Survey of Environmental Conditions Relative to Display of Photographs in Consumer Homes – Phase II

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Abstract

The long-term stability of inkjet photographic prints is known to be sensitive to a variety of factors. These factors include chemical composition of the inks and media, as well as the ambient environmental conditions – light, heat, humidity, and air quality – under which the prints are stored and/or displayed. In order to correlate the results of accelerated testing in the laboratory with what actually happens to a photographic print under long-term, real-world conditions, it is necessary to better understand the typical ambient environmental conditions under which the prints are being displayed and/or stored. In Phase I of this study, light levels, spectral energy distributions, temperatures, humidities, and ozone levels were monitored for 6 – 12 months in eight homes in each of four cities around the world. For Phase II, eight homes in each of four additional cities (Sao Paulo, Shanghai, Atlanta, and Tokyo) were monitored for 10-12 months. These additional data reinforce the Phase I conclusions that ambient home display conditions are dominated by relatively low intensity, indirect, window-filtered daylight. In addition, we will describe an appropriate filtration package for use with high intensity Xenon arc lamps that more closely matches the average home spectral energy distribution. This combination of source and filter will be proposed for the next generation accelerated light fade standard.

Introduction

In order to develop accelerated test methods to more accurately predict the long-term effects of the storage and/or display environment on a photograph, it is critical to first characterize the ambient conditions that are typical of the home consumer environment. In our Phase I report we described the various factors that can affect the long-term stability of photographs. [1] For example, the image stability of current digital photographic print materials is known to be sensitive to light, heat, humidity, and/or air pollutants, particularly ozone.[2] We also discussed the importance of understanding how home consumers actually display and store their photographs. Although light only affects a print that is on display, the other three factors can degrade a print both in storage and on display. Stated another way, an unprotected print on display is subjected to all four environmental factors simultaneously. To that end, in Phase I we monitored light levels, spectral energy distributions, temperatures, humidities, and ozone levels for 6 – 12 months in eight homes in each of four cities around the world: London, Rochester, Los Angeles, and Melbourne. Based on the results of Phase I, it was decided to extend this study to an additional four cities, as will be described in further detail below.

The primary objective of Phase II was to expand upon the Phase I data collection of ambient light levels (including the spectral energy distribution), temperature, and humidity in typical homes around the world. In Phase II, eight homes in each of four new locations were selected: Brazil (Sao Paulo), Japan (Tokyo), China (Shanghai), and the United States (Atlanta). Temperatures and humidities were monitored continuously in all 32 homes for 10 – 12 months. However, light levels and spectral energy distributions were only collected in Shanghai and Atlanta, where measurements were taken every thirty minutes in each of the 16 homes over a period of 6 – 8 months.

It is well documented that the light-induced fade of photographs is a strong function of the spectral energy distribution of the illumination.[3,4] Therefore, any accelerated test method that is intended to simulate the long-term light-fade of photographs should use an illuminant with a spectral energy distribution that matches the actual-use condition as closely as possible. One key conclusion of our Phase I study (and reinforced by the Phase II study as discussed below) is that the average spectral energy distribution found in consumers' homes around the world is dominated by diffuse, window-filtered daylight. Commercially available high-intensity xenon lamps, when filtered with soda-lime window glass, have been recognized as a good match to window-filtered sunlight.[4,5] However, compared to the average home spectrum (AHS), as determined by the combination of our Phase I and II results, we have found that simple glass-filtered xenon illumination comprises a significantly higher proportion of the more damaging blue (400-500 nm) and ultraviolet (300-400 nm) wavelengths.[3] Polycarbonate filtration, on the other hand, excludes nearly all of the UV light but removes very little of the excess blue energy. [3] In order to better match the AHS, a number of commercially available filters were evaluated in combination with varying thicknesses of window glass as a means to better "trim" the blue and UV regions of the xenon spectrum. The results of this work will also be presented in this paper.

Methods

Choice of Cities

The following criteria were considered in the choices of cities for Phase II:

- representative of relatively large populations of active photographic consumers;
- at least one city with known high concentrations of air pollution;
- at least one city with greater than average amounts of sunshine; and
- at least one city in the southern hemisphere to reflect opposite seasonality of the northern hemisphere.

In Phase I, cities were in North America, Europe, and Australia. In order to expand the worldwide testing, Phase II cities were selected in Asia (Tokyo, Japan and Shanghai, China), South America (Sao Paulo, Brazil), and North America (Atlanta, United States).

