IEA Technology Collaboration Programme
on Energy Efficient End-Use Equipment

IEA-4E SSL Annex - Task 2
Lifetime of SSL Lamps and Luminaires

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Predictive life test incorporating accelerated aging

Australian Research Activity

Two main points for research investigation

- A **shorter test duration** that is financially viable for manufacturer and regulator, which incorporates stresses of the following nature:
  - Elevated ambient temperature
  - Elevated humidity
  - Thermal and mechanical stresses from switch cycling
- A test method which **predicts a lifetime based on all common modes of product failure**, including:
  - Reduction in light output
  - Colour shift due to phosphor degradation
  - Electrical failure due to mechanical failure of circuit boards and connections
  - Electronic component failure

- Proposed research is to gather test data to explore one identified option for accelerated LED lifetime testing through the measurement of the rate of decline in light output while a lamp is operated at an elevated ambient temperature (e.g. 60 °C) for 1,500 hours and linking with luminous flux relationship with ambient and junction temperatures.

Test Method

1. **Accelerated Degradation Test (ADT)**

   a) 5 sample lamps (#1 - #5)

   b) 5 sample lamps (#11 - #15)

   c) Operate lamps #1 - #5 in thermal chamber at a constant 60°C ambient temperature for a total of 1500 hours with measurements conducted at 0 hours, and subsequently at 150-hour intervals

   d) Store (i.e. no power connected) lamps #11 - #15 in thermal chamber at a constant 60°C ambient temperature for a total of 1500 hours with measurements conducted at 0 hours, and subsequently at 150-hour intervals.

   e) Measurement of lamps #1 - #5 and #11 - #15 of listed photometric quantities in integrating sphere (at 25°C ambient)

      i) total luminous flux

      ii) spectral power distribution

      iii) temporal light modulation (SVM, PstLM)

Test Method

2. **Pulse and Soak Tests**

   a) 5 sample lamps (#6 - #10)
   b) Measure initial total luminous flux in integrating sphere at 25°C ambient
   c) Place lamps in thermal chamber with independent power switching to each lamp socket
      i) Thermally stabilise samples at 25°C ambient
      ii) For each lamp, switch on for 0.5 second and measure relative luminance on reference white tile surface inside thermal chamber within 0.3 seconds
      iii) For each lamp, switch on and monitor relative luminance on reference white tile surface inside thermal chamber until luminance variation is less than 2% in last 15 minutes. Record the stabilised luminance measurement.
      iv) Repeat measurement steps i) to iii) for ambient temperatures from 40°C to 100°C in 10°C steps

Model Types to Test

Anticipated sample types

Rated lifetimes of ~10,000 hours

1) GU10 MR16 single COB
2) E27 A60 LED filament
3) E27 A60 LED multichip

Number of models tested determined thermal chamber space availability (and budget)

Theory

Luminous flux decay model

- Luminous flux maintenance is determined from the exponential decay function:

$$\frac{\emptyset_{T_0,I_0,t}}{\emptyset_{T_0,I_0,t=0}} = A_{T_0 I_0} . e^{-\beta_{T_0 I_0} . t}$$

for a set LED chip junction temperature, T_j, due to the forward current, I_0, and ambient operating temperature, T_0.

- Note: ANSI/IES TM-21-19 Annexes F (Consideration of manufacturer's prediction model) & G (Analysis of mathematical modelling as a method of projecting lumen maintenance life) provide a very good assessment of different mathematical models but failed to find a more reliable model so have stayed with the simple exponential model.

- The luminous flux of a LED source can be predicted for standard operating conditions based upon the separate influences of junction temperature and drive current and the combined influence of drive current on junction temperature, such that at any point in operating life:

$$\emptyset_{T_1,I_1,t} = \emptyset_{T_0,I_0,t}.K_T.K_i.K_{iT}$$

- Need to determine K co-efficients which are intrinsic to the product design
  - K_i not required in this discussion as current for a product is fixed (for dimmable/tuneable products considered at maximum operating current).

