Smart Sustainability in
Lighting and Controls SSLC

Improvements in Test Methods and Metrics

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International Lighting Seminar: Perspectives on Sustainability, Performance, Health & Smart Lighting
London, UK 14th May 2024

iea-4e.org

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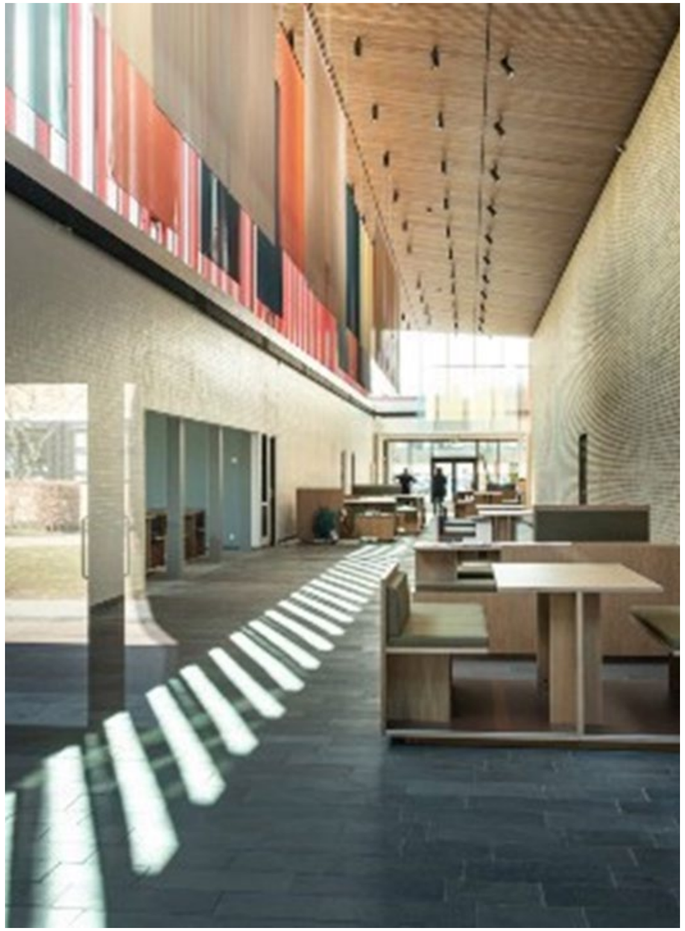
  - Methods and instruments

- Influence of power supply selection on flicker metric P_{st}^{LM}

- Stroboscopic effect visibility measure (SVM) calculation:
  - current calculation approach and potential improvements
  - Peak estimation in frequency
  - Lowering uncertainty in calculations



Test of Temporal Light Modulation (TLM)

CIE TN 006:2016, Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models
CIE TN 012:2021, Guidance on the Measurement of Temporal Light Modulation of Light Sources and Lighting Systems

P_{st}^{LM} Short term flicker indicator measured with light flickermeter, **IEC TR 61547-1:2020**

- Requires measurement ≥ 60 s (180 s)
- Sampling rate ≥ 10 kHz
- Light flicker assessment toolbox (temporal, statistical analysis)

Konika Banerjee (2017), https://www.mathworks.com/matlabcentral/fileexchange/63445-light-flicker-assessment-toolbox

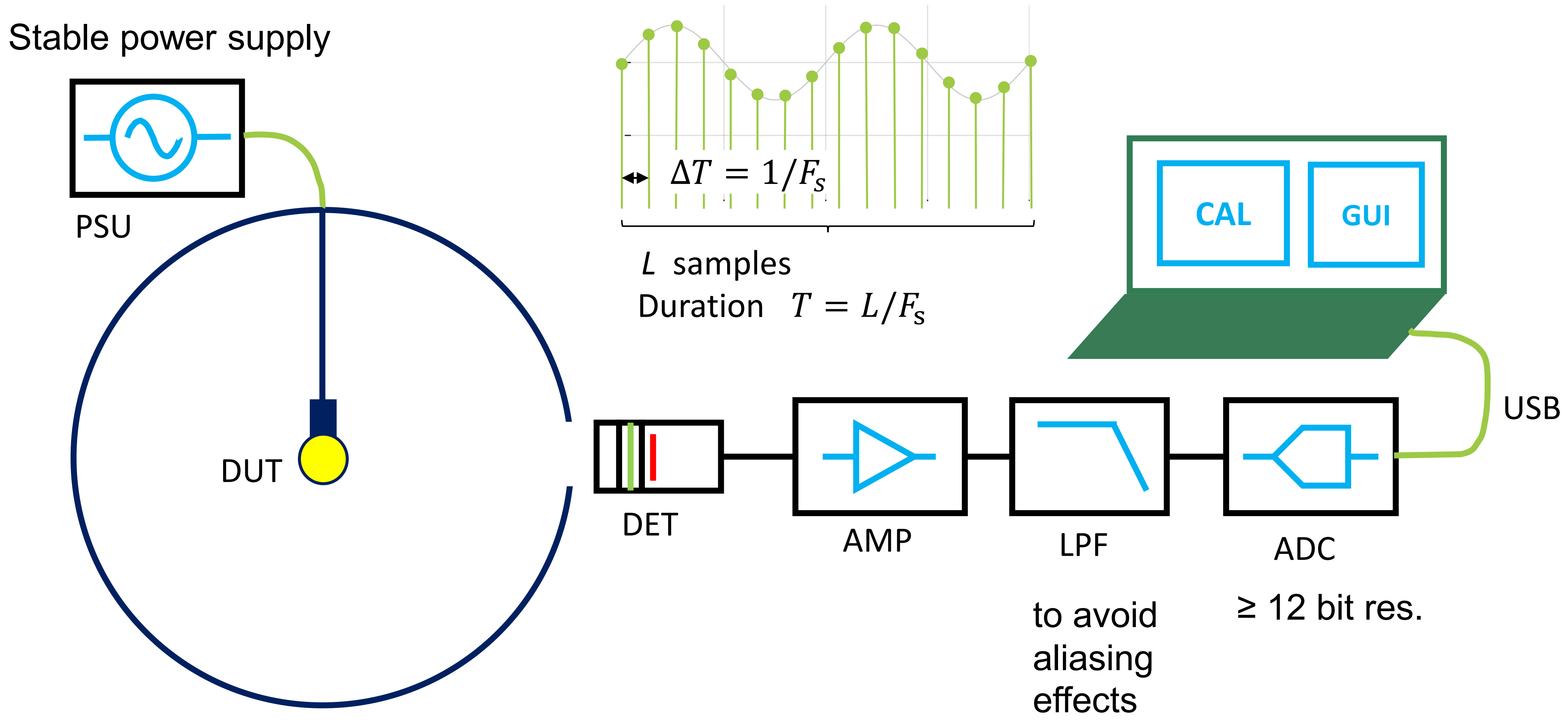
SVM (M_{VS}) Stroboscopic effect visibility measure, IEC TR 63158:2018

- Requires measurement ≥ 1 s,
- Sampling rate ≥ 20 kHz
- Stroboscopic effect visibility measure toolbox (frequency analysis)

Konika Banerjee (2016), https://www.mathworks.com/matlabcentral/fileexchange/59242-stroboscopic-effect-visibility-measure-toolbox

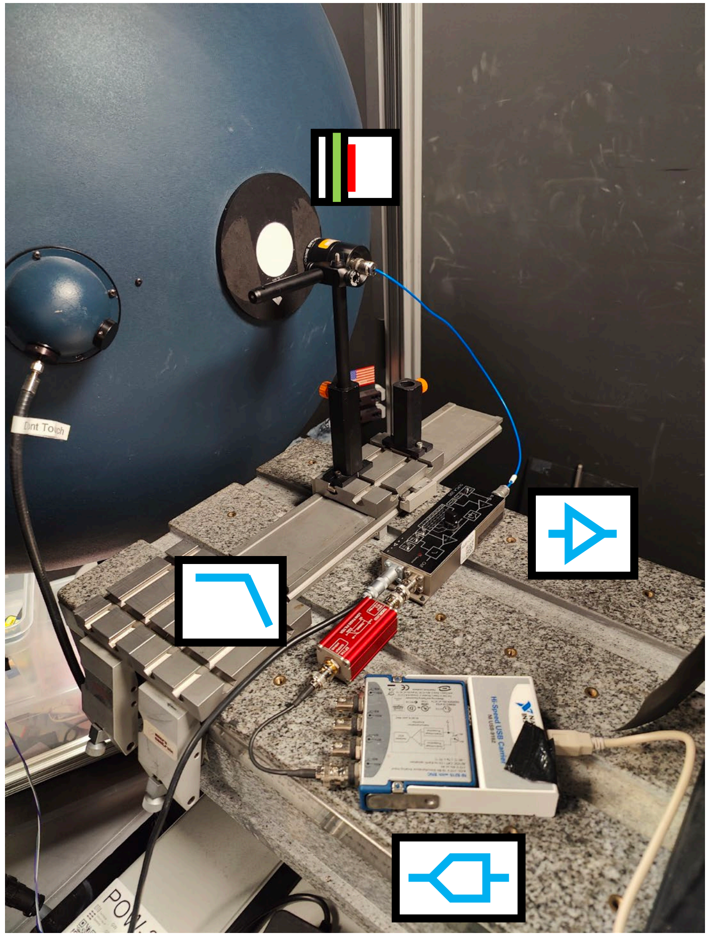
Test of Temporal Light Modulation (TLM)

Schematic of test setup for measuring TLM

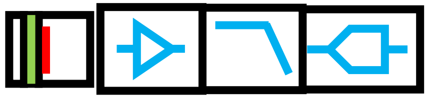


Test of Temporal Light Modulation (TLM)