Choice of Participants

Participants were carefully selected to represent locations and compass orientations throughout the metropolitan region of each city. In addition, homes were chosen to represent the cross-section of available housing options, including homes, condominiums, and apartments, as well as factors such as socioeconomic status, and the type of heating, cooling, and ventilation (HVAC) system. For further details of the selection and documentation of participants' homes, please refer to the Phase I report.[1]

Instrumentation

The equipment and procedures have been described in detail in our Phase I report.[1] The measuring equipment was positioned immediately adjacent to the photographic display, with the probe of the spectroradiometer oriented such that the plane of the sensor was parallel to the plane of the photographs. Data was processed and analyzed as described in the Phase I report. One improvement over Phase I is the removal of the low-intensity dark baseline response that is characteristic of each spectrometer. This results in a more accurate representation of spectrum, especially in the near UV (300–400 nm) region. The Phase I spectra have been recalculated using this technique and results are included in this paper. Another improvement is that the spectroradiometers were left in place for the duration of the study.

Results and Discussion

Temperature and Humidity

The Phase II temperature and humidity data are summarized in Table 1. As in the Phase I report, two measures of humidity are reported: dew point and relative humidity. Overall statistics including Phase I data are also included.

Table 1. Temperature, Dew Point, Humidity Summary.

	Mean Temp (°C)	σ (°C)	Mean DP (°C)	σ (°C)	Mean RH (%)	σ
Atlanta	21.7	3.2	10.7	5.8	51	13
Shanghai	22.5	6.0	14.0	6.9	60	12
Sao Paolo	23.3	3.3	15.7	3.4	63	10
Tokyo	19.5	5.3	9.9	6.4	55	12
Phase II	21.8	4.6	12.6	6.1	57	13
Phases I + II	21.1	3.9	11.1	5.5	54	13

Atlanta exhibited a low temperature standard deviation due to the presence of centralized heating and air conditioning in all homes. Sao Paulo had similar low overall temperature standard deviation even though none of the homes had central air. The reason for the low variability in temperature is likely due to the temperate local climate and its proximity to the Atlantic Ocean. The standard deviation in dew point is also low. Shanghai exhibited a broad range of indoor temperature (13.0–28.9°C), including the warmest indoor temperature for all cities. All Shanghai homes had air conditioning, but usage was conservative. Shanghai and Tokyo exhibited broad ranges of dew point throughout the year (2.8–22.2°C and 3.1–19.4°C, respectively). Both cities also had significant percentages of low indoor temperatures compared to Atlanta and Sao Paulo. Of the Phase II cities, Tokyo had the lowest average temperature and dew point, but exhibited an intermediate average relative humidity (19°C, 9.9°C, and 55%RH, respectively).[6] The reasons for this will be discussed further below.

As was observed for Phase I, there is a general diurnal pattern for both temperature and relative humidity for a given home. This is driven primarily by the daily outdoor temperature cycle. As the outdoor temperatures drop at nighttime, so do the indoor temperatures to some extent. However, the dew point does not vary nearly as much. The net result is that as indoor temperatures rise and fall during the course of 24-hour period, the relative humidity tends to move in the opposite direction.

When the temperature and humidity distributions of the Phase I and Phase II cities are compared, it can be seen that Atlanta is most comparable to the Phase I results. Shanghai and Sao Paolo, on the other hand, exhibit much broader distributions that are centered at higher levels of temperature, dew point, and RH. This can be explained by the combination of more temperate climates, proximity to the oceans, and much lower utilization of centralized heating and cooling systems. The Tokyo data is somewhat skewed by unusually cool temperature readings in the 10–15°C range for a couple of the homes. As noted above, lower overnight temperatures can lead to a greater frequency of high RH readings, but not necessarily higher dew points. This is borne out in the Tokyo dew point histogram, which is in fact skewed to lower dew point temperatures, i.e., lower absolute humidities, compared to the other Phase I and Phase II cities.

