IEA Technology Collaboration Programme
on Energy Efficient End-Use Equipment

Lifetime testing, standards and methods

IEA-4E SSL Annex

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LED Seminar 2023-02-28

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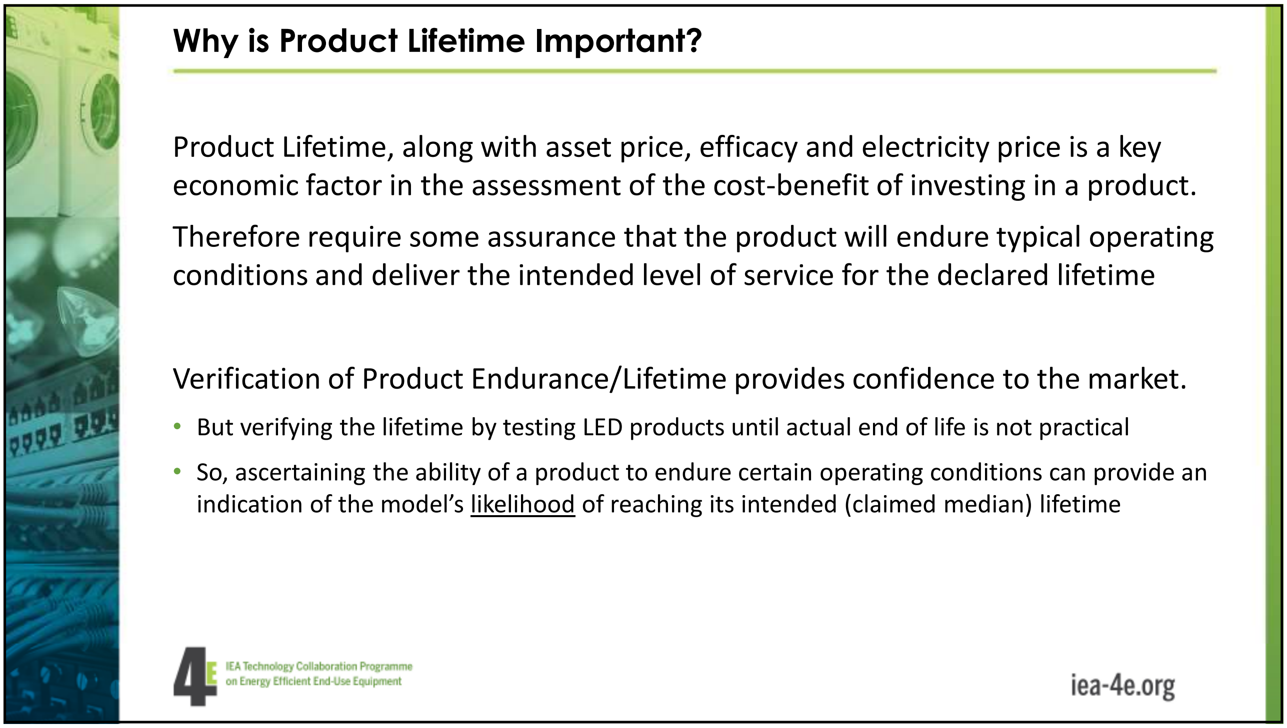


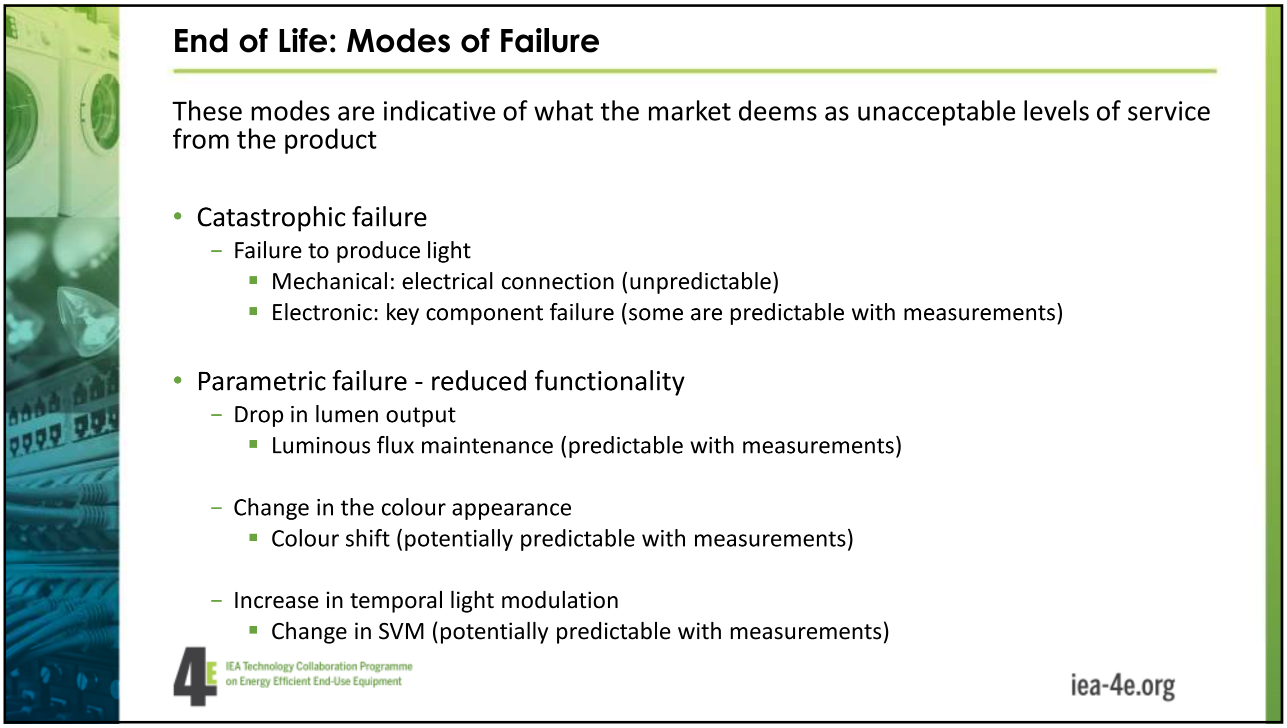
Why is Product Lifetime Important?

Product Lifetime, along with asset price, efficacy and electricity price is a key economic factor in the assessment of the cost-benefit of investing in a product.

Therefore require some assurance that the product will endure typical operating conditions and deliver the intended level of service for the declared lifetime

Verification of Product Endurance/Lifetime provides confidence to the market.

- But verifying the lifetime by testing LED products until actual end of life is not practical
- So, ascertaining the ability of a product to endure certain operating conditions can provide an indication of the model's likelihood of reaching its intended (claimed median) lifetime



End of Life: Modes of Failure

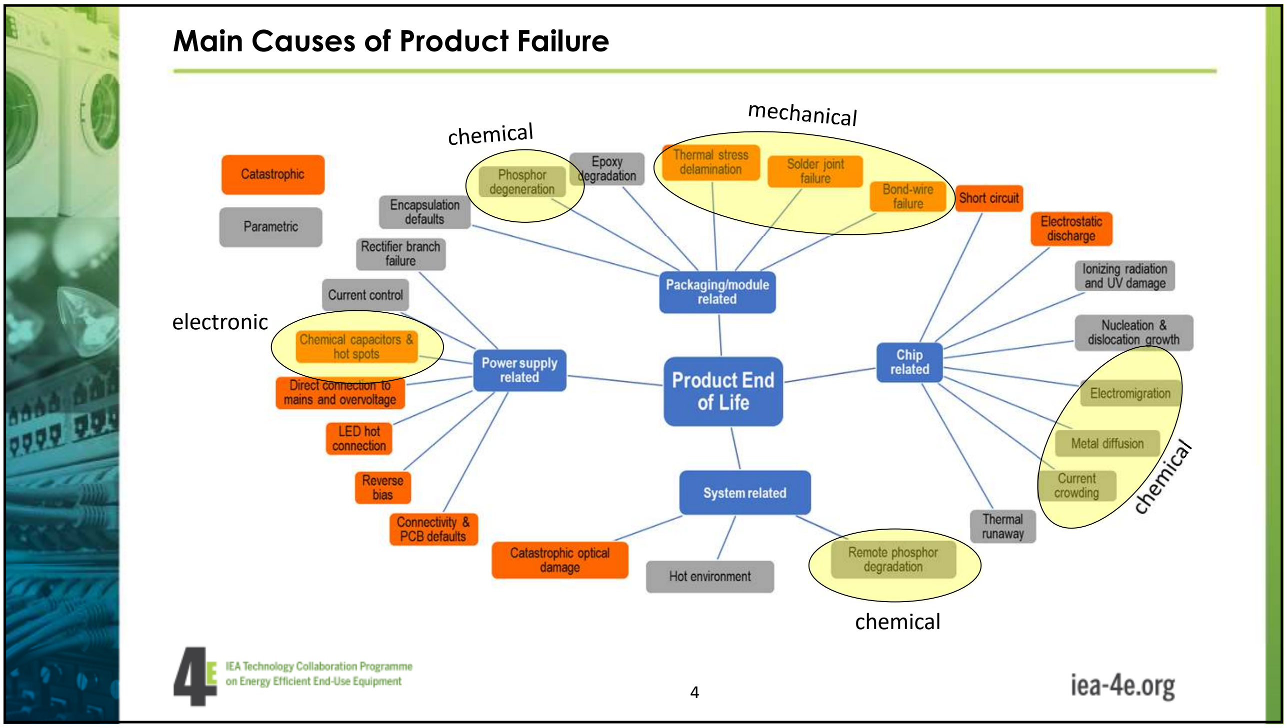
These modes are indicative of what the market deems as unacceptable levels of service from the product