- Custom built systems



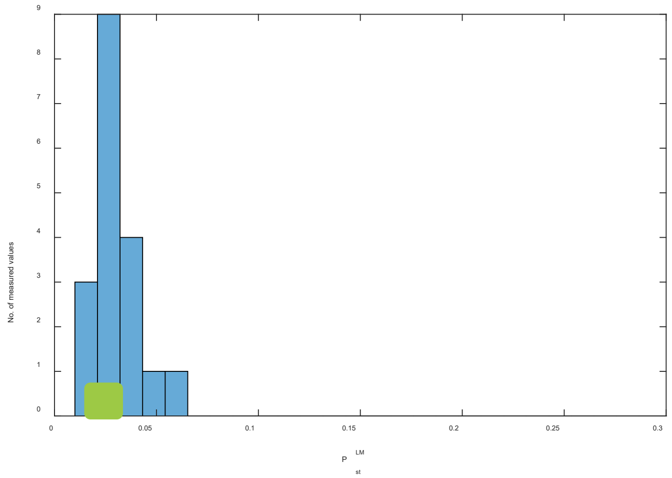
- Dedicated instruments



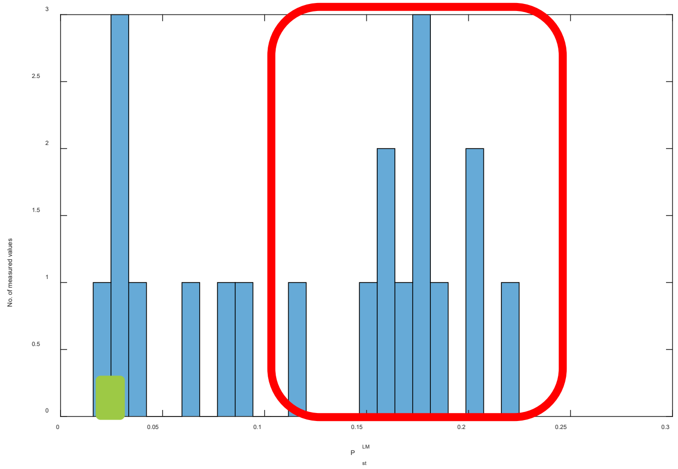
Cannot be handheld during 180 s P_{st}^{LM} measurement

Variation in measured P_{st}^{LM} values for two LED lamps

All measured values around reference value
Normal distribution



More than 50 % of the measured values are much larger than the reference value
Non normal distribution

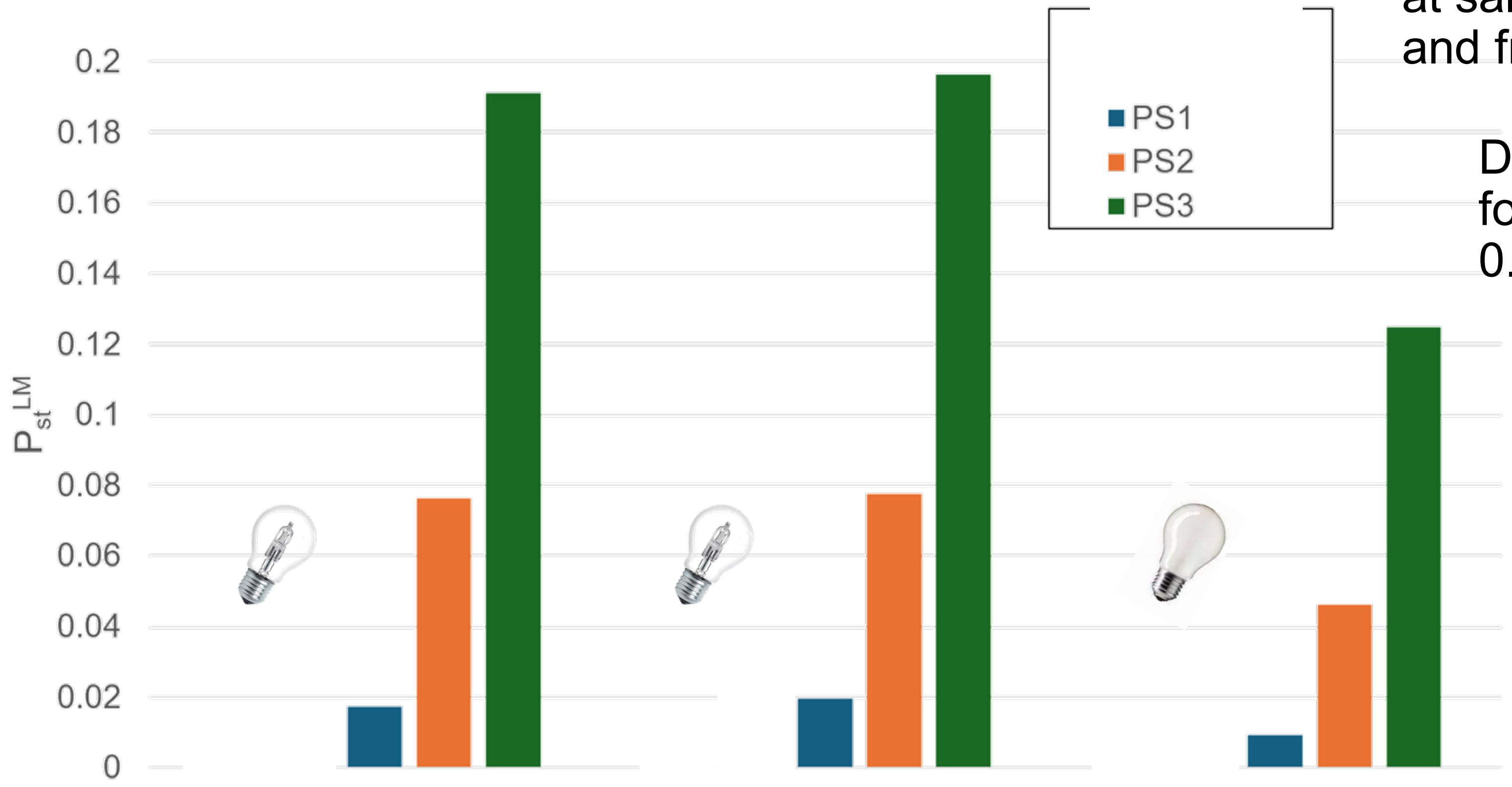


What is the origin of these large variations?
The NLC results showed that P_{st}^{LM} values changed markedly when using different power supplies

Flicker measurement , P_{st}^{LM}

Measurement of P_{st}^{LM} using three different AC power supplies (230 V 50 Hz)

- two 42 W halogen lamps
- a 60 W incandescent lamp



P_{st}^{LM} calculated for simulated pure sine waves at same modulation depth and frequency

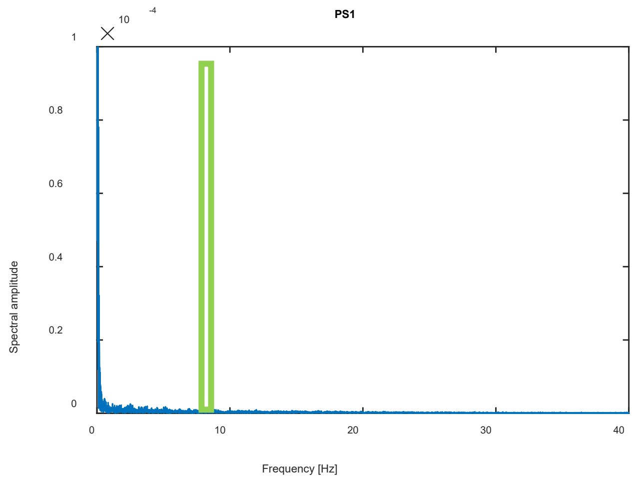
Detection limit, measured for a stable DC light source 0.002

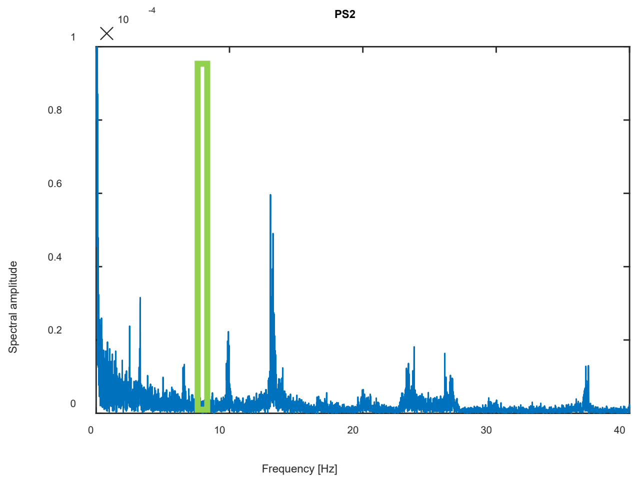
There is a marked dependence on the used AC power supply
Could be 10x too high

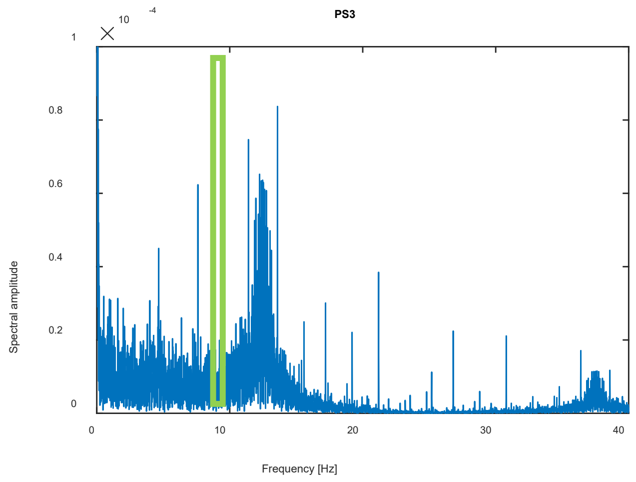
Flicker measurement, P_{st}^{LM}

Measurement of P_{st}^{LM} using three different AC power supplies (230 V 50 Hz)

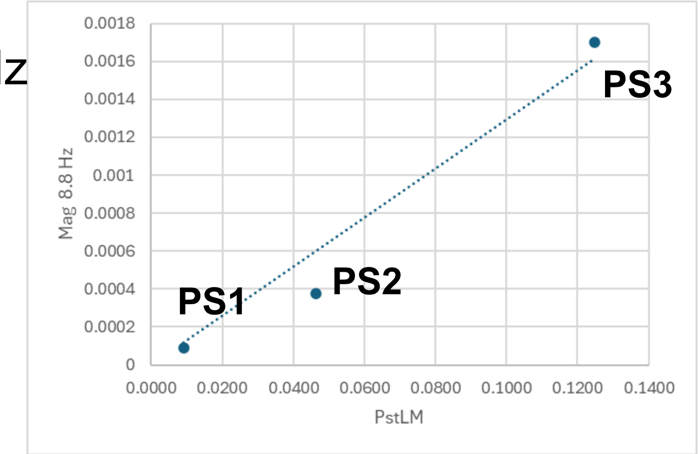
- a 60 W incandescent lamp
- Frequency spectra below 40 Hz reveals large differences