Light Levels and Spectral Distributions

The Phase II light levels and spectral distributions are summarized in Table 2 and Figures 1–3. The light level statistics for the Phase II cities are very comparable to the data collected for the Phase I cities, and reinforce the conclusions drawn for the Phase I study. Specifically, both the mean and median for the daytime light levels were found to be well under 100 lux, with a 90th percentile in the range of 100–150 lux. *It is important to note that >99% of the over 130,000 daytime measurements taken over the course of the Phase I and Phase II studies are below 450 lux, a light level often cited as representative of the average or typical home.*[7]

Another way to view the light level data is given in Figure 2, which displays a histogram of the *average* daytime light level for each of the 48 homes included in Phases I and II. It can be seen that 47 of the 48 (98%) homes average less than 200 lux, and 41/48 (>85%) of the houses average less than 125 lux. *None of the 48 homes averaged 450 lux or greater.*

Somewhat surprising were the relatively low light levels found in Atlanta, given its location in the "sun belt." A review of the geographical and architectural characteristics of the homes in Atlanta found a preponderance of overhanging roof styles, wraparound porches, and shade trees, all of which are intentionally designed to limit the amount of interior exposure to direct sunlight (and also limiting the generation of heat). Consistent with this finding is the observation that many Atlanta homes actually display inverse seasonality, i.e., the light levels are generally higher in the winter when the trees are bare of leaves and the angle of the sun is low enough to dip below the overhanging roof line.

Although it is not evident in the average spectral energy distributions shown in Figure 3, examination of the individual spectra for the Shanghai homes reveals a much higher incidence of fluorescent artificial lighting than seen in any of the other cities that we have monitored. However, as has been observed for all Phase I and Phase II cities, the long-term average spectral energy distribution of Shanghai is dominated by diffuse, window-filtered daylight.

Comparison of the AHS to Filtered Xenon Spectra

Figure 4 shows the data from Figure 3 in the form of 100-nm bands vs percentage of the total irradiance between 300 and 700 nm for the overall average and separately for Phase 1 and Phase 2 of the study. One key observation from Figures 3 and 4 is that the relative distribution of the irradiance between the UV (300–400 nm), blue (400–500 nm), green (500–600 nm) and red (600–700 nm) regions of the spectrum is nearly constant, with less than 5% of the total irradiance in the UV, 27% in the blue, 33% in the green, and 35% in the red.

Table 2. Light Level Statistics (Daytime Readings Only).

	Median (lux)	Mean (lux)	90th %ile (lux)	Std. Error	N
Atlanta	10	20	43	0.16	37154
Shanghai	12	58	153	0.95	29288
Phase II Avg City	11	39	98	0.55	66442
Phase I & Phase II Avg City	22	64	136	1.43	137778

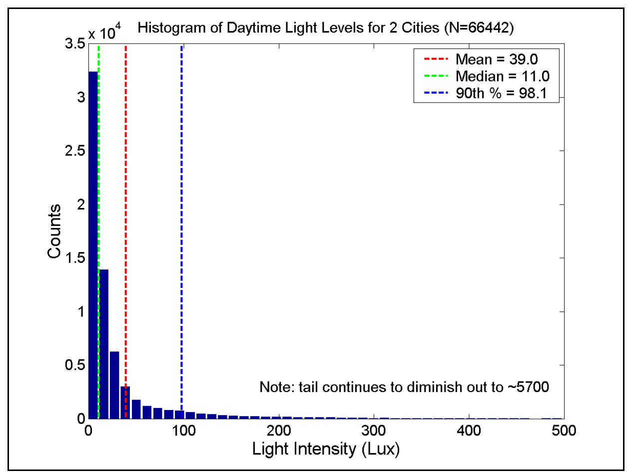

Figure 1. Histogram of daytime light levels for all homes, all cities.

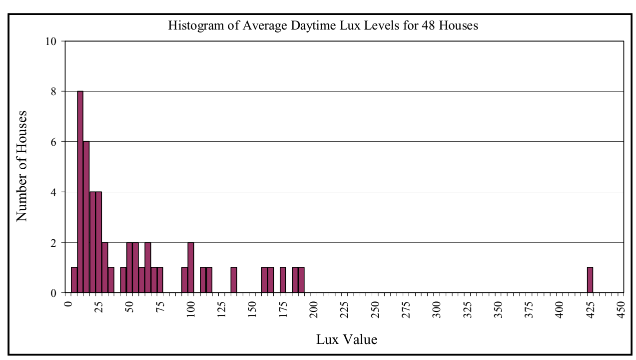

Figure 2. Histogram of average daytime light levels for each of the 48 homes in Phases I and II.