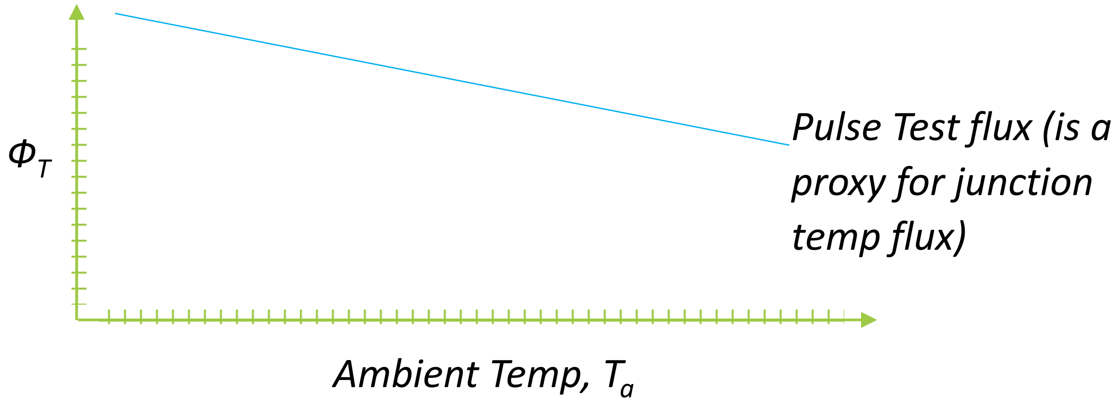
$$\emptyset_{T_1,t} = \emptyset_{T_0,t}.K_T.K_{iT}$$

Pulse Test

Thermal co-efficient

$$K_T = 1 + \alpha . \Delta T$$
$$= 1 + \alpha . (T_0 - T_1)$$

K_T is determined from a **pulse test** (0.5 s) with fixed drive current, I, and various ambient temperatures, which are same as the LED chip junction temperatures.