- Catastrophic failure
  - Failure to produce light
    - Mechanical: electrical connection (unpredictable)
    - Electronic: key component failure (some are predictable with measurements)

- Parametric failure - reduced functionality
  - Drop in lumen output
    - Luminous flux maintenance (predictable with measurements)

  - Change in the colour appearance
    - Colour shift (potentially predictable with measurements)

  - Increase in temporal light modulation
    - Change in SVM (potentially predictable with measurements)



Main Causes of Product Failure

Catastrophic
Parametric

Product End of Life

Packaging/module related
chemical
Phosphor degeneration
Epoxy degradation
Encapsulation defaults
mechanical
Thermal stress delamination
Solder joint failure
Bond-wire failure

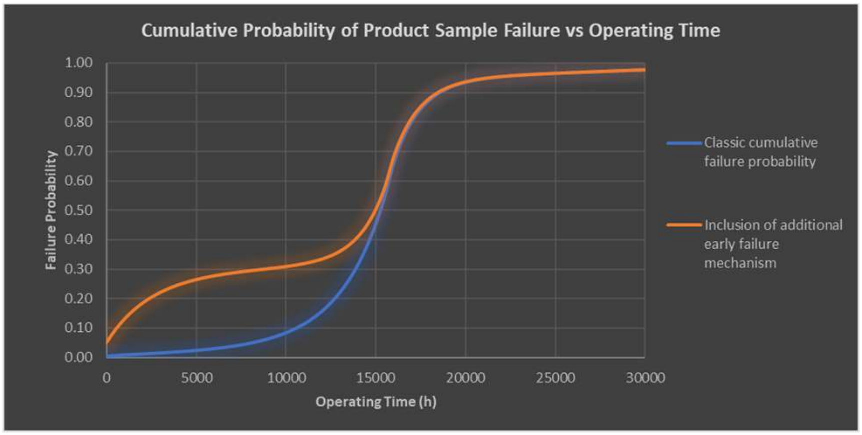
Power supply related
Rectifier branch failure
Current control
electronic
Chemical capacitors & hot spots
Direct connection to mains and overvoltage
LED hot connection
Reverse bias
Connectivity & PCB defaults

Chip related
Short circuit
Electrostatic discharge
Ionizing radiation and UV damage
Nucleation & dislocation growth
chemical
Electromigration
Metal diffusion
Current crowding
Thermal runaway

System related
Catastrophic optical damage
Hot environment
Remote phosphor degradation
chemical

Desirable Performance Information in Relation to Product Failure

- Early failure rate (predominantly catastrophic but unpredictable)
- Expected median lifetime (generally parametric and predictable)



Endurance Tests within IEC 62612 & IEC 62717

1. Accelerated operational life (i.e. Extreme conditions)
   - 10°C above maximum rated operating temperature
   - ON continuously
   - 1000 hours

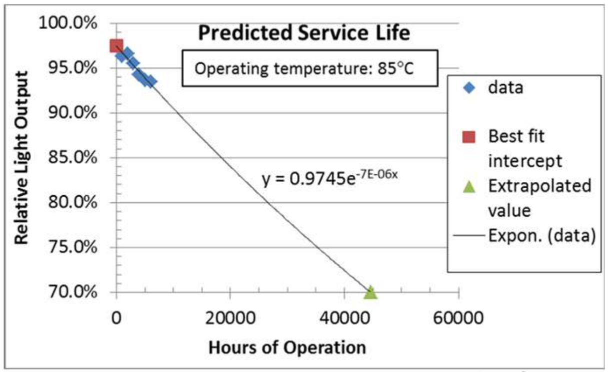
2. Ambient temperature cycling (i.e. Max rated)
   - -10°C (1 h hold) transition for 1 h to 40°C (1h hold)
   - ON (34 min): OFF (34 min)
   - 250 thermal cycles (1000 hours)

3. Supply switching (i.e. Typical)
   - 25°C ambient temperature
   - ON (30s): OFF (30s)
   - # cycle equals half the hours of rated life (eg 125 hours for 15k hour product)

- IEC 63221 LED Light sources – Performance requirements (expected 2023)
  - Replaces IEC 62612 & IEC 62717 but retains the 3 endurance tests above
  - And, includes informative Annexes for Luminous flux maintenance test methods
    - Annex L – EU 3000 h test (Annex V, EU Reg 2019/2020)
    - Annex M – ANSI/IES LM-80-20

Median Lifetime Prediction – Recognised Methods

- Extrapolation based on luminous flux maintenance
  - In terms of product lifetime, limited test operating time (minimum of 6,000 h); no switching; rated operating conditions; ambient temperature of 25 °C
  - Maximum extrapolation limited (based on number of sample units) to 6x test operating hours
    - Longer L_{70} requires longer testing (eg 10,000 h of test required for verifying L_{70} of 60,000 h)
- Test methods:
  - ANSI/IES LM-80-20
  - ANSI/IES LM-84-20
- Prediction methods:
  - ANSI/IES TM-21-21
  - ANSI/IES TM-28-20



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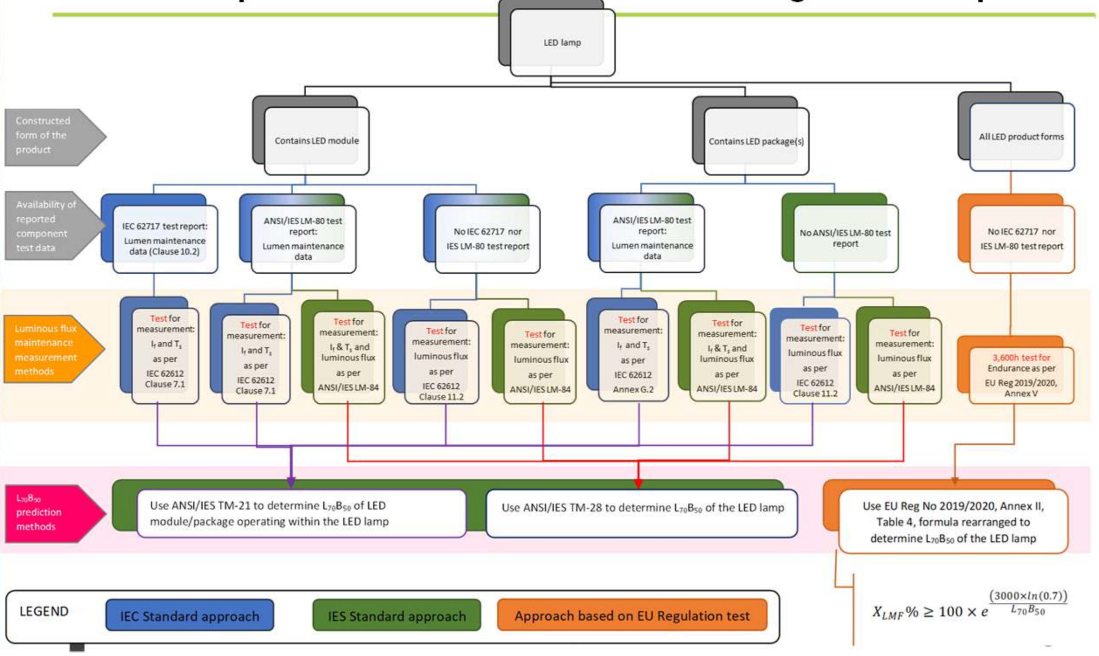
All current options in standards for lifetime testing of LED lamp



Constructed form of the product

Availability of reported component test data

Luminous flux maintenance measurement methods

$L_{70}B_{50}$ prediction methods

LED lamp

Contains LED module

Contains LED package(s)

All LED product forms

IEC 62717 test report: Lumen maintenance data (Clause 10.2)

ANSI/IES LM-80 test report: Lumen maintenance data

No IEC 62717 nor IES LM-80 test report

ANSI/IES LM-80 test report: Lumen maintenance data

No ANSI/IES LM-80 test report

No IEC 62717 nor IES LM-80 test report

Test for measurement: I_f and T_s as per IEC 62612 Clause 7.1

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Test for measurement: I_f & T_s and luminous flux as per ANSI/IES LM-84

Test for measurement: luminous flux as per IEC 62612 Clause 11.2

Test for measurement: luminous flux as per ANSI/IES LM-84

Test for measurement: I_f and T_s as per IEC 62612 Annex G.2

Test for measurement: I_f & T_s and luminous flux as per ANSI/IES LM-84

Test for measurement: luminous flux as per IEC 62612 Clause 11.2

Test for measurement: luminous flux as per ANSI/IES LM-84

3,600h test for Endurance as per EU Reg 2019/2020, Annex V

Use ANSI/IES TM-21 to determine $L_{70}B_{50}$ of LED module/package operating within the LED lamp

Use ANSI/IES TM-28 to determine $L_{70}B_{50}$ of the LED lamp

Use EU Reg No 2019/2020, Annex II, Table 4, formula rearranged to determine $L_{70}B_{50}$ of the LED lamp

$$X_{LMF}\% \geq 100 \times e^{\frac{(3000 \times ln(0.7))}{L_{70}B_{50}}}$$

LEGEND

🟦 IEC Standard approach

🟩 IES Standard approach

🟧 Approach based on EU Regulation test

EU Reg 2019/2020, Annex V - Functionality after endurance testing

Compromise between extensive testing and sufficient testing to identify significant product endurance issues and substantiate lifetime claims based on luminous flux maintenance.

