# Correlation of Activation Energy between LEDs and Luminaires in the Lumen Depreciation Test

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**Abstract**

This paper investigated the correlation of activation energy between LED light source and LED luminaire in lumen depreciation test. Two nonlinear fitting methods were used to verify the stability of the different algorithms to extract the activation energy. The results show that the activation energy of LED luminaire is very close to the LED light source. Activation Energy is typically around 0.20eV and ranges from 0.18eV to 0.23eV for LED luminaire, compared to typically 0.17eV and ranging from 0.11eV to 0.26eV of LED light source.

**Keywords:** LED, Luminaire, Arrhenius Equation, Activation Energy, Lumen Depreciation Test.

**Introduction**

Unlike the traditional lighting, the lifetime of LEDs, LED modules and LED based lighting products is generally defined when the luminous flux falls to 70% (L70) of its initial value under natural operation conditions.[1-3]. With the application of the standard IES- LM-80-08 combined with TM-21, which is based on the proven assumption that the lumen decay follows the exponential decay model and the depreciation parameter obeys the Arrhenius equation, the lifetime of LED or LED modules can be predicted. However, many concerns exist. It is difficult to know how the lens or second optics impact the depreciation, how much the control circuit or driver contribute to the degradation , and what's impact of thermal design, and so on. Nevertheless, the activation energy Ea plays an important role in lumen depreciation prediction. This paper will investigate the correlation of Ea between LED light sources and LED lamps or luminaires based on the assumed exponential decay model and Arrhenius equation.

**Method**

Assume that both the LEDs and LED luminaires follow the exponential decay model as shown below in Equation (1) as follows.

$$\phi(t) = \beta e^{-\alpha t} \qquad (1)$$

Where $\phi(t)$ represents the normalized lumen output, t is the time, $\beta$ is 1.0 theoretically, but varies around 1.0 when real experimental data is applied. $\alpha$ is depreciation parameter. According to Arrhenius function, $\alpha$ can be written as:

$$\alpha = Ae^{-\frac{Ea}{k_b T}} \qquad (2)$$

Where A is the pre-factor, and $Ea$ is activation energy, $k_b$ is the Boltzmann constant (8.617385x$10^{-5}$eV/K) and T is the temperature in Kelvin.

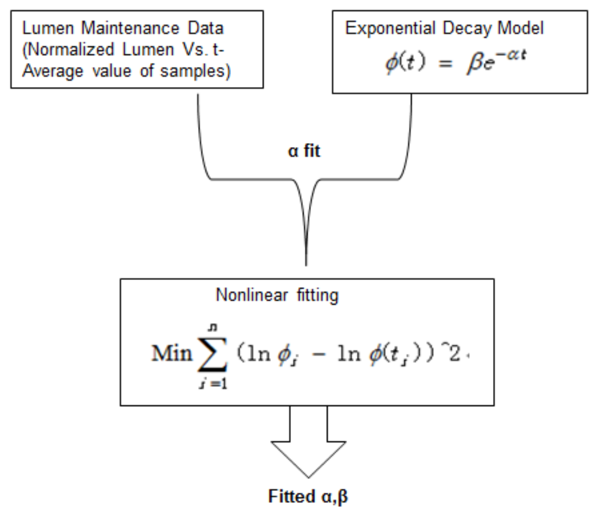


Fig.1 Depreciation parameter α fitting procedure

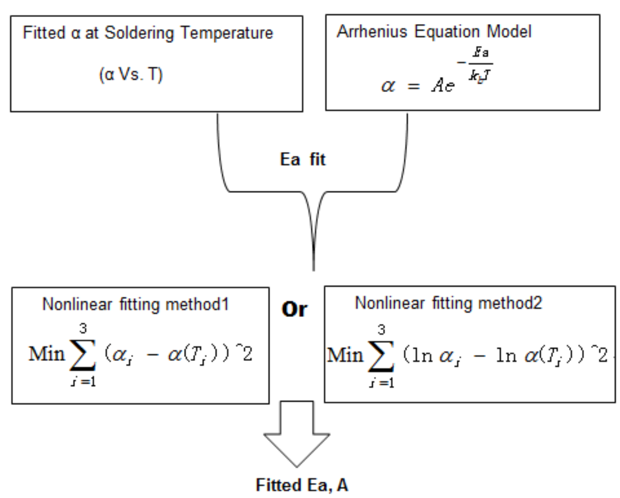


Fig.2 Activation energy Ea fitting procedure

Fig.1 and 2 show the fitting procedures for the depreciation parameter α and Activation Energy Ea respectively. Activation Energy Ea can be deducted through 2 steps via fitting method. First step is to obtain the α value with the available lumen depreciation data combined with exponential decay model by the nonlinear fitting method as shown in Fig.1 The second step is to use the fitted α value under different temperatures and the Arrhenius equation with a fitting method. There are two options for nonlinear fitting, as described in the Fig.2, in the second step. According to LM-80 and TM-21, the temperature used in the Arrhenius equation is soldering temperature. Here during the Ea fitting, the temperature used is also the soldering temperature for both LED light sources and LED luminaires.

While for the Ea fitting of LED light sources, the lumen depreciation data are from the available LM-80 database. For the Ea fitting of LED luminaires, lumen depreciation data from 4 brand luminaires were tested by authors. The soldering temperature is obtained through thermal couple during normal operating conditions. Luminaires tested are shown in Fig.3. Two down lights, one spot light (Par light) and one retrofit bulb are used.


Fig.3 Pictures of Luminaires

## Experiments

For each luminaire one sample was randomly chosen to do soldering temperature (Ts) measurement with thermal couples. Among three thermal couples used for the measurement, two (Ts,1 and Ts,2) were used for Ts measurement and one(Tr) was used for ambient temperature monitoring. Fig.4 shows the Ts measurement for the Retrofit bulb as an example. Table 1 shows the Ts measurement data for the 4 luminaires.