- P_{st}^{LM} most sensitive at 8.8 Hz



Possible correlation with spectral amplitude at 8.8 Hz ±0.5 Hz

Further investigations ongoing
Journal paper being prepared

SVM calculation and uncertainty

$$M_{VS} = \sqrt[3.7]{\sum_{m=1}^{N(\leq 2kHz)} \left(\frac{C_m}{T_m}\right)^{3.7}}$$

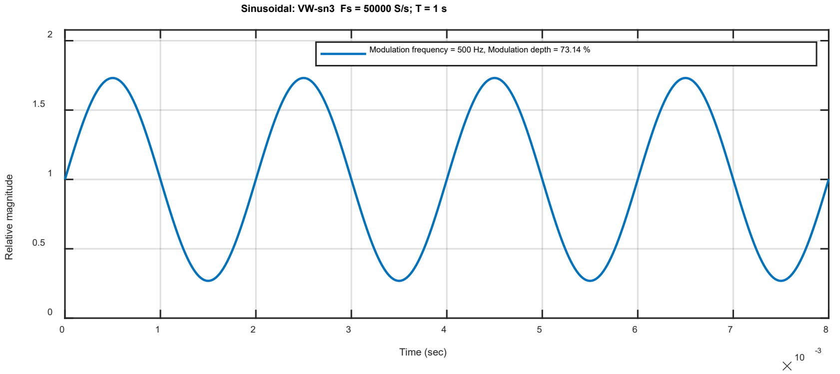
$$T(f) = \frac{1}{1 + e^{-a(f-b)}} + 20e^{-f/10}$$