Test Conditions

- Power supply switching cycle:
  - ON 2.5 h and OFF 0.5 h
  - 1200 cycles (3,000 h of operation, test duration 3,600 h)
  - Ambient temperature 25 °C ± 10 °C

Criteria to be satisfied

- Catastrophic Failure
  - Maximum of 1 of 10 samples fails to operate at end of test
- Parametric Failure
  - Lumen maintenance factor, $X_{LMF}\%$, no less than $X_{LMF,MIN}\%$, (determined from declared lifetime, $L_{70}B_{50}$)

$$X_{LMF}\% \geq X_{LMF,MIN}\% = 100 \times e^{\frac{(3000 \times ln(0.7))}{L_{70}B_{50}}}$$

Up to a maximum requirement of 96% (approx. 25,000 h lifetime)

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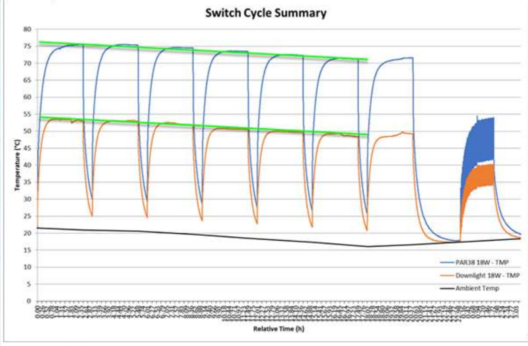
Background support to EU Endurance Testing

- 2018/2019 investigation by Australian Gov as part of IEA SSL Annex activities:

2.5 h ON, 0.5 h OFF vs 1 min ON, 1 min OFF

- Higher max TMP temperature, Lower min TMP temperature
- Larger temperature difference (max-min)
- Greater changes in temperature gradients between adjacent materials within a product, due to differences in thermal resistance and mass.
- Various mechanical stresses due to different thermal expansion rates



$$X_{LMF,MIN}\% = 100 \times e^{\frac{(3000 \times ln(0.7))}{L_{70}B_{50}}}$$

Based on claimed life

Model	2.5h ON / 0.5 OFF (3000hr)		
	Failures Total	Average Lumen Maintenance	Required Minimum
A	5/5	na	95.8%
B	0/5	103.0%	93.1%
C	0/5	89.1%	93.1%
D	0/5	89.4%	95.8%
E	0/5	114.7%	93.1%
F	0/5	98.7%	94.8%
G	3/4	107.2%	95.8%
H	0/4	65.8%	no claim
I	0/4	95.9%	96.5%
J (linear)	0/5	93.9%	no claim
K (linear)	0/5	93.2%	no claim

Directional PAR38 lamp 18W: 465g

TMP

Downlight 18W: 285g

TMP

TMP = Temperature Measurement Point

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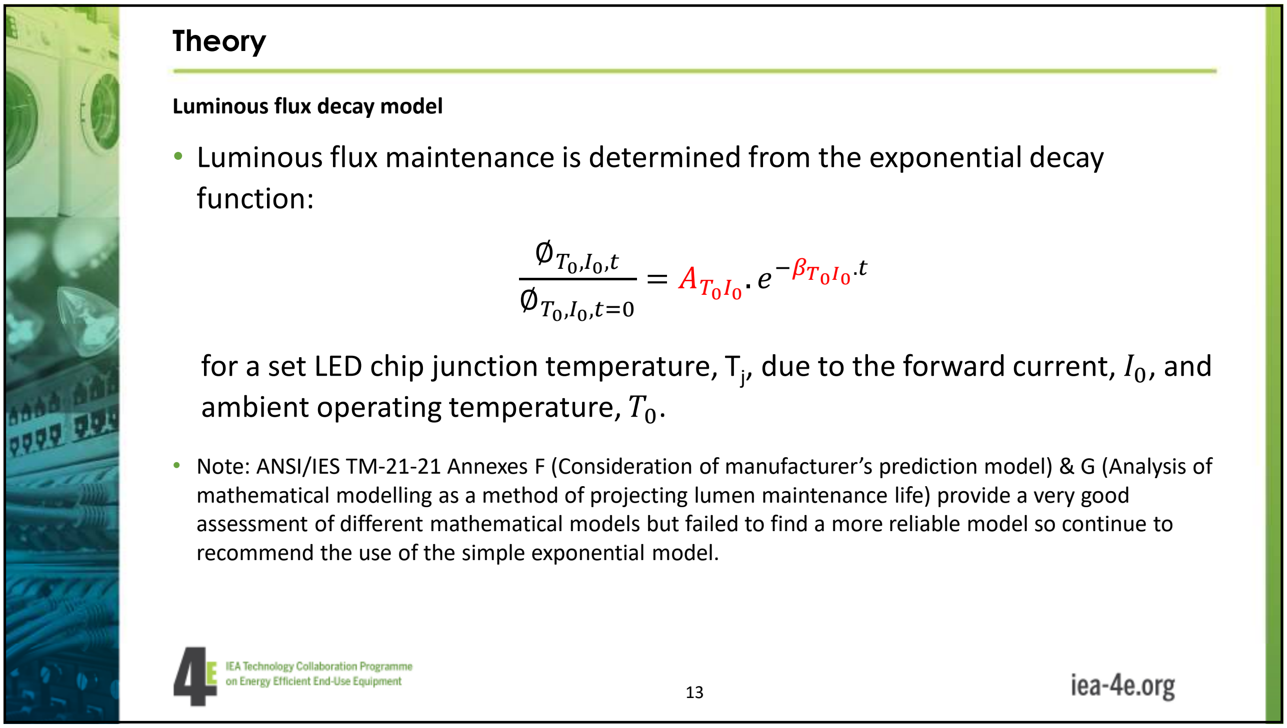
Can we shorten predictive life test by incorporating accelerated aging?

Australian Gov activity as part of IEA SSL Annex

Current Investigation

- To gather test data to explore accelerated LED lifetime testing through the measurement of luminous flux depreciation while a lamp is operated within an elevated ambient temperature (e.g. 60 °C) for 1,500 hours and linking these results with the determined luminous flux relationship between ambient and junction temperatures.