Ts used for the ambient temperature of 25deg.C is the average value of Ts readings at steady state. Since there is some difference (Td) between the ambient temperature Tr and the normal room temperature 25deg.C during measurement due to environmental temperature change, the adjustment of Ts was done in the Ea fitting. Take the measurement data of downlight A as an example, Tr reading is 26.5deg.C, the average of Ts is 59.8deg.C, and to take into consideration the temperature difference Td of 1.5deg.C as an adjustment, the actual Ts used for the ambient temperature of 25deg.C in the Ea fitting is 58.3deg.C. Table 2 shows the actual Ts for Ea fitting.


Fig.4 Ts measurement with thermal couples

Table1 Ts measurement data for luminaires (Unit:deg.C)

| | DownlightA | DownlightB | Par30 A | Retrofit bulb A |
|---|---|---|---|---|
| Ts, 1 | 60.4 | 71.1 | 51.6 | 63.6 |
| Ts. 2 | 59.1 | 73.0 | / | 63.7 |
| Tr | 26.5 | 25.9 | 25.6 | 19.1 |

Table 2 Ts for Ea fitting

| Ta (deg. C) | Ts(deg. C) | | | |
|---|---|---|---|---|
| | DownlightA | DownlightB | Par30 A | Retrofit bulb A |
| 25 | 58.3 | 71.2 | 51.0 | 69.6 |
| 55 | 88.3 | 101.2 | 81.0 | 99.6 |
| 85 | 118.3 | 131.2 | 111.0 | 129.6 |

## Results &Discussion

Table 3 Ea fit results for Luminaires

| Luminaires# | Fitting Method 1 | | Fitting Method 2 | |
|---|---|---|---|---|
| | Ea | A | Ea | A |
| Downlight A | 0.4134 | 13.79 | 0.2081 | 0.0289 |
| Downlight B | 0.4077 | 2.09 | 0.1958 | 0.0027 |
| Par30 | 0.4193 | 5.92 | 0.1823 | 0.0043 |
| Retrofit Bulb | 0.4046 | 1.88 | 0.2285 | 0.0108 |

Table 4 Ea fit results for lighting sources ( some of them)

| LED Light Sources (only show part of them) | Fitting Method 2 | |
|---|---|---|
| | Ea | A |
| | 0.1797 | 0.0012 |
| | 0.2548 | 0.0287 |
| | 0.1493 | 0.0007 |
| | 0.2029 | 0.0062 |

Table3 shows the Ea fitting results for luminaires with 2 fitting methods. Ea fit results between two methods are quite different ， around 0.2eV difference. Meanwhile, the pre-factor A is also quite different, 2~3 orders of magnitude difference.

Note that use the first nonlinear method, the Ea fit is unstable; the result depends much on the numerical precision and convergence condition, even the step length of the variables has much influence on the fitting results. So the Ea fit data with nonlinear method 1 shown in Table 3 is not reliable.

Hence, in the Ea fitting for the light sources, fitting method 1 was not used. Around 20 sets of LM-80 data were used, and some results were shown in Table 4.

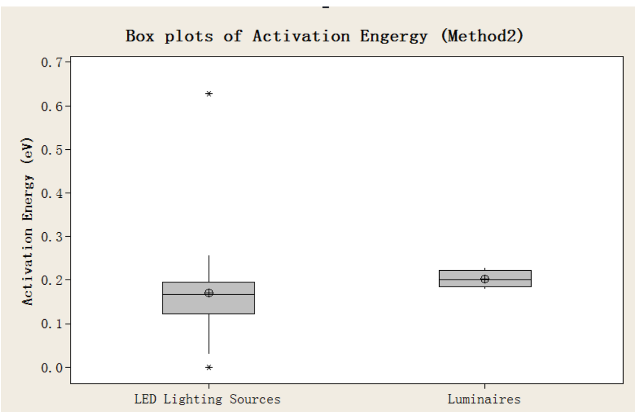


Fig.5 Box plots of Ea of Method 2

Fig.5 shows the box plots of Ea fitting results with nonlinear method 2 for both luminaires and light sources. Here all the Ea fitting results are included. Not considered the outliers, the Ea of LED light sources ranges from 0.11eV to 0.26eV, while the Ea of the Luminaires from 0.18eV to 0.23eV. Typical Ea value for the Luminaires is around 0.20eV, around 0.03eV higher than the light sources which have a typical value around 0.17eV.

Since the fitting method 2 is more robust and consistent with the linear fit result which set 1/T as a variable, Ea fit results with the fitting method2 is much more reliable. 0.03eV Ea difference between LED light sources and luminaires could be from a lot of factors as below

1) Measurement error. Including the lumen maintenance Data from LM-80 and luminaires measured with integrated sphere, temperature measurement with thermal couples.
2) Sample to sample variation. Different Ea values exist among different samples both for luminaire and light source
3) Contribution by the luminaire itself. Including the control circuit degradation during temperature strength loading, yellowing of lens or other optical parts, or possible interactions, and so on.

## Conclusions

Two nonlinear fitting methods were used to verify the stability of the different algorithms to extract the activation energy. Correlation of activation energy between LED luminaires from some brand manufacturers and LED light sources from many brand suppliers were investigated. Results were shown the Ea value of LED luminaire is very close to the LED light source. Activation Energy is typically around 0.20eV and ranges from 0.18eV to 0.23eV for LED luminaire, compared to typically 0.17eV and ranging from 0.11eV to 0.26eV of LED light source.

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