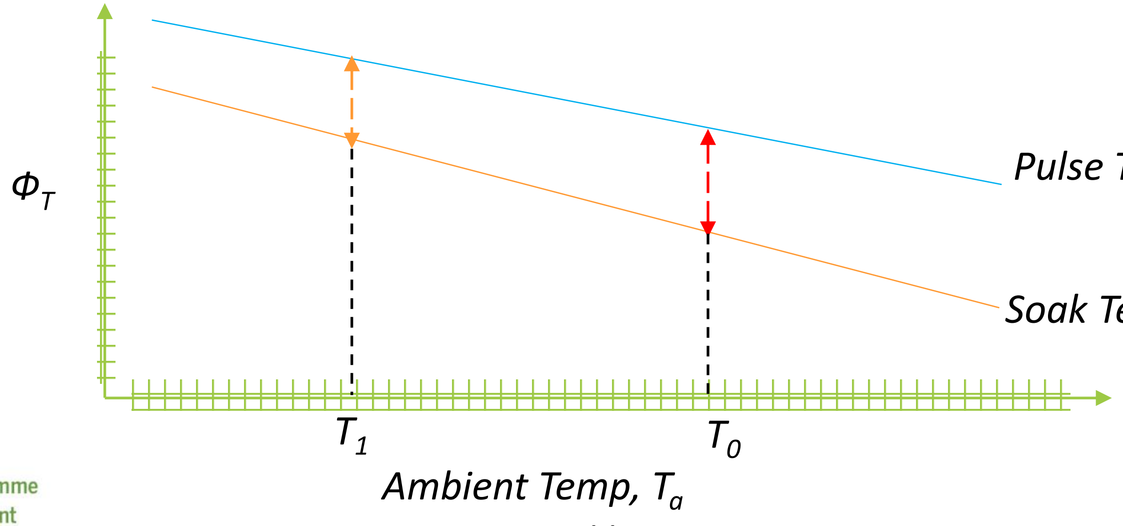


Soak Test

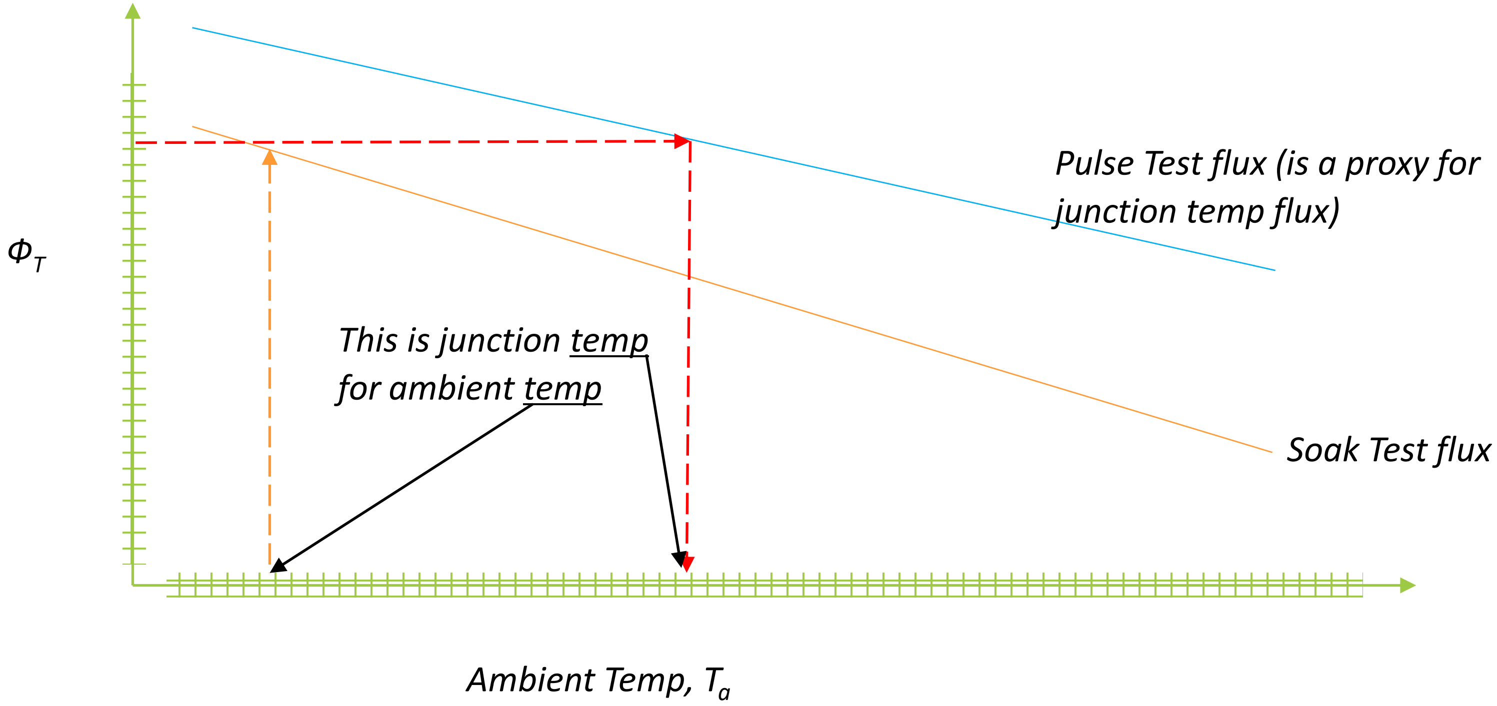
Current-thermal interaction co-efficient

$$K_{iT} = \frac{\left(\phi_{P_{T_0}} - \phi_{S_{T_0}}\right)}{\left(\phi_{P_{T_1}} - \phi_{S_{T_1}}\right)}$$

K_{iT} is determined from combination of the **pulse test** results above and a **soak test** with fixed drive current, I, with stabilised LED chip operating junction temperatures for the set ambient temperatures of T_0 and T_1.