Theory

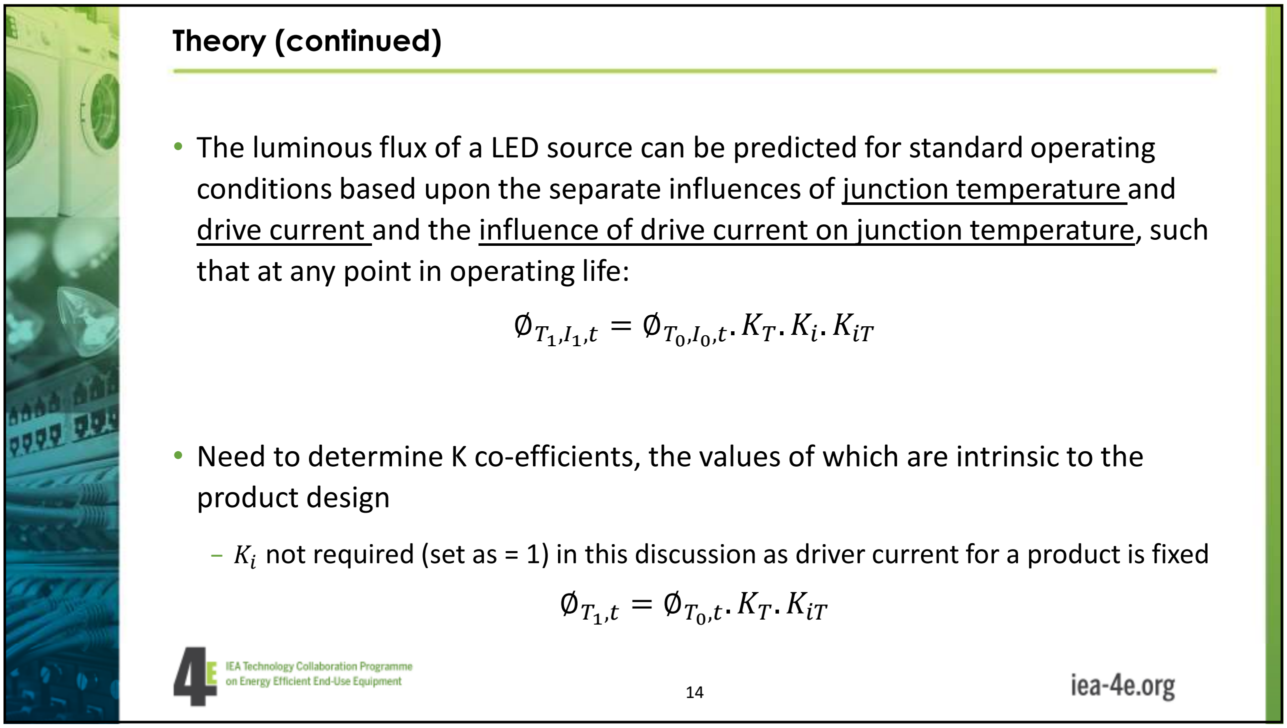
Luminous flux decay model

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

$$\frac{\varnothing_{T_0,I_0,t}}{\varnothing_{T_0,I_0,t=0}} = A_{T_0I_0}.e^{-\beta_{T_0I_0}.t}$$

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-21-21 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 continue to recommend the use of the simple exponential model.



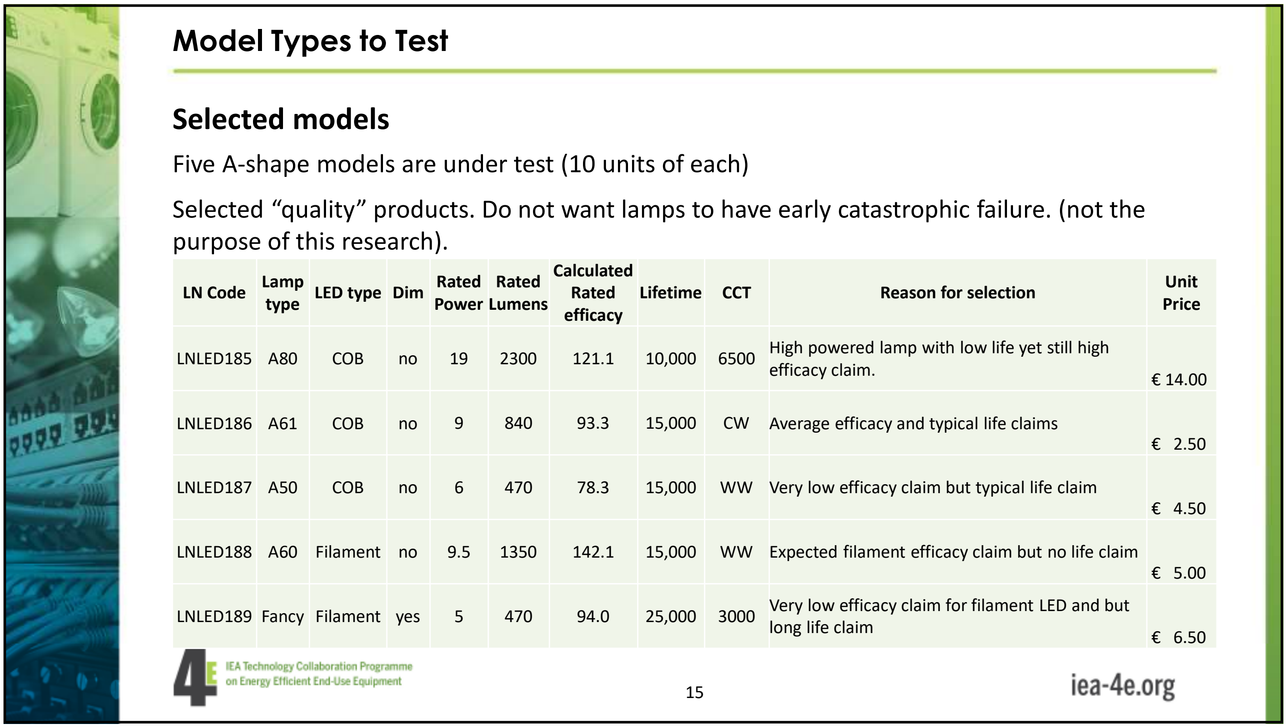
Theory (continued)

- 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 influence of drive current on junction temperature, such that at any point in operating life:

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

- Need to determine K co-efficients, the values of which are intrinsic to the product design
  - K_i not required (set as = 1) in this discussion as driver current for a product is fixed

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



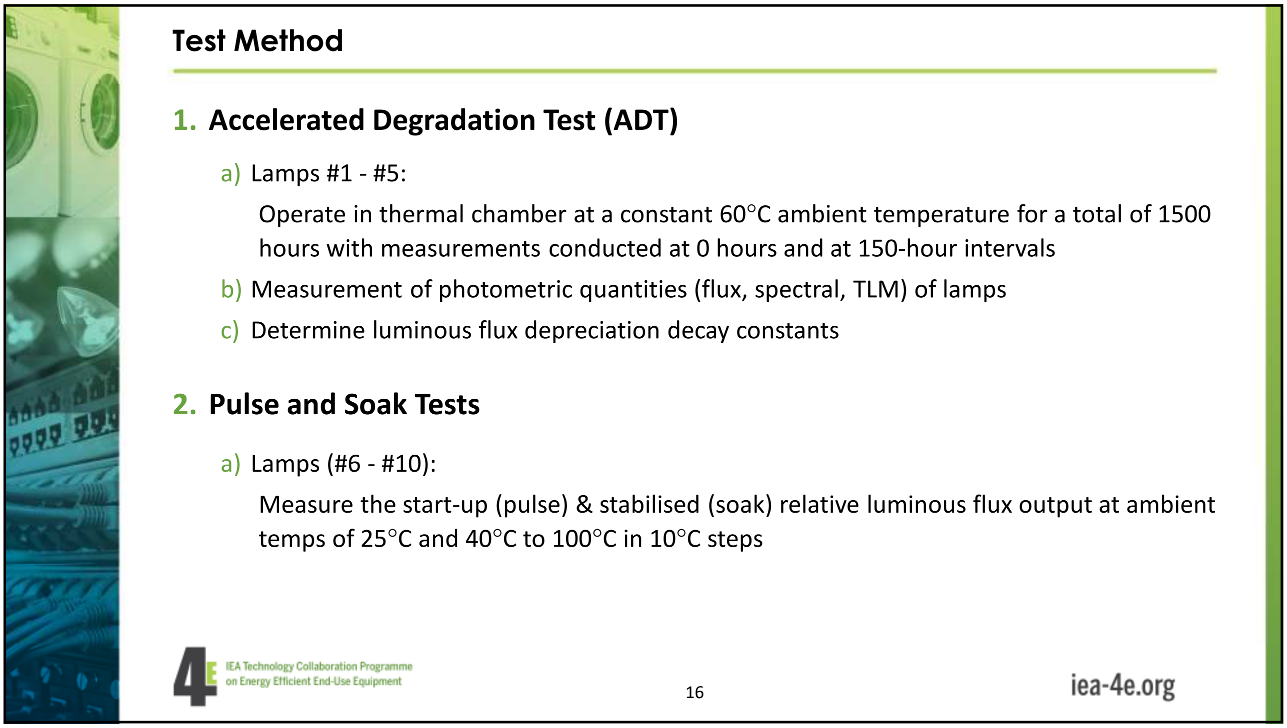
Model Types to Test

Selected models

Five A-shape models are under test (10 units of each)

Selected “quality” products. Do not want lamps to have early catastrophic failure. (not the purpose of this research).