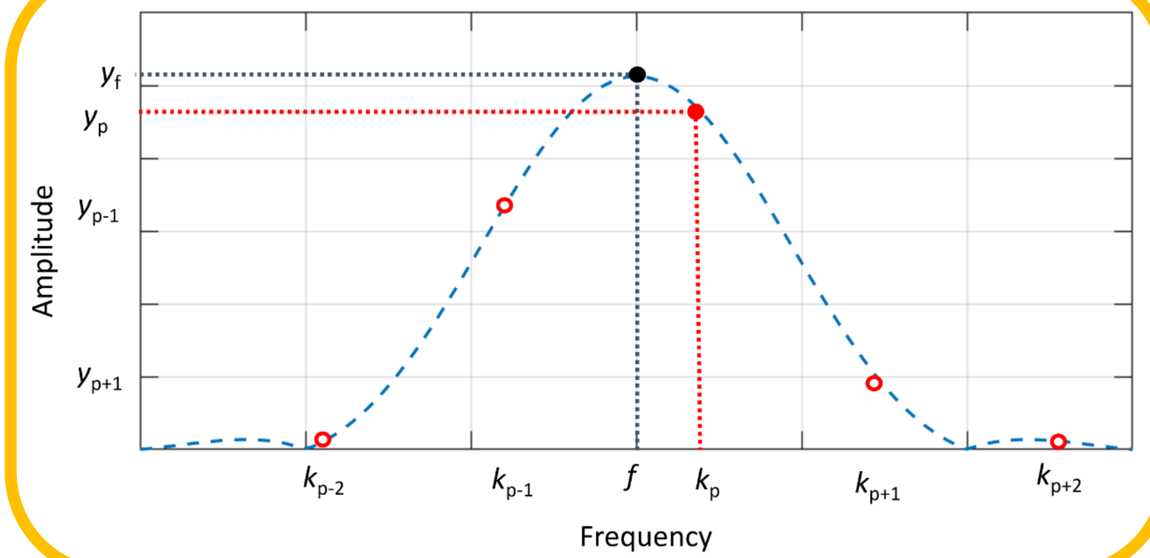
Single sinusoidal waveform

$$E(t) = 1 + m\ \sin(2\pi f t)$$

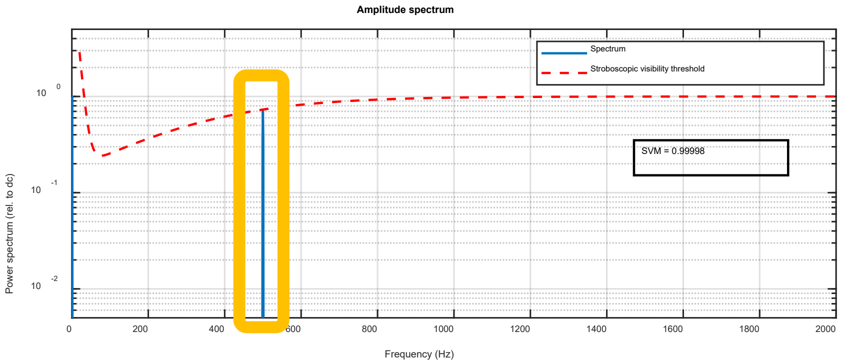
$$M_{VS} = \frac{C_1}{T_1}$$

$$M_{VS} = \frac{y_f}{T(f)}$$



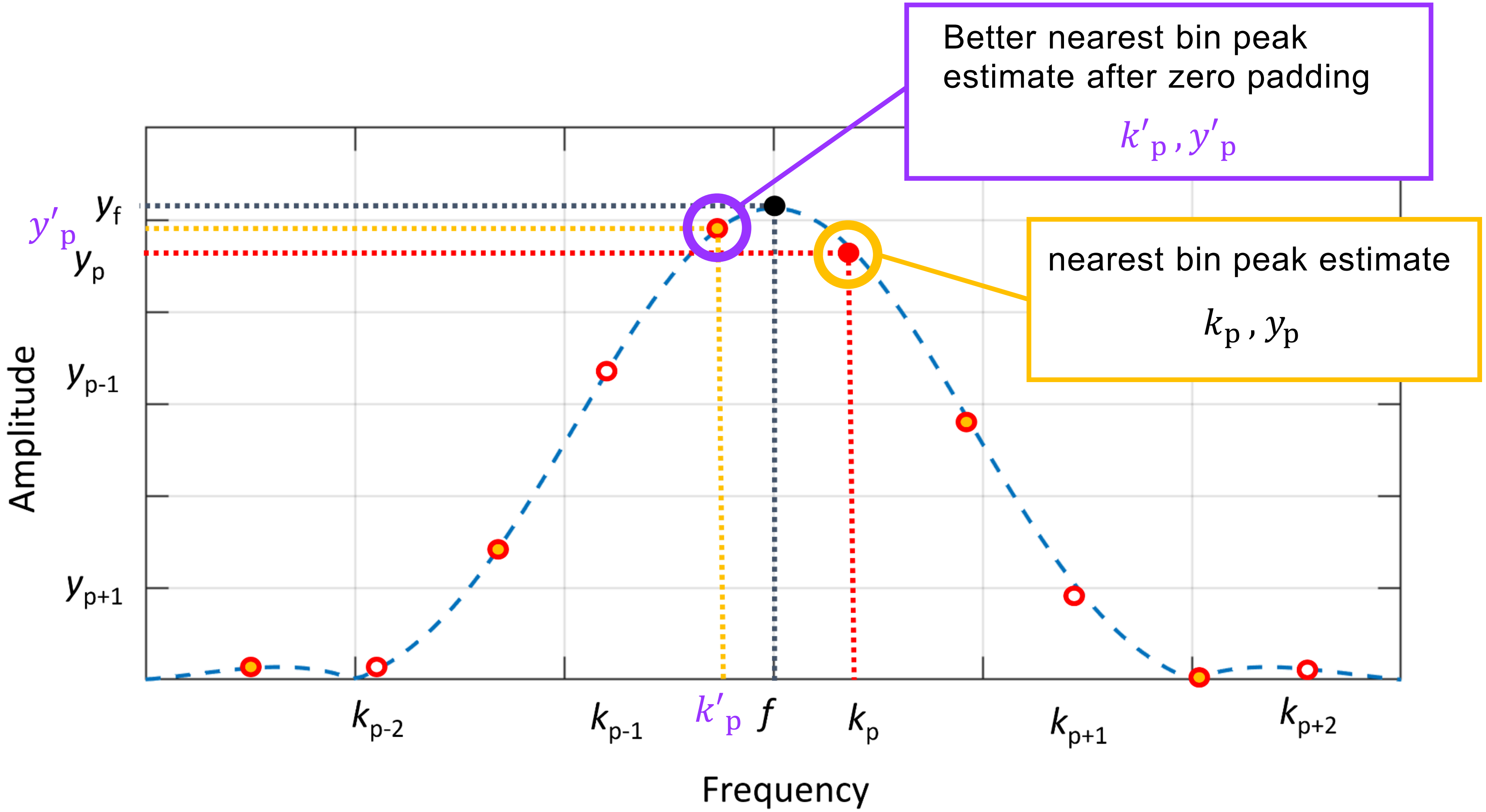


FFT analysis

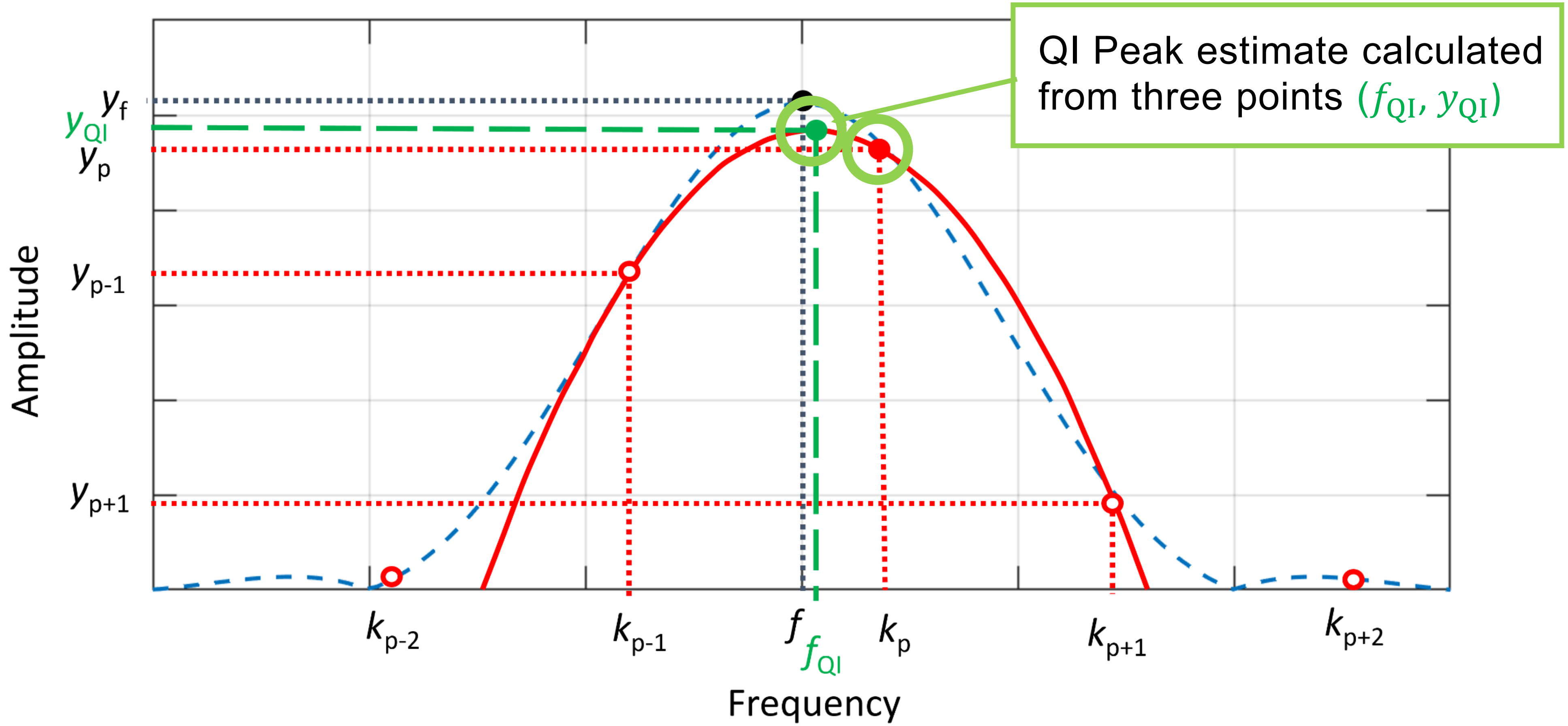


Uncertainty of calculated SVM depends on peak estimation, i.e. amplitude and frequency

Zero-padding

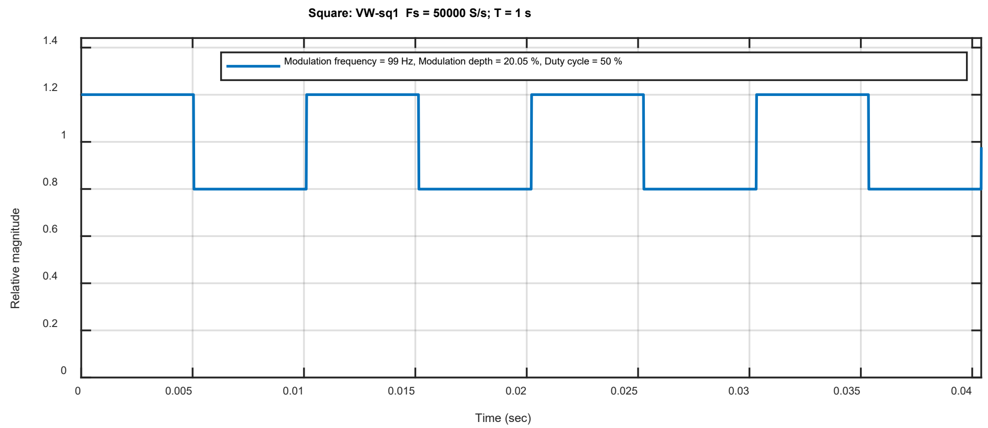


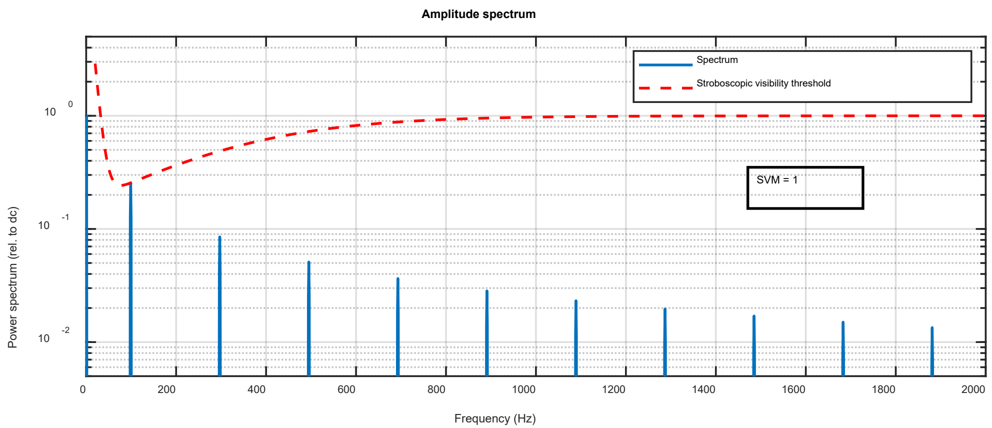
Quadratic interpolation (QI)

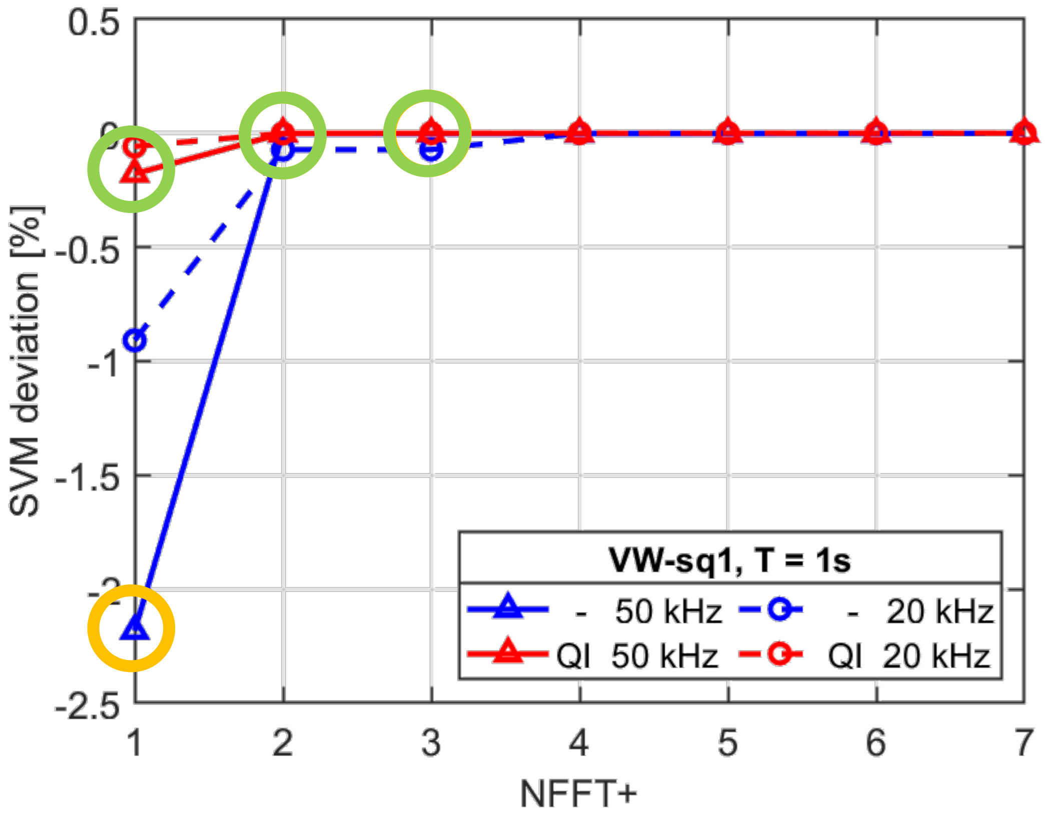


Simulations, square waveforms

Duration = 1 s, 20 kHz and 50 kHz







Deviation < 0.05% for

- NFFT+ = 4
- QI and NFFT+ = 2 (faster)

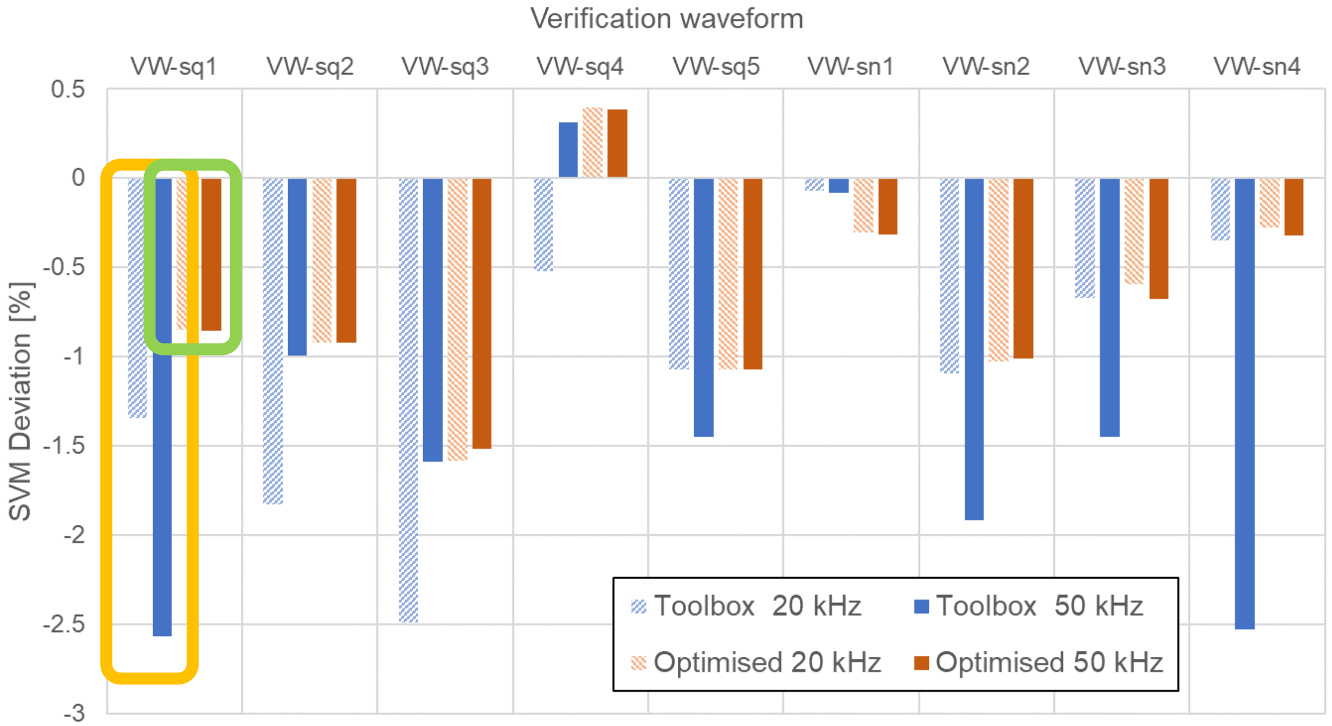
Measurements

Verification waveforms generated and measured at two sampling rates 20 kHz and 50 kHz

