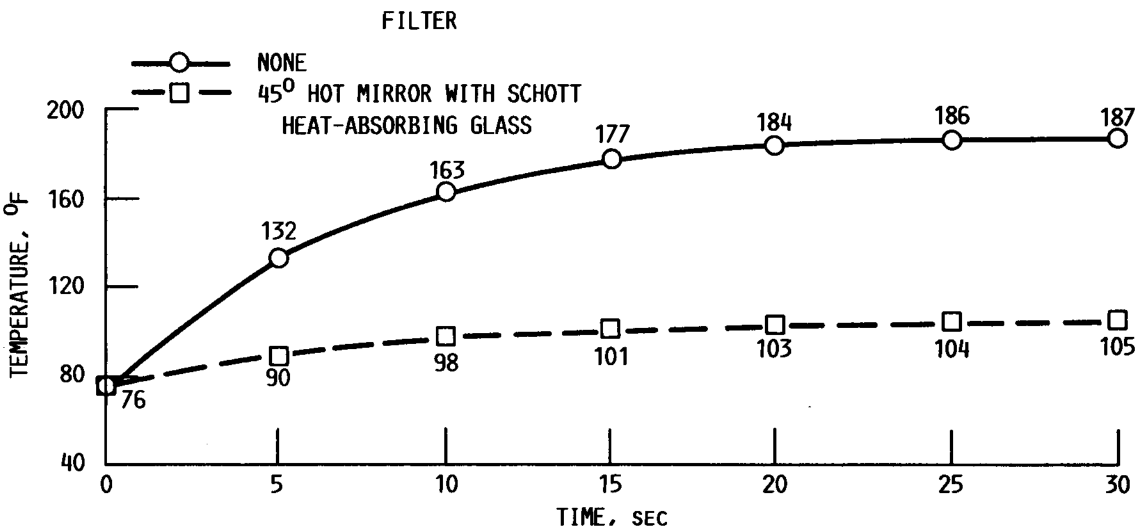


FIGURE 13. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR 45^{0} HOT MIRROR WITH SCHOTT HEAT-ABSORBING GLASS FILTER.

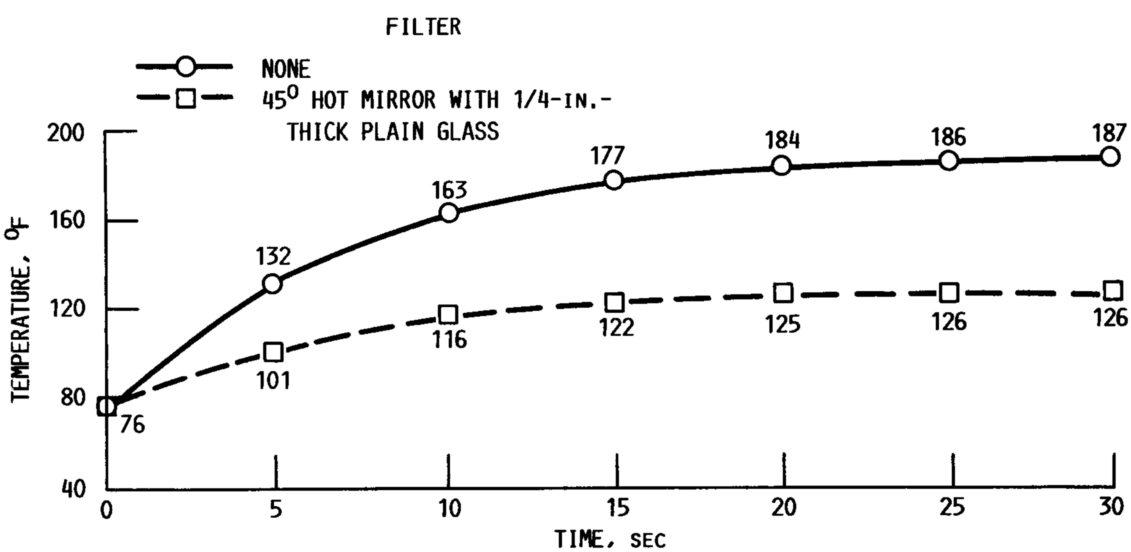


FIGURE 14. - TEMPERATURE RISE AT A DISTANCE OF 6 IN. FROM LIGHT FOR 45^{0} HOT MIRROR WITH 1/4-IN.-THICK PLAIN GLASS FILTER.

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16. Abstract

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