LN Code	Lamp type	LED type	Dim	Rated Power	Rated Lumens	Calculated Rated efficacy	Lifetime	CCT	Reason for selection	Unit Price
LNLED185	A80	COB	no	19	2300	121.1	10,000	6500	High powered lamp with low life yet still high efficacy claim.	€ 14.00
LNLED186	A61	COB	no	9	840	93.3	15,000	CW	Average efficacy and typical life claims	€ 2.50
LNLED187	A50	COB	no	6	470	78.3	15,000	WW	Very low efficacy claim but typical life claim	€ 4.50
LNLED188	A60	Filament	no	9.5	1350	142.1	15,000	WW	Expected filament efficacy claim but no life claim	€ 5.00
LNLED189	Fancy	Filament	yes	5	470	94.0	25,000	3000	Very low efficacy claim for filament LED and but long life claim	€ 6.50



Test Method

1. Accelerated Degradation Test (ADT)

a) Lamps #1 - #5:

Operate in thermal chamber at a constant 60°C ambient temperature for a total of 1500 hours with measurements conducted at 0 hours and at 150-hour intervals

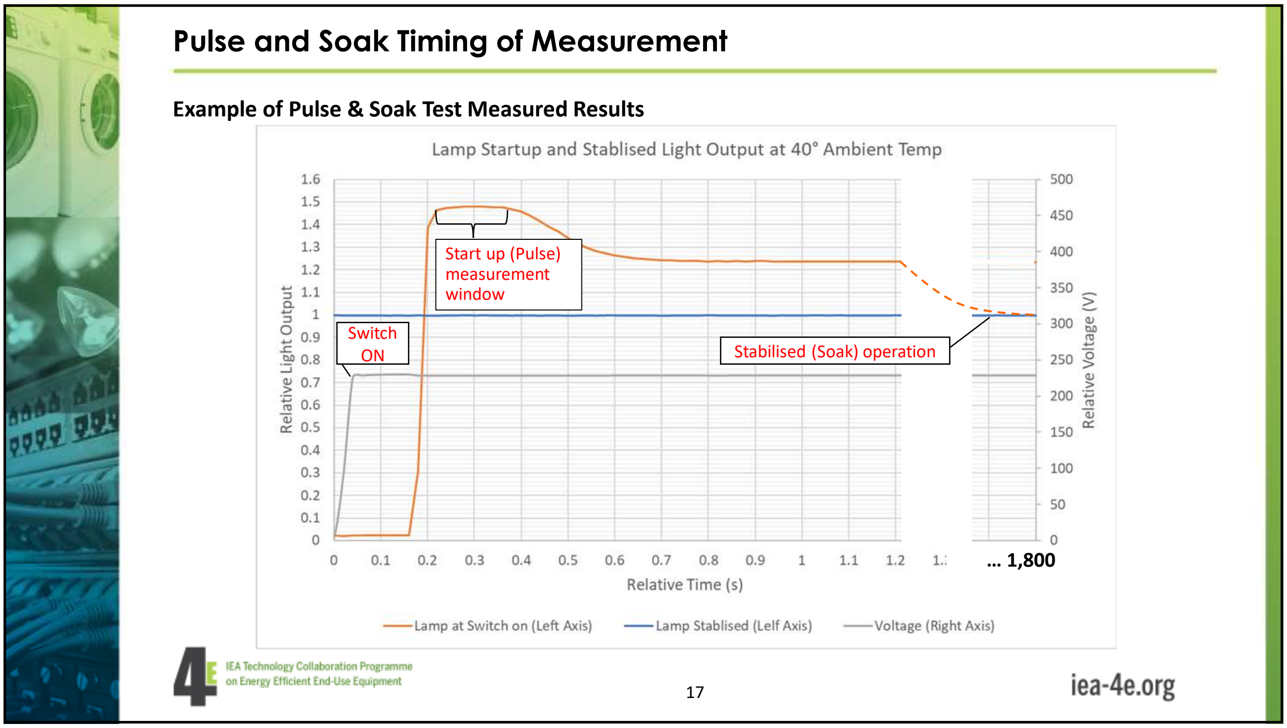
b) Measurement of photometric quantities (flux, spectral, TLM) of lamps

c) Determine luminous flux depreciation decay constants

2. Pulse and Soak Tests

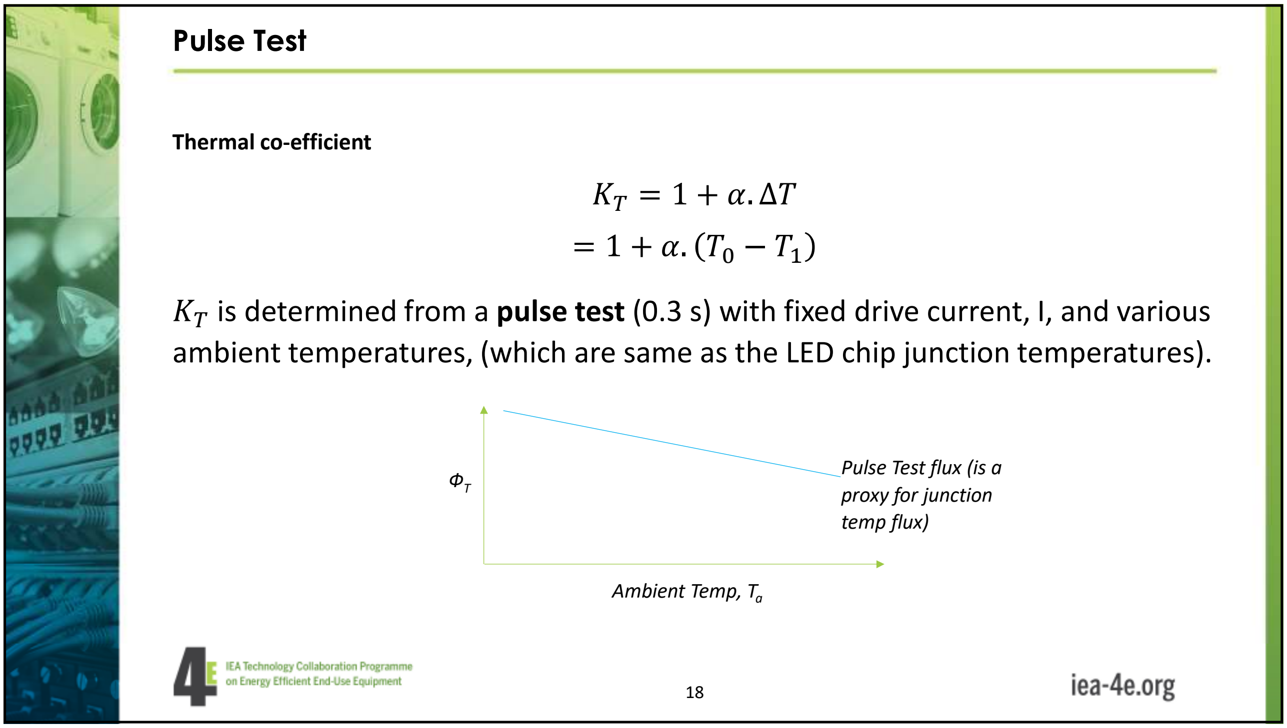
a) Lamps (#6 - #10):

Measure the start-up (pulse) & stabilised (soak) relative luminous flux output at ambient temps of 25°C and 40°C to 100°C in 10°C steps



Pulse and Soak Timing of Measurement

Example of Pulse & Soak Test Measured Results

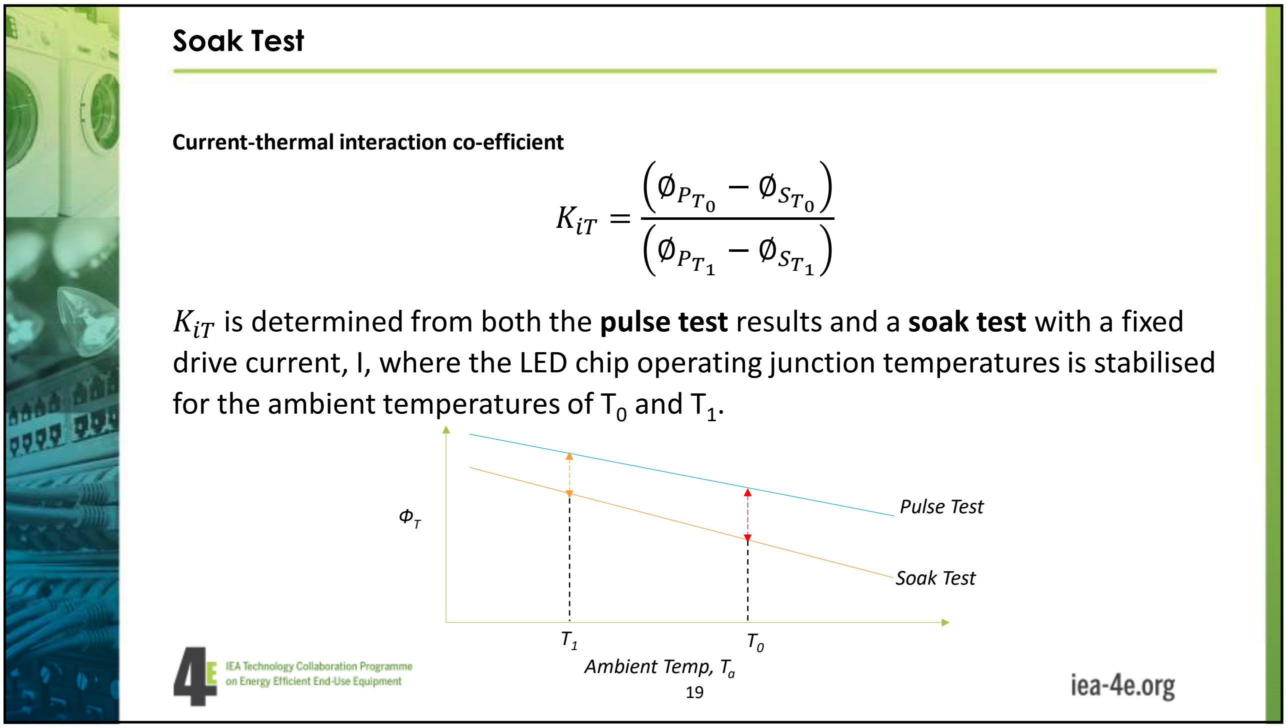


Pulse Test

Thermal co-efficient

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

K_T is determined from a **pulse test** (0.3 s) with fixed drive current, I, and various ambient temperatures, (which are same as the LED chip junction temperatures).