SVM calculated:

Toolbox: NFFT+ = 1, nearest bin method

Optimised: NFFT+ = 3, quadratic interpolation



With optimised method low deviation and results independent of sampling rate are achieved

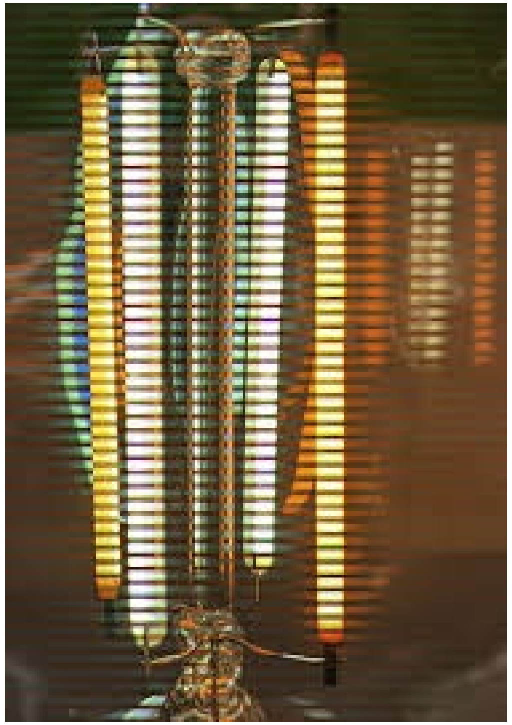
Conclusions

P_{st}^{LM}

- Choice of power supply may have large influence on measured PstLM

SVM

- Using multiple zero padding or combination with quadratic interpolation to reduce calculation uncertainty is recommended
- removes dependence of sampling frequency



Contents

Lifetime Testing, Standards and Methods

Why is Product Lifetime Important?

Key economic factors in cost-benefit analysis:

Product **lifetime**, price, efficacy and electricity price.

Require assurance 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.

- 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 <u>likelihood</u> 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

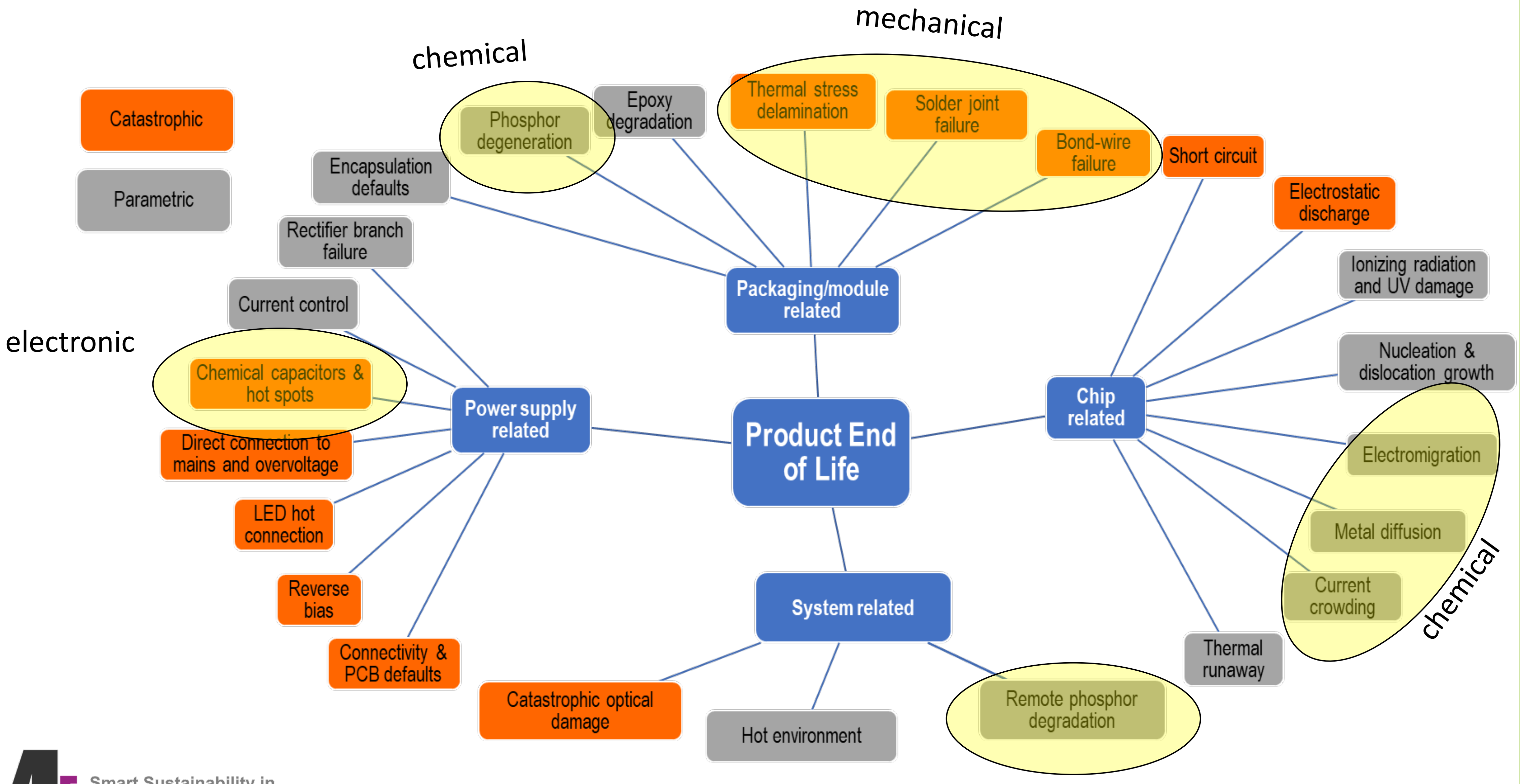
- Catastrophic failure
  - Failure to produce light
    - Mechanical: electrical connection (unpredictable)
    - Electronic: key component failure (some are predictable with measurements)

- 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)

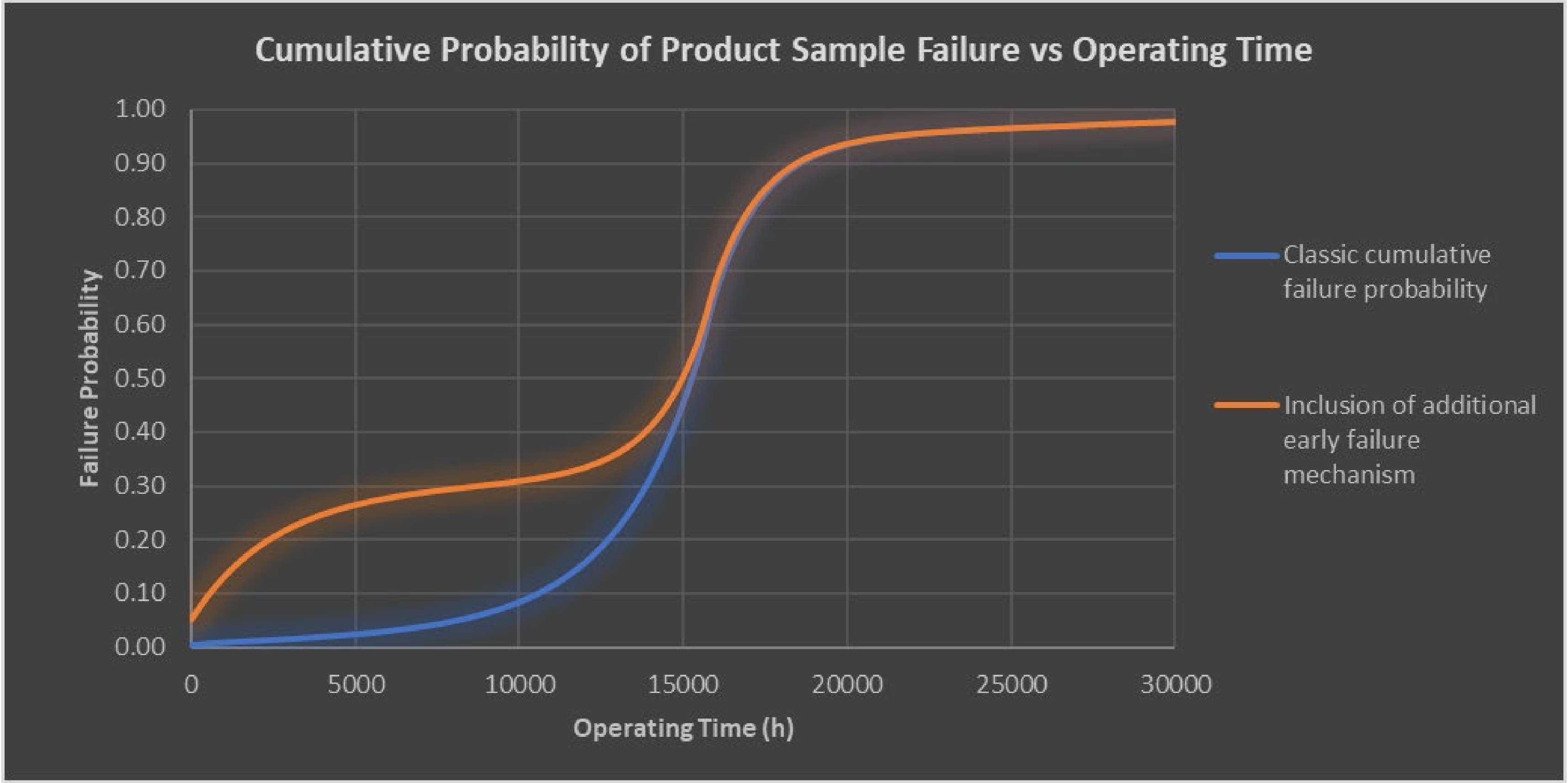
  - Increase in temporal light modulation
    - Increase in SVM (potentially predictable with measurements)
    - Increase in P_{st}^{LM} (evidenced by SEA testing)

Main Causes of Product Failure



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)