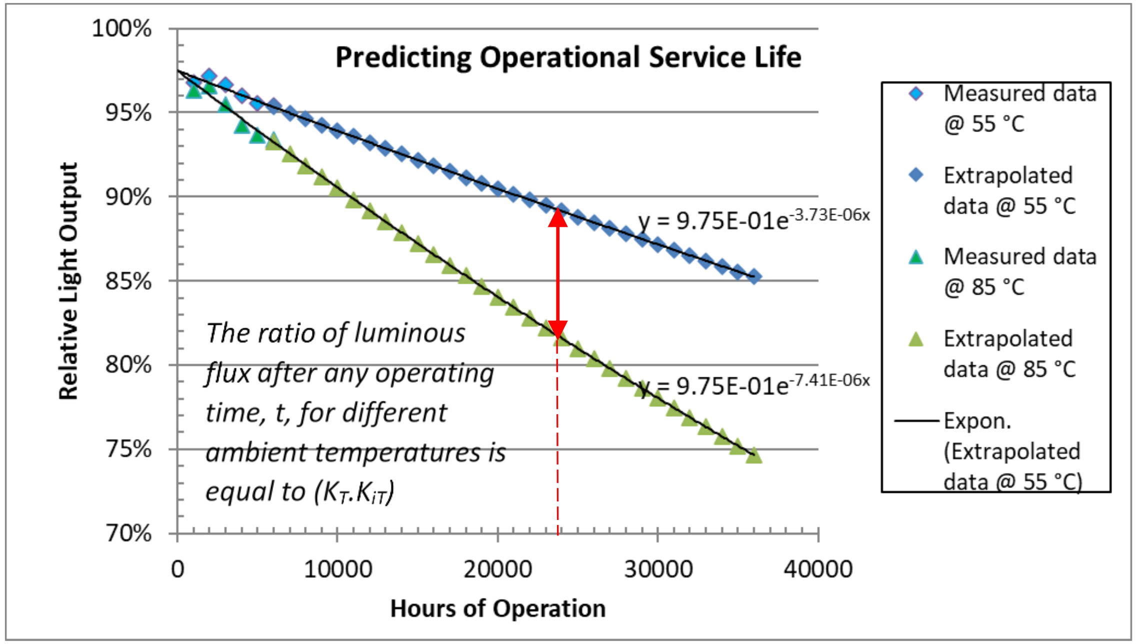


Pulse Test is a proxy for LED chip junction temperature



The ratio of luminous flux after any operating time, t, for different ambient temperatures is equal to

$$\frac{\emptyset_{T_1,t}}{\emptyset_{T_0,t}} = K_T . K_{iT}$$



Resolving equations

$$L_{70,\,25^\circ} = -\left[\frac{ln\left(\frac{0.7}{A_{25^\circ}}\right)}{\beta_{25^\circ}}\right]$$