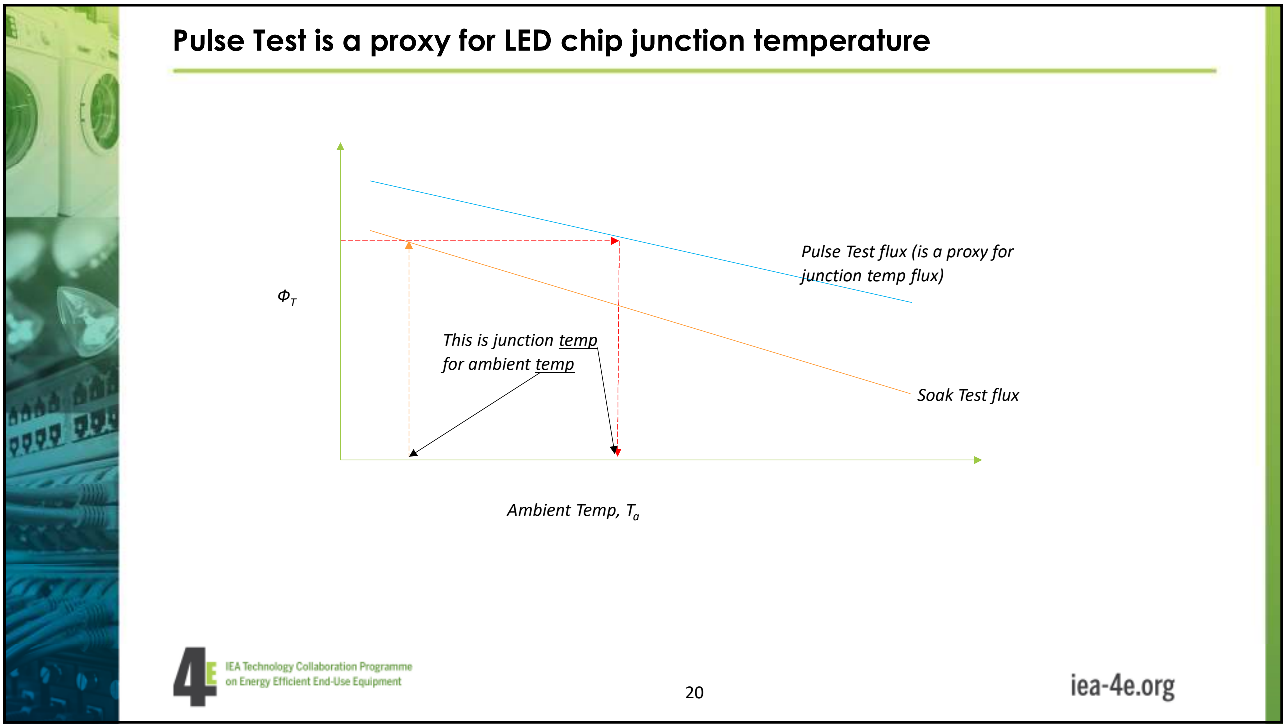


Soak Test

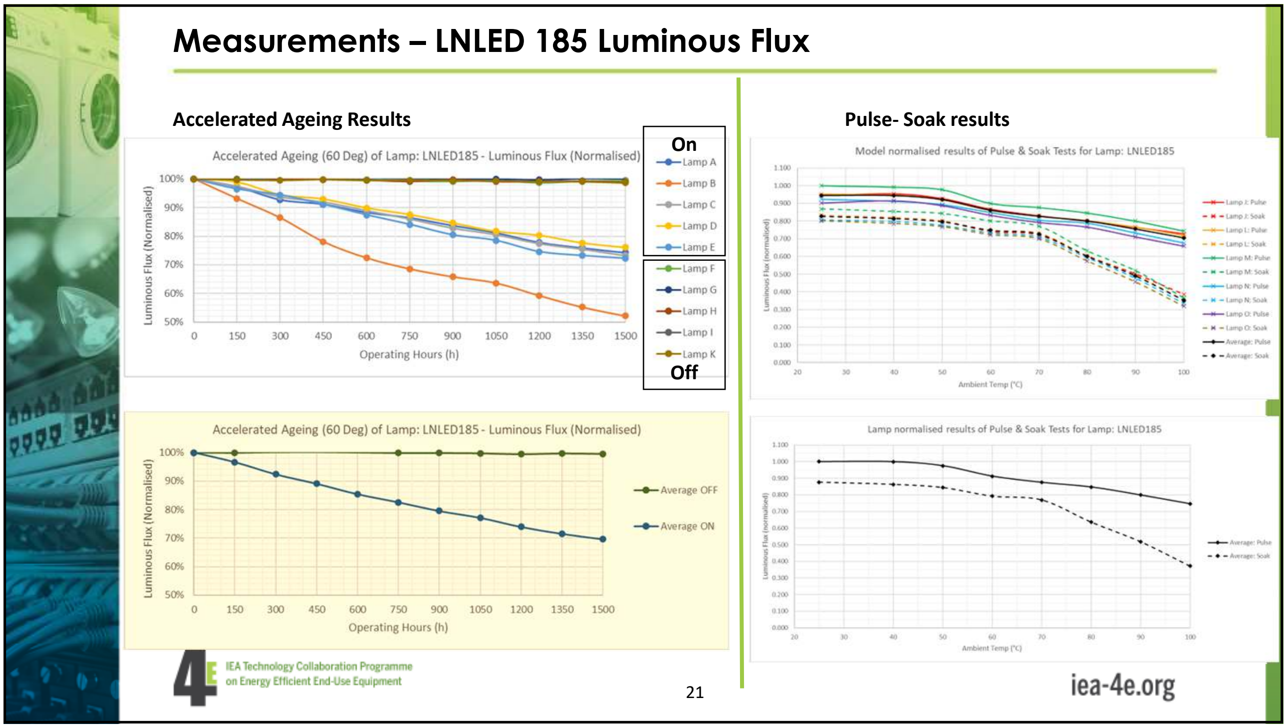
Current-thermal interaction co-efficient

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

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



Pulse Test is a proxy for LED chip junction temperature



Measurements – LNLED 185 Luminous Flux

Accelerated Ageing Results

Pulse- Soak results

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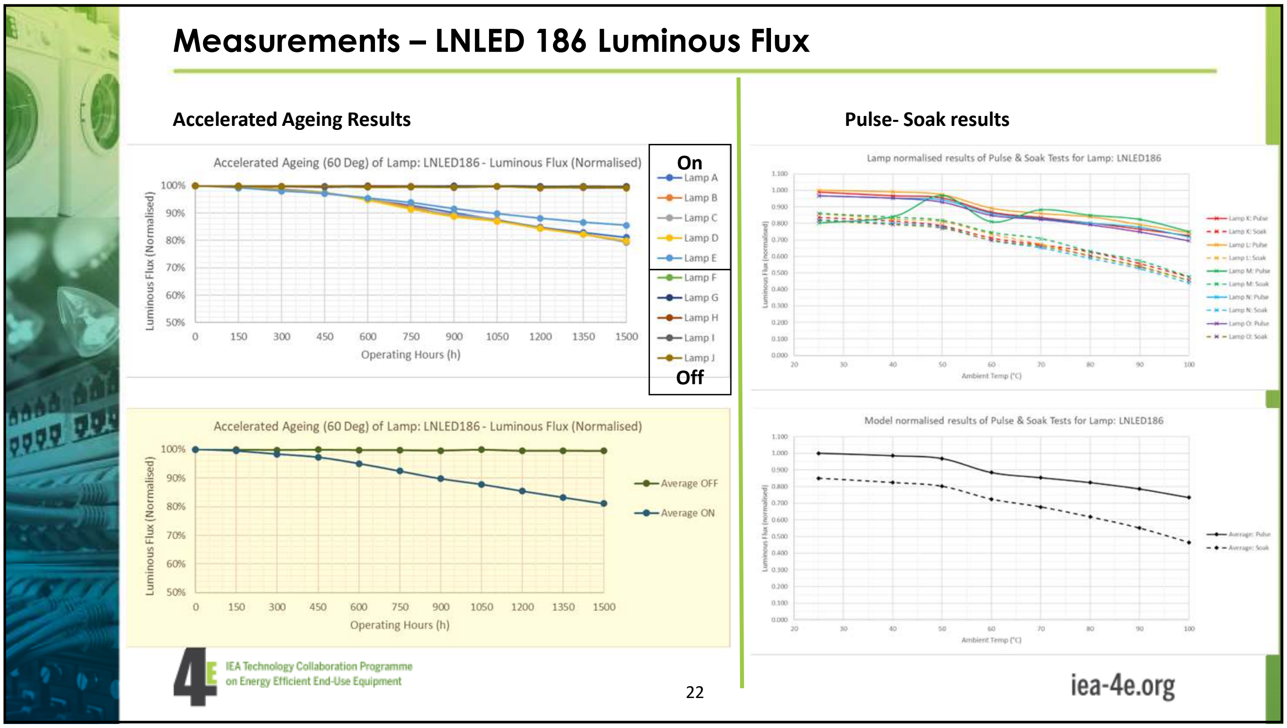