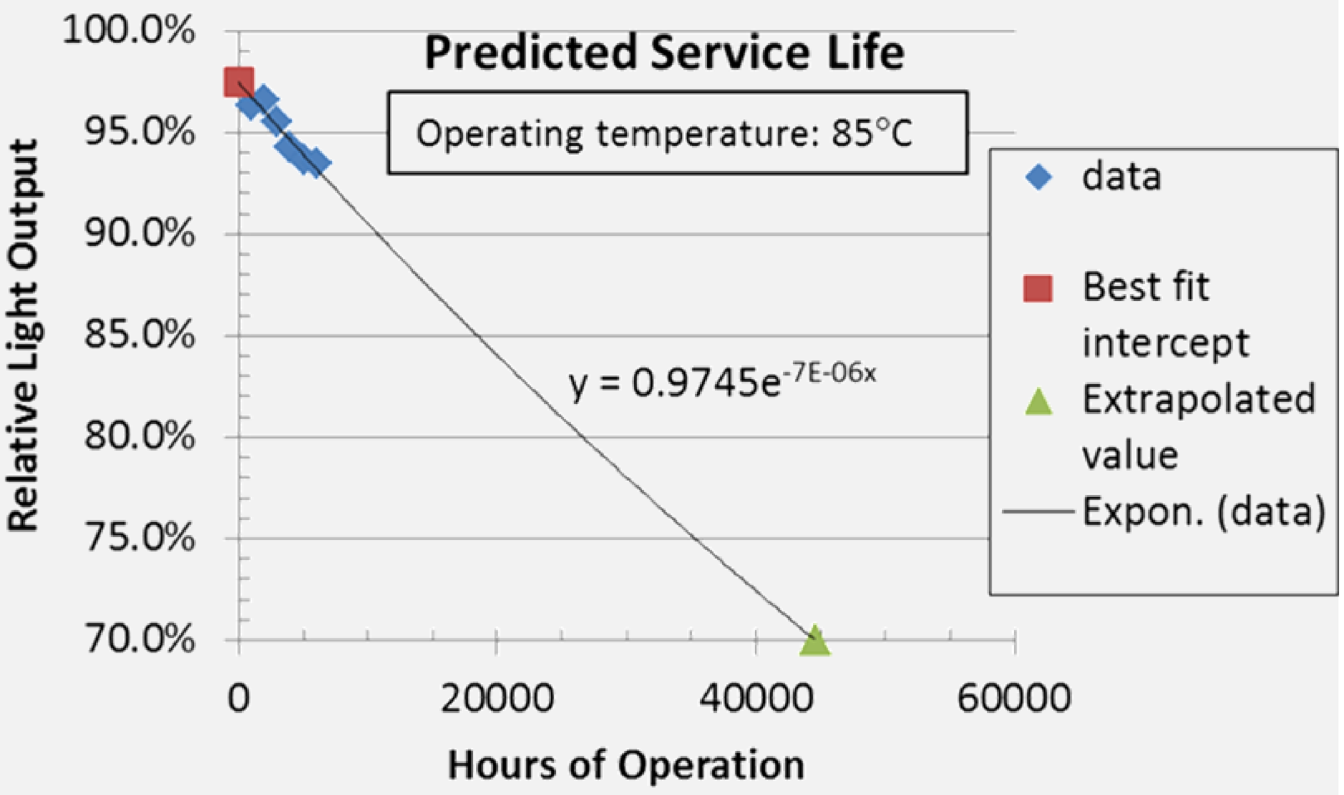
3. Supply switching (i.e. Typical)
   - 25°C ambient temperature
   - ON (30s): OFF (30s)
   - # cycle equals half the hours of rated life (eg 125 hours for 15k hour product)

4. IEC 63555 LED Light sources – Performance requirements (expected June 2025)
   - 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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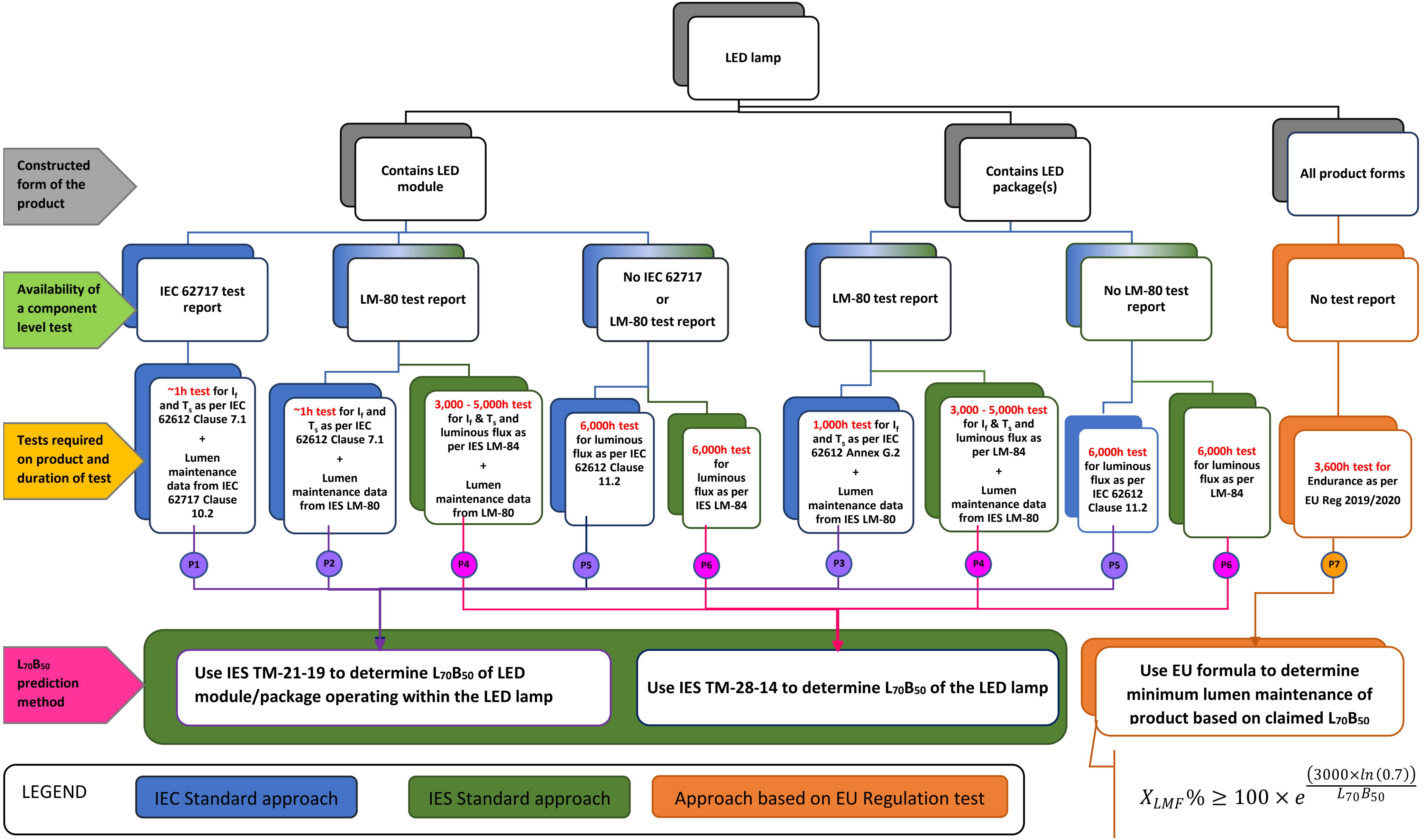
All current options in standards for lifetime testing of LED lamp



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 measured 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, $L_{70}B_{50}$)

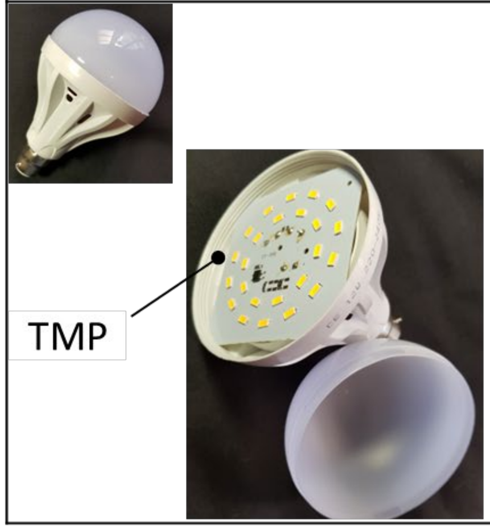
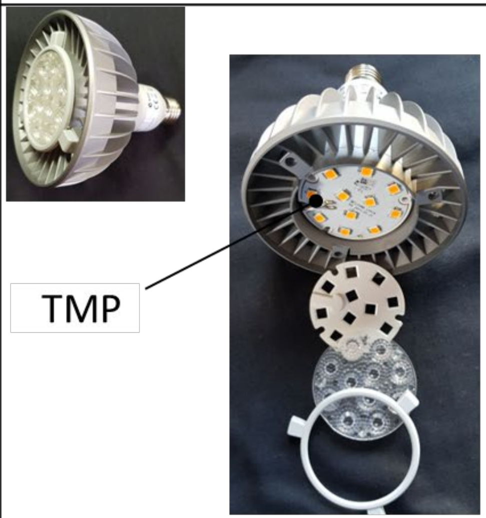
$$X_{LMF}\% \geq X_{LMF,MIN}\% = 100 \times e^{\frac{(3000 \times ln(0.7))}{L_{70}B_{50}}}$$

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

EU Endurance Testing

Investigation by Australian Gov (2018/2019) as part of IEA SSL Annex activities:

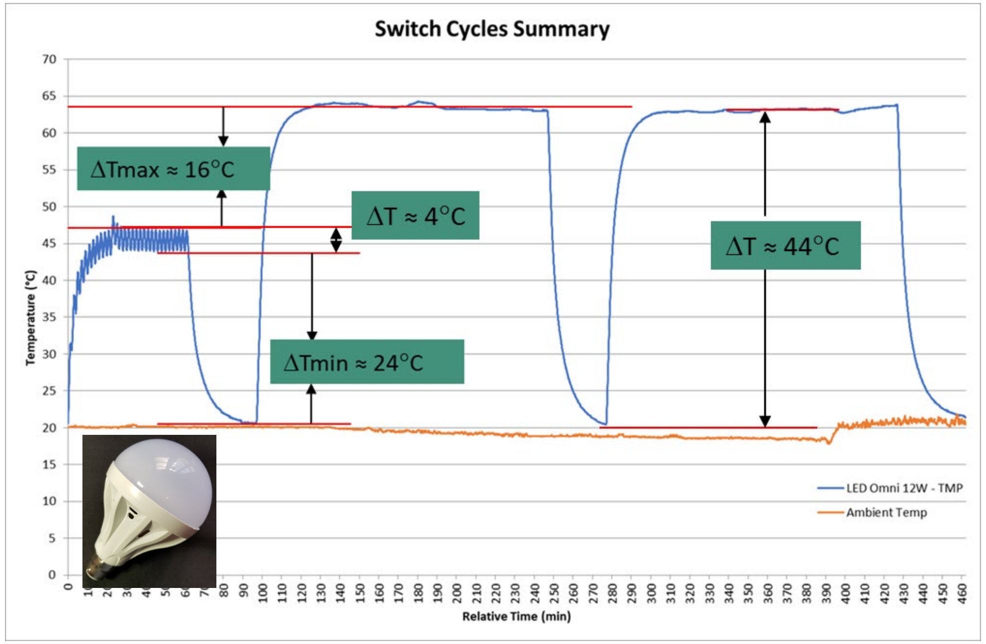
2.5 h ON, 0.5 h OFF vs 1 min ON, 1 min OFF

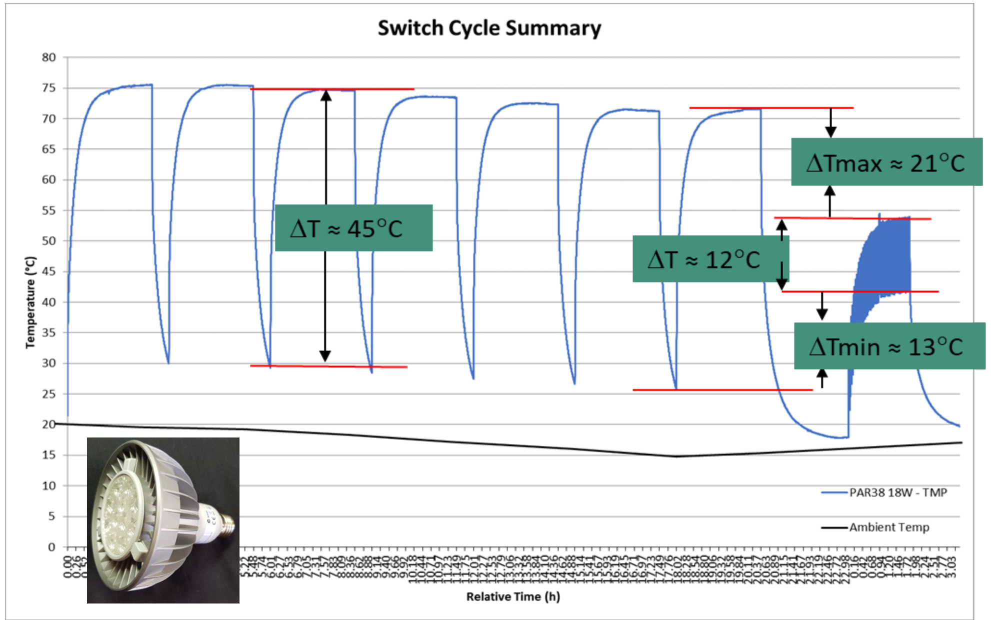
Non-directional GSL lamp 12W (65g)	Directional PAR38 lamp 18W (465g)	Downlight with remote driver 18W (module = 285g)
		

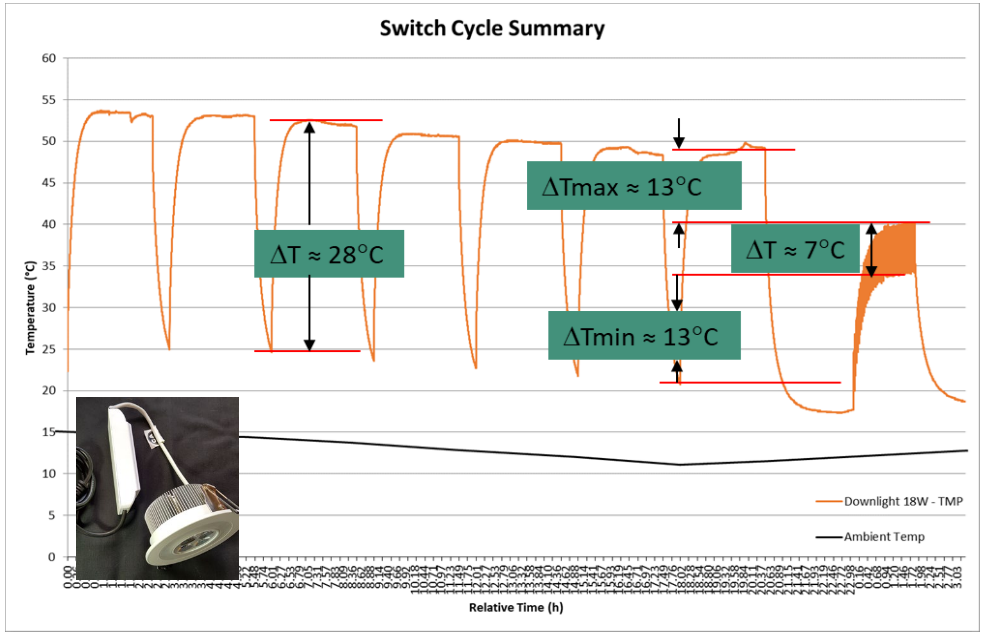
TMP = Temperature Measurement Point

Results for 3 LED light sources

- 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, create mechanical stresses from different thermal expansion rates







Comparison with IEC Endurance Switching Test

Australian LED Lamp Laboratory Test (2018) Findings

- 30s ON : 30s OFF (life/2 cycles)
  - 20 LED lamp models, 5 samples of each
  - **Created zero failures out of 100 samples**
- 2.5h ON : 0.5h OFF (1200 cycles)
  - Subset of 11 LED models, 5 samples of each
  - **Created catastrophic and parametric failures**

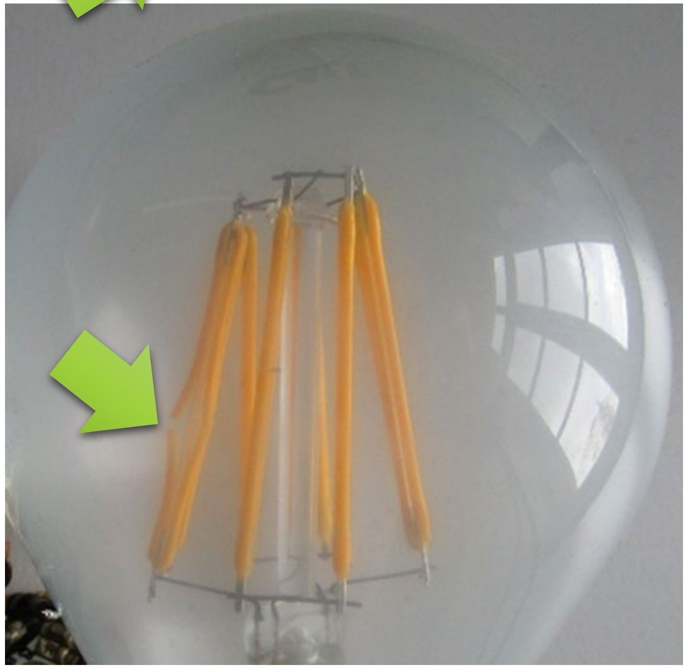
Based on claimed life

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

Teardown Analysis of Failures

Investigation of lamps which failed endurance testing for 2.5h ON : 0.5h OFF in Sweden

- Results
  - Socket has come off the lamp disconnecting one wire. No other defect.
  - Connection between LEDs broken (thermal stress?) All LED chips and driver still functional.
  - Phosphor peeled off the LED filaments. One filament defective. Driver still o.k.
  - Resistor burned (overloaded). LED filaments are still o.k.
  - One lamp flashes some seconds when powered. Another lamp fails to operate. Both lamps, all LEDs still o.k. Driver defects could not be analysed because it is glued into heat sink using cast resin.



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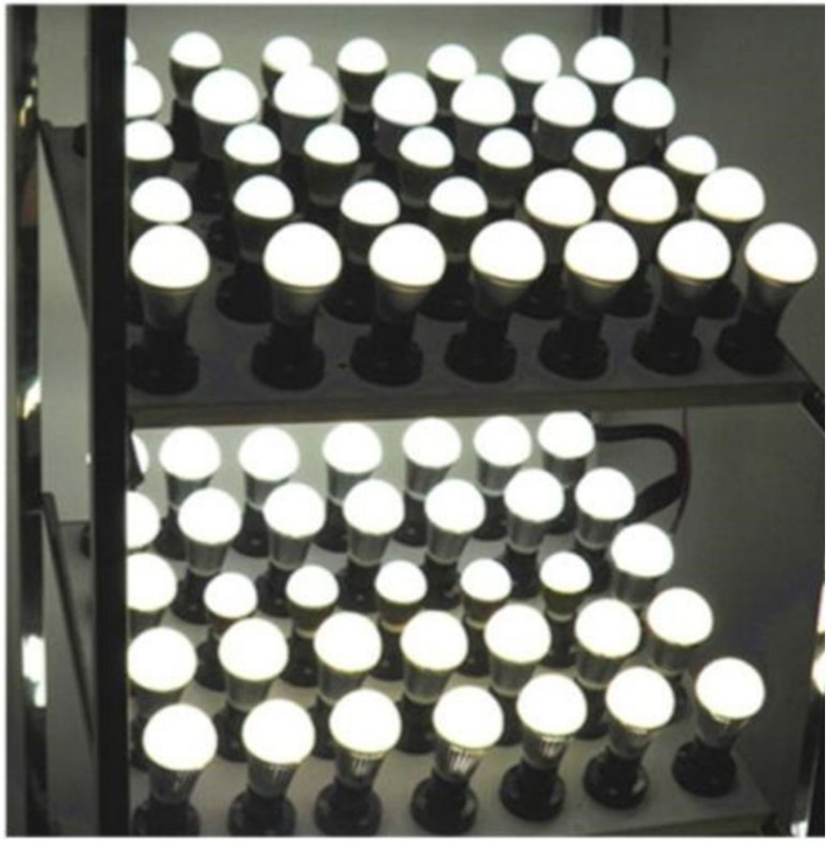
Can we shorten predictive life test by incorporating accelerated aging?

Australian Gov activity as part of IEA SSL Annex

First Stage 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.