ADT test

$$A_{25^\circ} = A_{60^\circ}$$

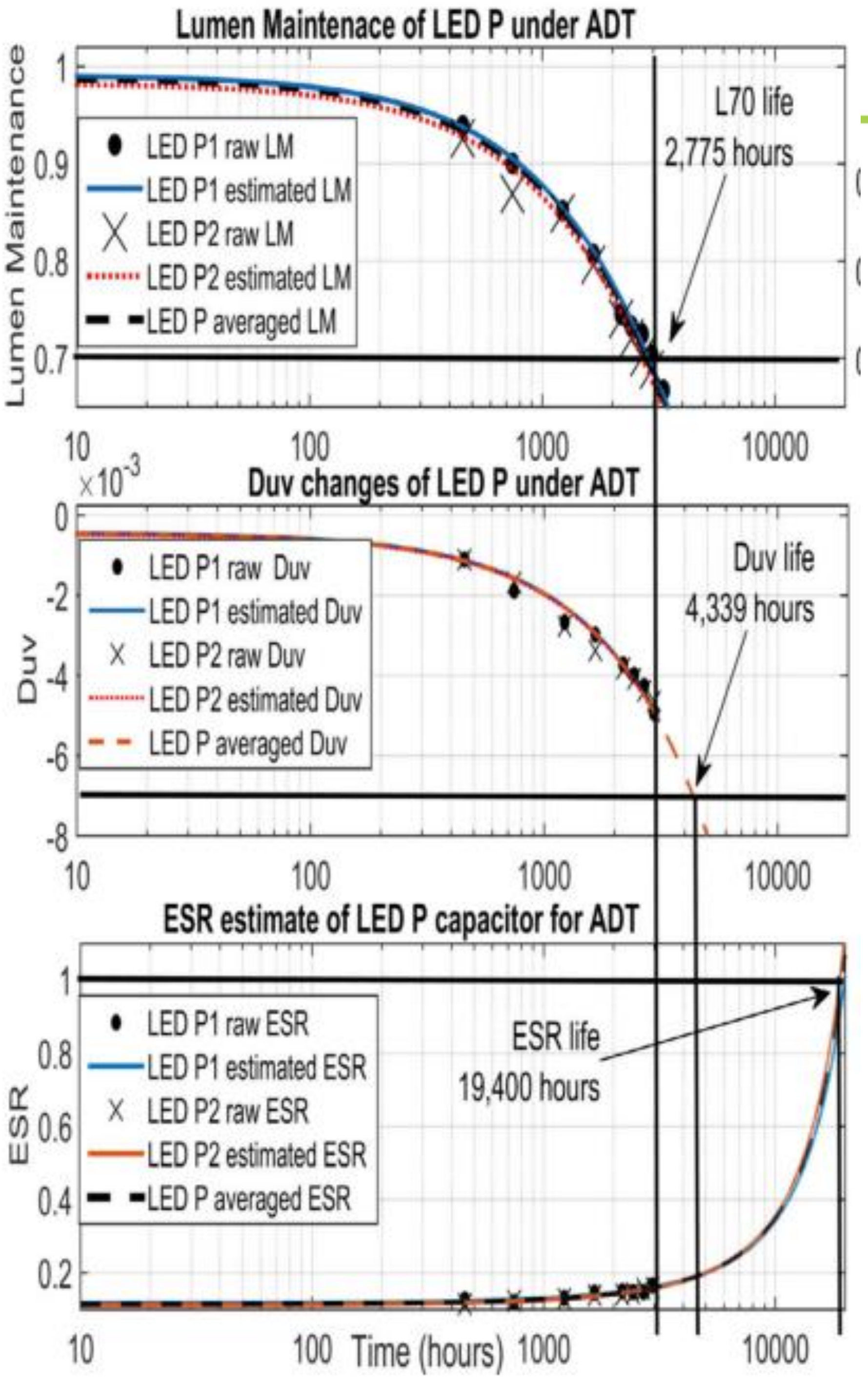
Pulse test

Pulse & Soak tests

$$\beta_{25^\circ} = \beta_{60^\circ} - \frac{ln\left(K_{T_{(60^\circ:25^\circ)}} \cdot K_{iT_{(60^\circ:25^\circ)}}\right)}{L_{70,\,60^\circ}}$$