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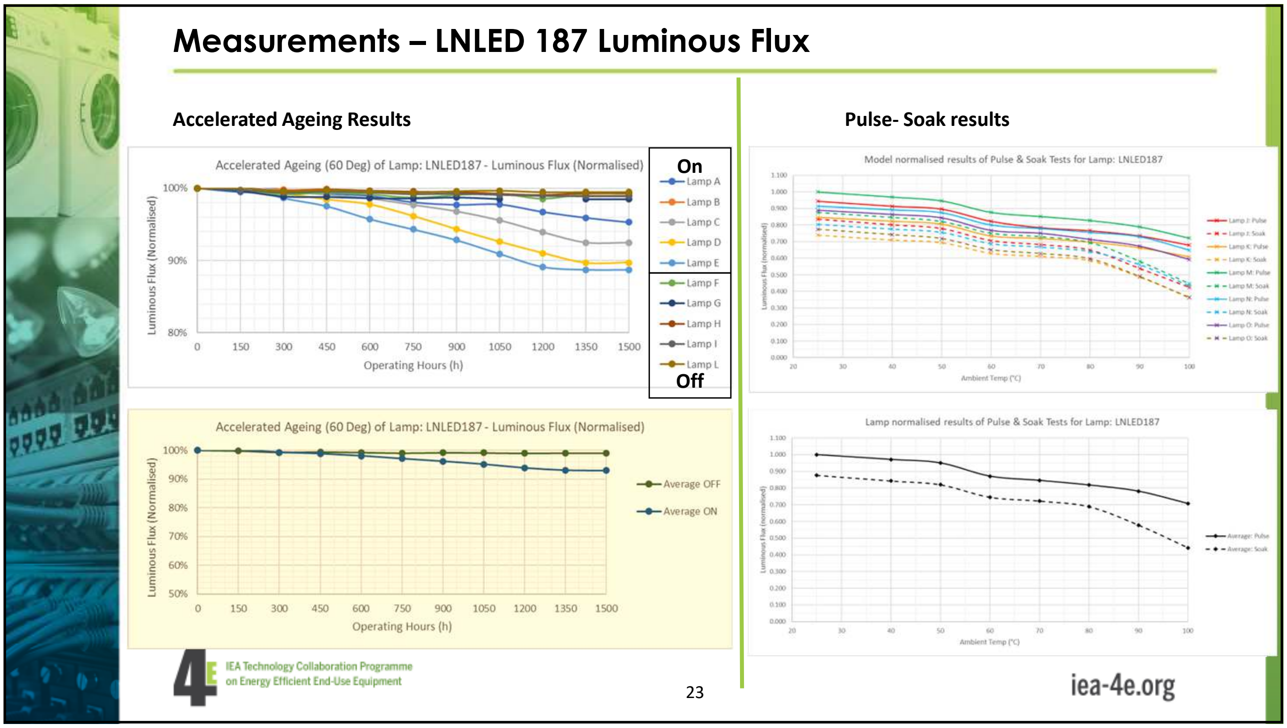

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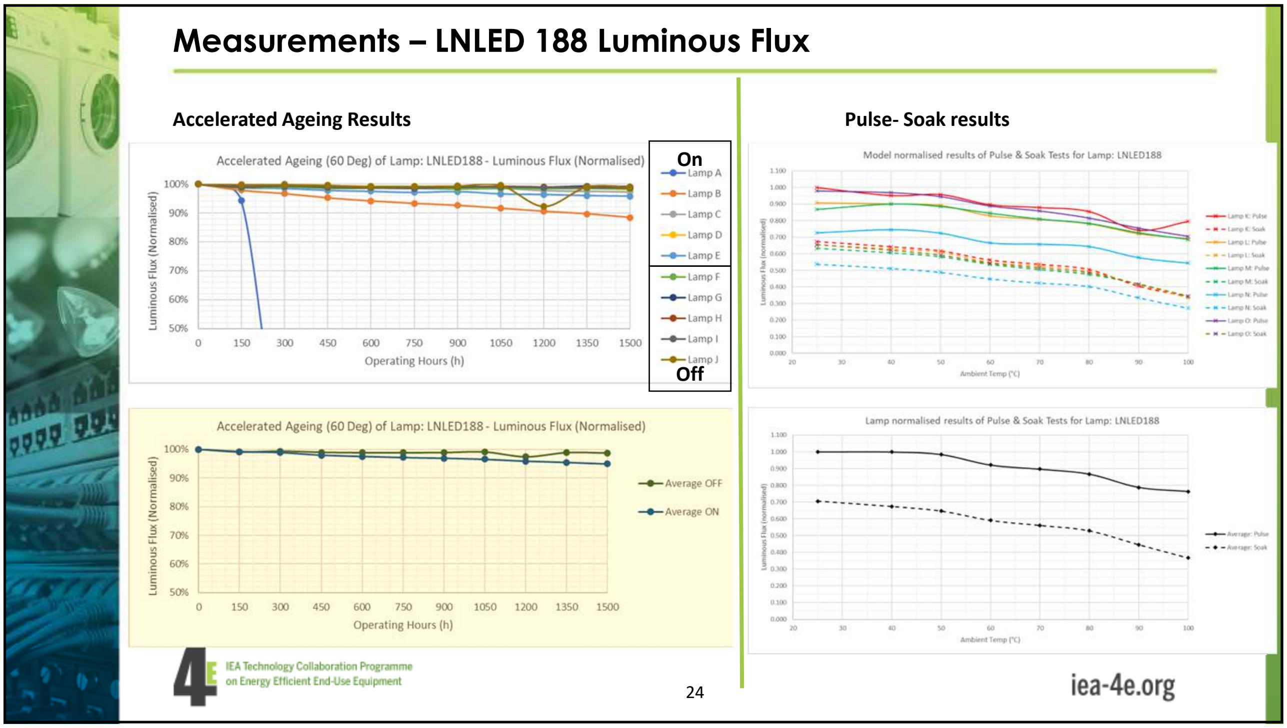