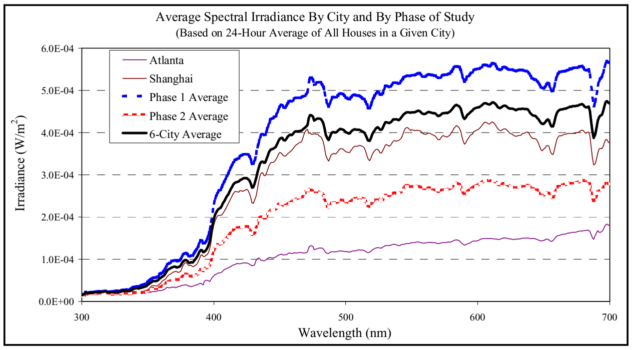

Figure 3. Average spectral energy distributions by Phase II city, by Phase, and overall.

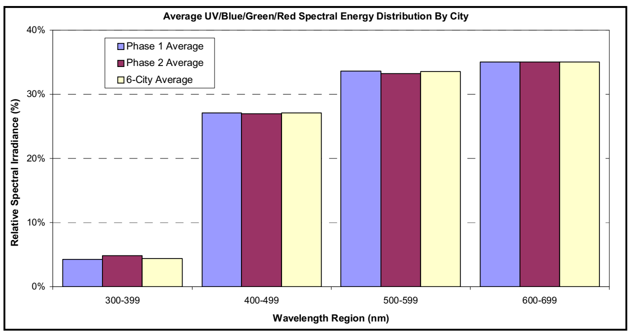

Figure 4. Histogram of spectral irradiance in 100-nm bands by Phase, and overall.

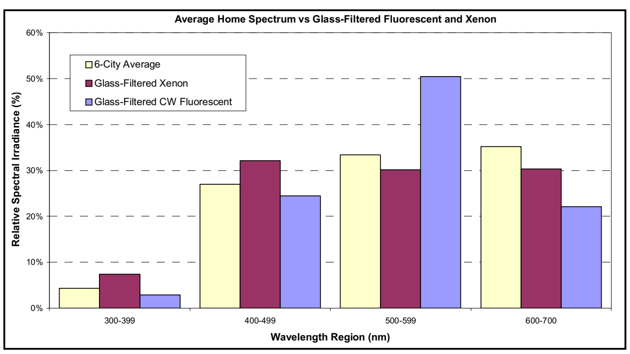

Figure 5. Histogram of spectral irradiance in 100-nm bands comparing the 6-city AHS to glass-filtered xenon and fluorescent illumination.

In contrast, the spectral irradiance distribution for a high-intensity xenon lamp filtered with 6-mm soda lime ("window") glass contains a disproportionately higher UV and blue irradiance and lower green and red irradiance than the average home distribution (Figure 5). Also shown for reference are the results for glass-filtered cool-white fluorescent lighting, which shows a disproportionately high amount of green irradiance relative to the average home. Additionally, the fluorescent spectrum contains troublesome "spikes" in the UV and blue regions, which could further confound the results for certain colorants that may happen to absorb strongly at those wavelengths.

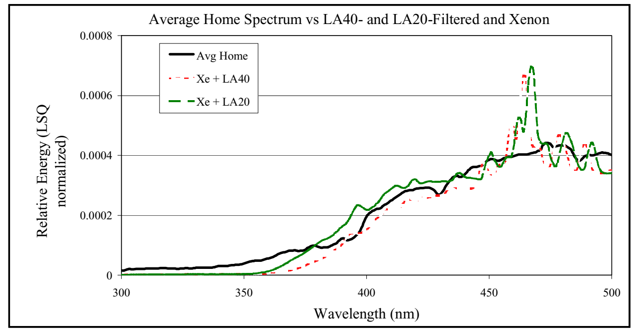

Figure 6. Spectral energy distributions (300-500 nm) of xenon filtered with LA-20 and LA-40 compared to the 6-city AHS.

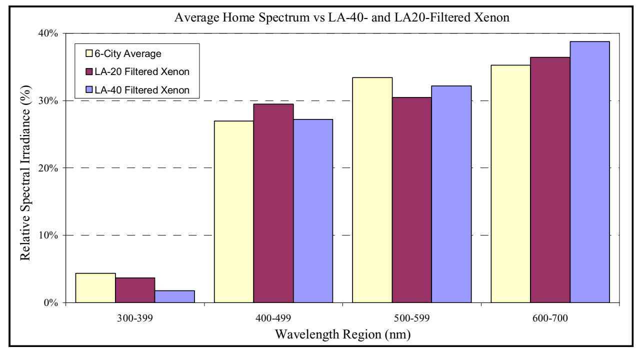

Figure 7. Histogram of spectral irradiance in 100-nm bands comparing xenon filtered with LA-20 and LA-40 to the 6-city AHS.