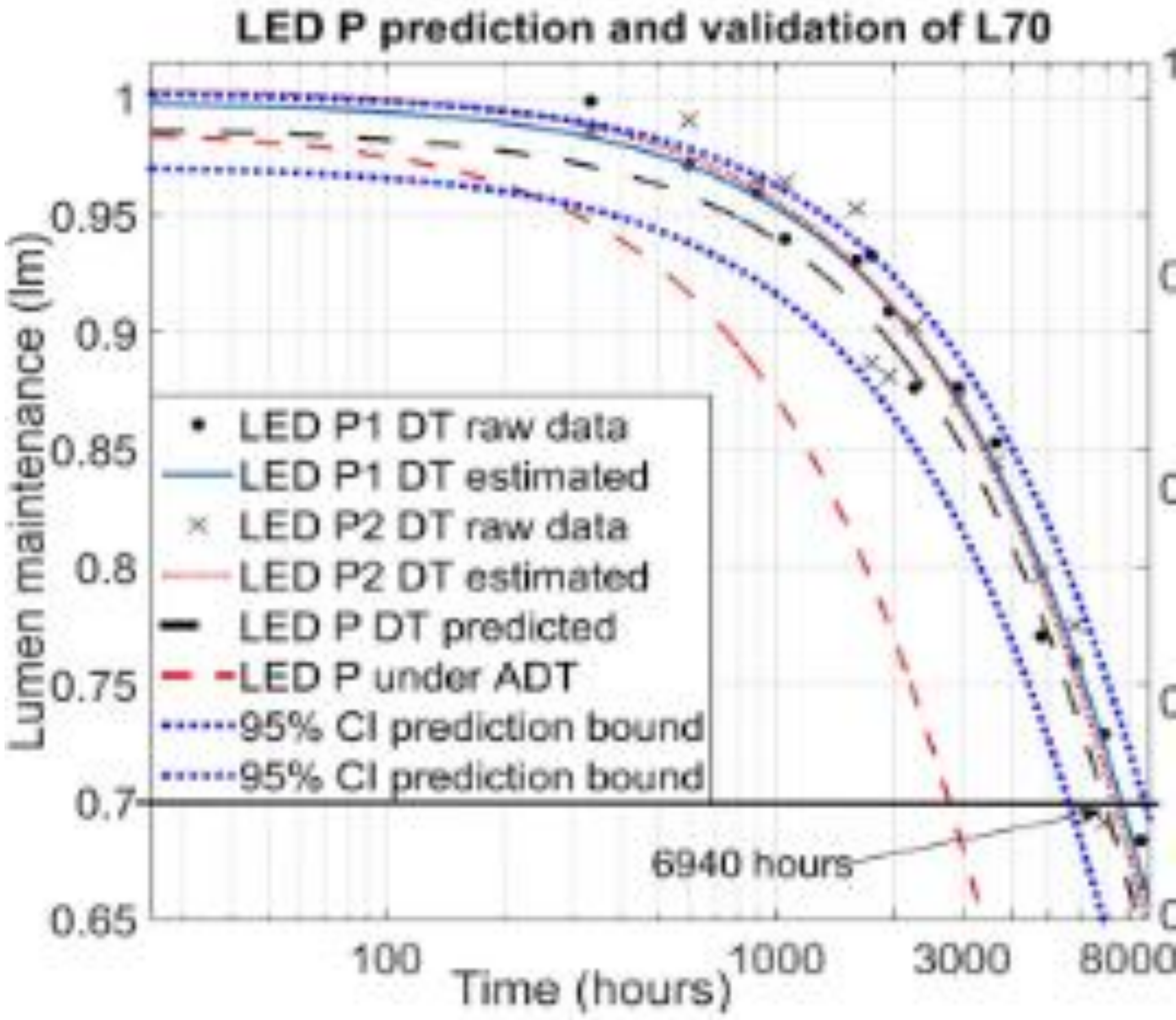
ADT test

Published results



Prediction for DT conditions using ETI model			
LED	$A_0 = A_n$	B_n	L70
P	0.987 (0.971, 1.003)	$4.951(5.826, 4.081)\times10^{-5}$	6940
[redacted]			
Experimental results of DT conditions			
LED	A_{exp}	B_{exp}	L70
P	1.00125	4.779×10^{-5}	7400
[redacted]			

6.2% variation



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