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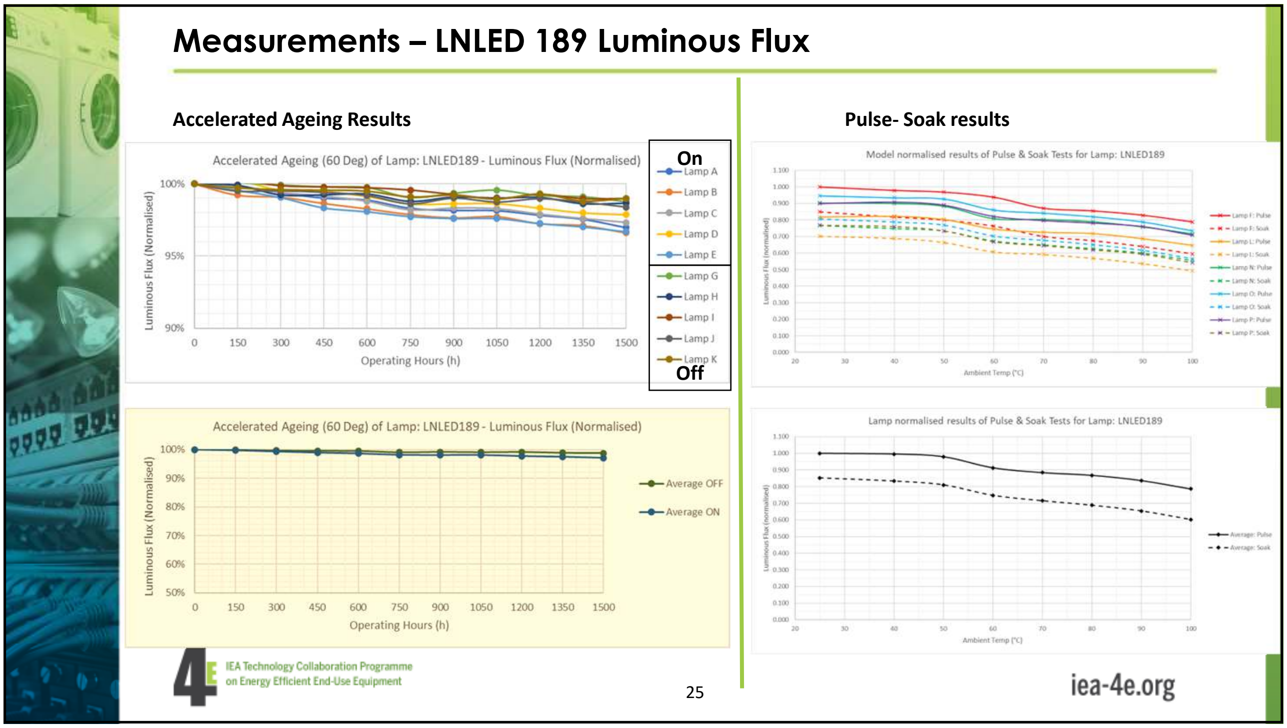
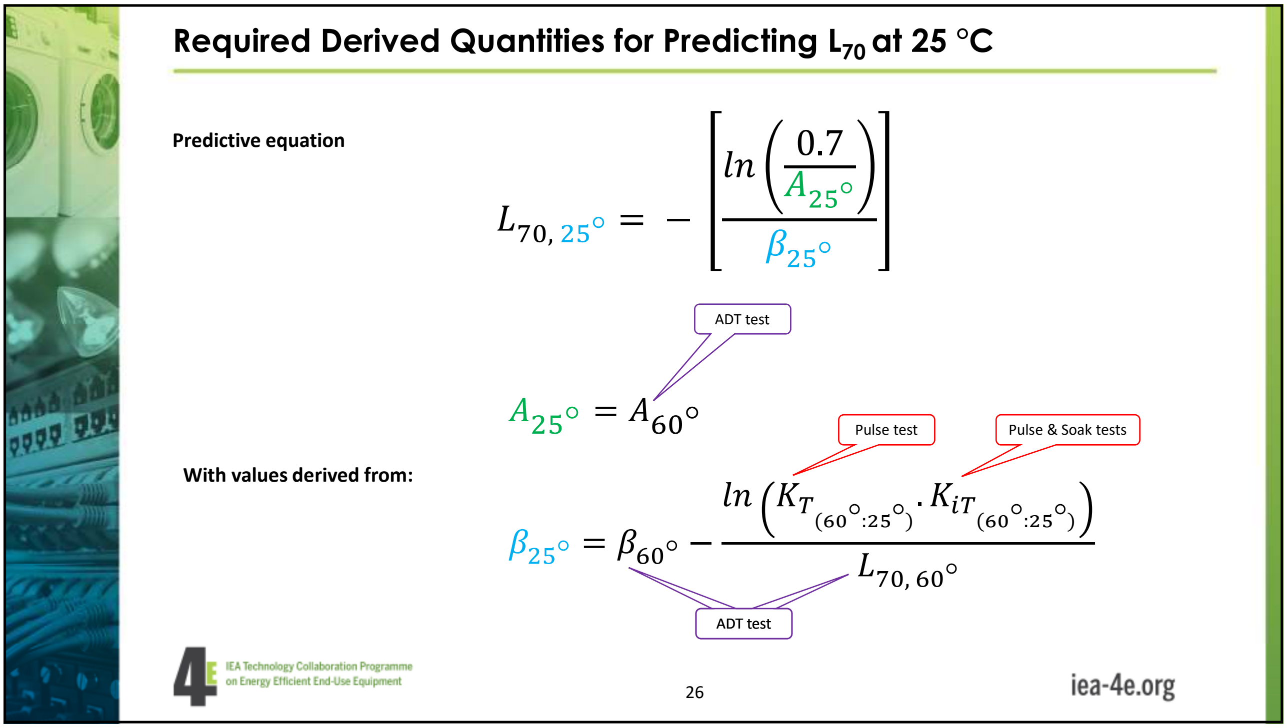


Measurements – LNLED 189 Luminous Flux

Accelerated Ageing Results

Pulse- Soak results



Required Derived Quantities for Predicting L_{70} at 25 °C

Predictive equation

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

ADT test

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

With values derived from:

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

Results: Prediction based on Accelerated Life Test & Pulse Soak Test

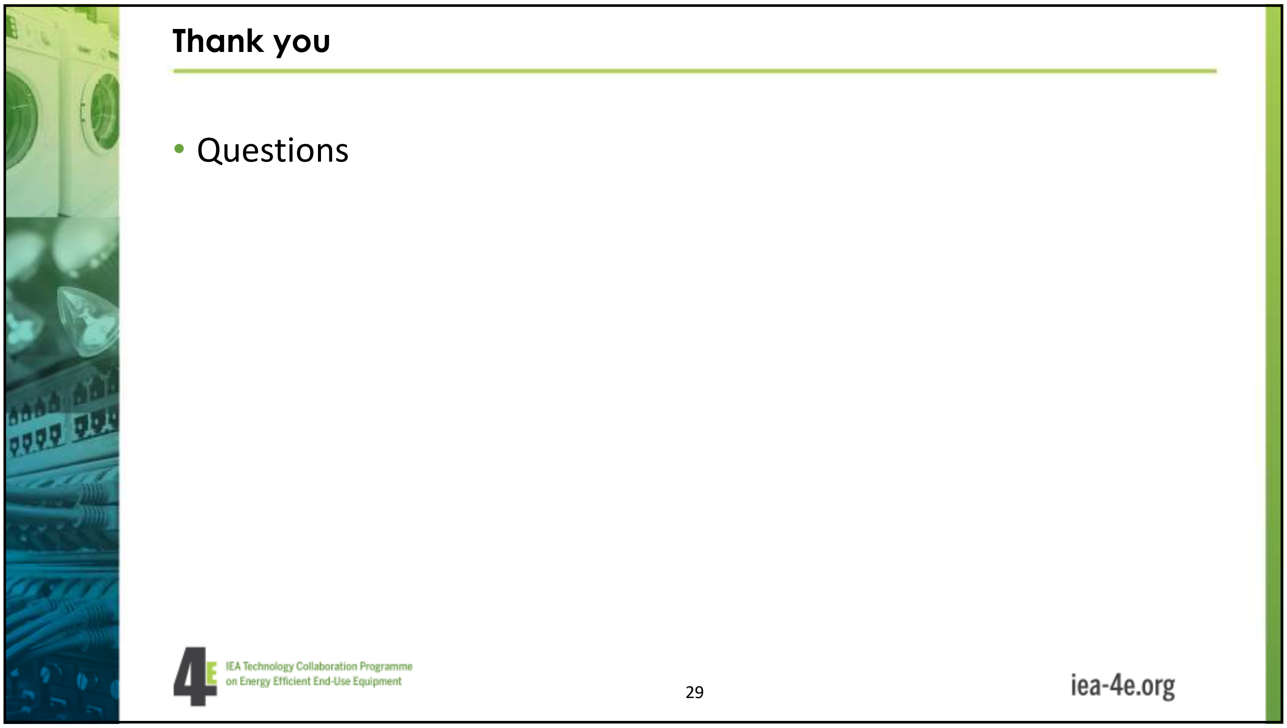
	A_{60°	β_{60°	K_T	K_{iT}	$L_{70,60^\circ}$	Predicted $L_{70,25^\circ}$	Rated $L_{70,25^\circ}$
LNLED 185	0.995748	-0.00025	0.917486	1.030325	1,438	1,711	12,000
LNLED 186	1.023181	-0.00015	0.893814	0.93969	2,566	4,748	15,000
LNLED 187	1.00904	-5.5E-05	0.879594	0.979994	6,608	11,127	15,000
LNLED 188	0.997225	-3.3E-05	0.92831	0.888968	10,740	23,490	15,000
LNLED 189	0.998672	-1.9E-05	0.920403	0.888731	18,792	43,238	15,000

Need to now investigate correlation with results from recognised test and prediction methods of ANSI/IES LM84 and ANSI/IES TM28).

Conclusion

- Continued research required
  - IEA 4E SSL Annex has published a literature review on lifetime testing: link here
- Ultimately, may resolve to have separate methodologies for affordable, shorter life “domestic” products and longer life “commercial” products
- Desirable to have information on early failures and median lifetime of products

  Ideally want test methodology that is
  - Non-invasive
  - Short duration (relative to product life)
  - Limited sample sets
  - Easily obtainable measurands
  - Covers assessment of dominant failure mechanisms
    - Electrical connection – occurrence of catastrophic failure
    - Luminous flux depreciation – predictive parametric failure
    - Colour shift – predictive parametric failure
    - Electrolytic capacitor (output side of driver) – predictive (ESR/TLM) parametric failure



Thank you

- Questions

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