It is clear from Figure 5 that neither glass-filtered xenon nor glass-filtered fluorescent adequately match the average home spectrum. It should be noted that the UV and blue wavelengths are at the higher energy end of the distribution and are more likely to result in fade for colorants that absorb in those regions of the spectrum, especially yellow colorants that by definition absorb most strongly in the blue. All magenta and cyan colorants have some unwanted UV and blue absorptions and thus are also adversely affected to some degree by excessive UV and blue irradiance.[3]

In order to better match the AHS, a number of commercially available filters were evaluated in combination with varying thicknesses of window glass as a means to better "trim" the blue and UV regions of the xenon spectrum. Figures 6 and 7 illustrate the results for two such commercially available filters (LA-20 and LA-40 from Hoya). It can be seen that the LA-40 filter slightly overcompensates for the UV, but provides a reasonably close match to the blue, green and red regions. The LA-20 filter, on the other hand, provides a closer match in the UV region to the AHS, but it is a bit heavy in the blue band. Either filter is an overall much better match to the average home spectrum than is glass-filtered xenon, or glass-filtered fluorescent illumination.

One approach to determining the "goodness of fit" of a given combination of filter and illuminant to the AHS is to mathematically compare the filter-illuminant spectra to the

AHS. A result of such an analysis is summarized in Table 3, which confirms that xenon illumination filtered with either LA-20 and LA-40 provides a better match to the AHS compared to glass-filtered xenon, and especially glass-filtered fluorescent illumination.

Table 3. Goodness of Fit Summary of Various Filter-Illuminant Combinations Compared to the AHS.

Least Squares Normalized Spectral Profiles Over 300-700 nm Wavelength Range					
	Xenon	Xenon/ glass	Xenon/ LA-20	Xenon/ LA-40	Fluor./ glass
SS Residual Difference from Average Home	2.71 E-06	2.59 E-06	1.94 E-06	1.94 E-06	2.38 E-05
Fit Error Relative to Best Match	40%	33%	0%	0%	1124%

Stability of LA-20 and LA-40 Filters

An important property of any filter material for high-intensity accelerated light fade testing is the stability of the physical and optical properties over long enough cumulative exposures to be both cost-effective and practical from a typical test duration perspective. Studies are in progress to determine the practical stability of the LA-20 and LA-40 filters when irradiated continuously with up to 100 klux of xenon illumination. Current results indicate that there is a minor "burn-in" period during which the filters darken slightly but relatively uniformly, after which the filters appear to be sufficiently stable to meet the needs of the intended application.

Summary

In this study, we have extended our understanding of the typical home consumer environment for the storage and display of photographs to an additional four cities around the world: Atlanta, Sao Paulo, Shanghai, and Tokyo. With respect to temperature and humidity, homes in Sao Paulo and Shanghai displayed somewhat higher readings than were seen for the Phase I cities, while the Tokyo and Atlanta were more in line the Phase I results. This can be explained by the lack of, or conservative use of, air conditioning in Shanghai and Sao Paulo.

Light levels and spectral energy distributions, which were monitored only in Atlanta and Shanghai for Phase II, were found to be somewhat lower overall than the overall levels observed for Phase I, but the long-term average spectral distributions were still dominated by diffuse, window-filtered daylight.

In order to better simulate the average home spectrum, we have found that xenon illumination passed through daylight balancing filters such as either the LA-20 or LA-40 filter (Hoya) produces a significantly better match than the standard 6-mm window glass-filtered xenon specification. Further work is necessary to optimize the match, especially in the blue and UV regions of the spectrum.

Notes and References

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Biography

Douglas Bugner received a B.S. in Chemistry from The Ohio State University in 1975, an M.S. in Organic Chemistry from UCLA in 1980, and a Ph.D. in Organic Chemistry from UCLA in 1982. Dr. Bugner spent the first 10 years of his career at Eastman Kodak Company researching toners and photoconductors for electro-photographic applications. In 1993, Dr. Bugner established a research effort in the area of inkjet materials, and the Inkjet Materials Technology Laboratory was formed in 1994, which he headed until 1999. Dr. Bugner is currently Senior Laboratory Head, Cut-Sheet Commercialization Lab, Inkjet Systems Division.