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

Predictive equation:

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

With values derived from:

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

ADT test

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

Pulse test

Pulse & Soak tests

ADT test

Test Method

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

   a) Lamp samples #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 luminous flux of lamps

   c) Determine luminous flux depreciation decay constants

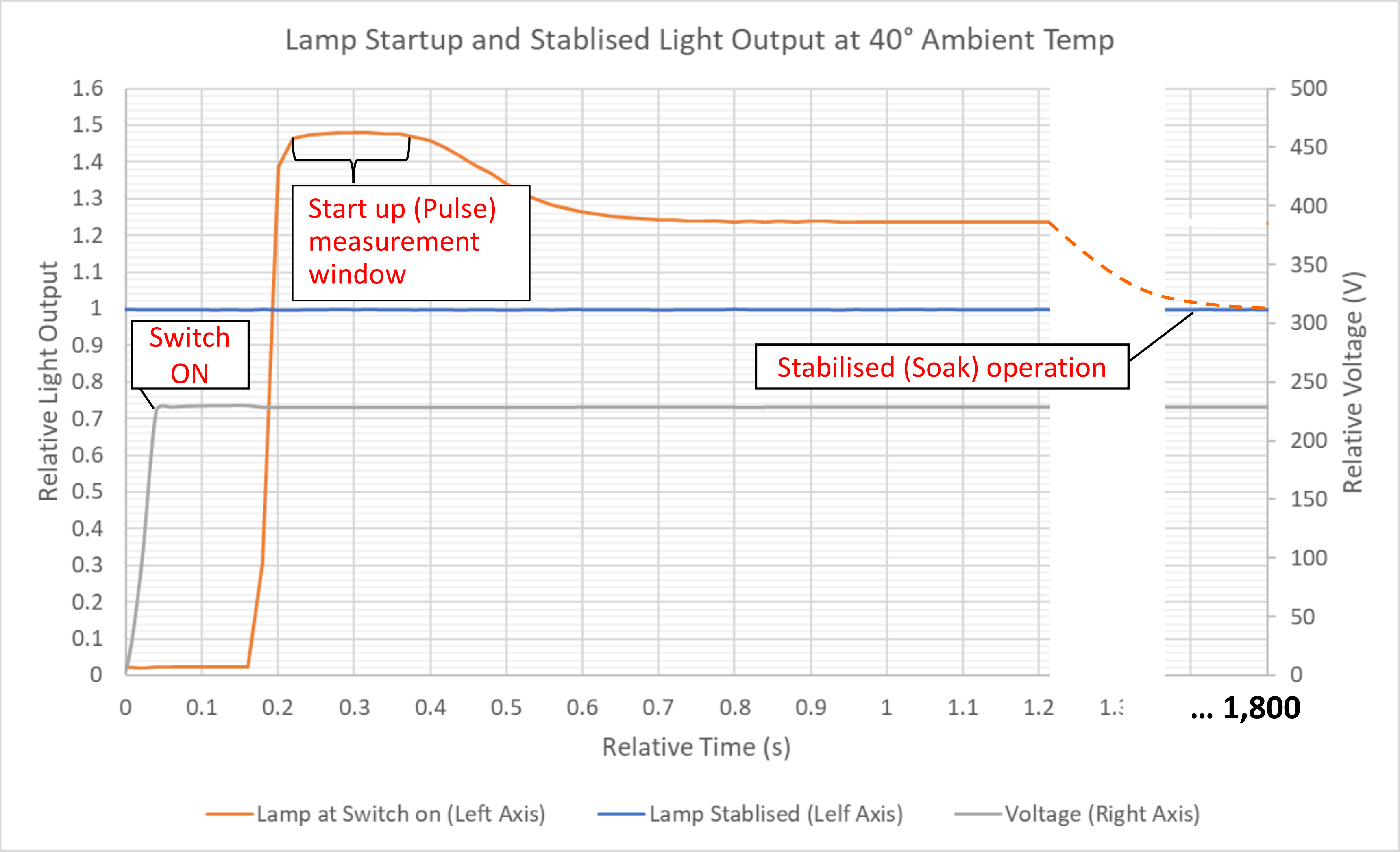
2. **Pulse and Soak Tests**

   a) Lamp samples (#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



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Pulse and Soak Tests (at different ambient temperatures)

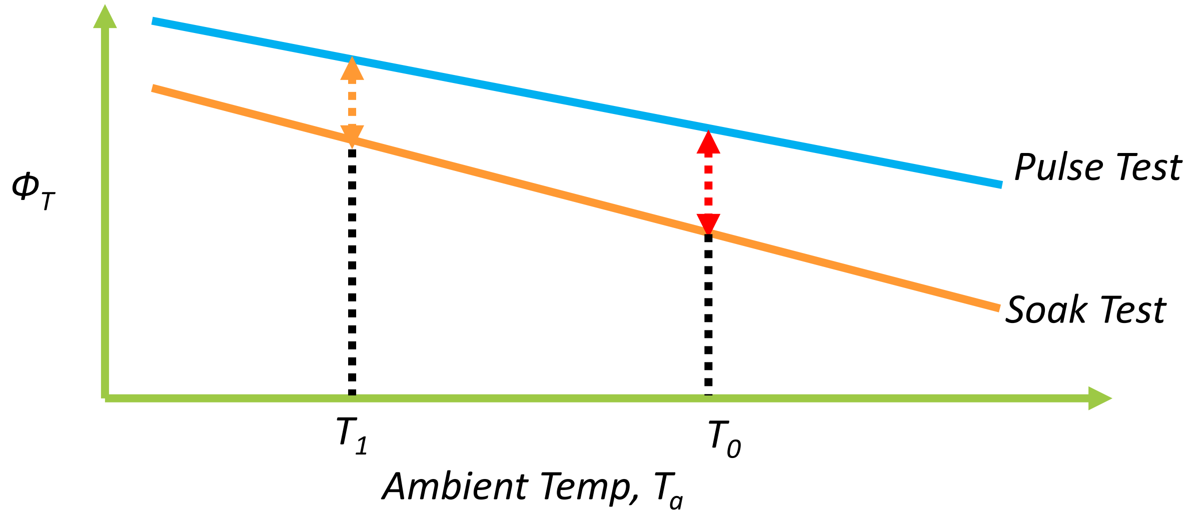
Thermal co-efficient, $\boldsymbol{K_T}$, is determined from the **pulse test** (0.3 s) with fixed drive current, I

$$K_T = 1 + \alpha.\Delta T$$

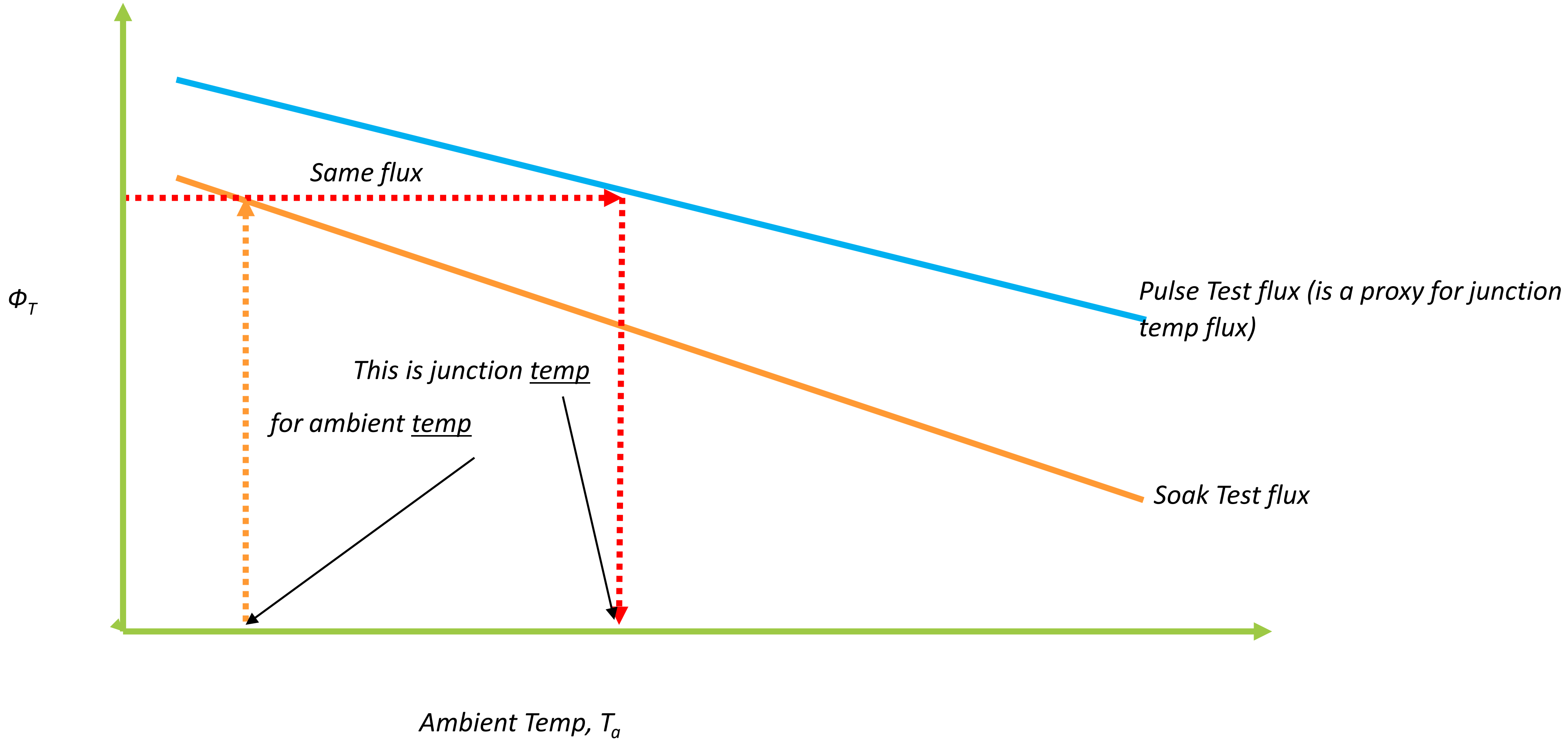
$$= 1 + \alpha.(T_0 - T_1)$$

Current-thermal interaction co-efficient, $\boldsymbol{K_{iT}}$, is determined from both the **pulse** and **soak tests** results with a fixed drive current, I

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



Pulse Test is a proxy for LED chip junction temperature



Model Types to Test

Selected models

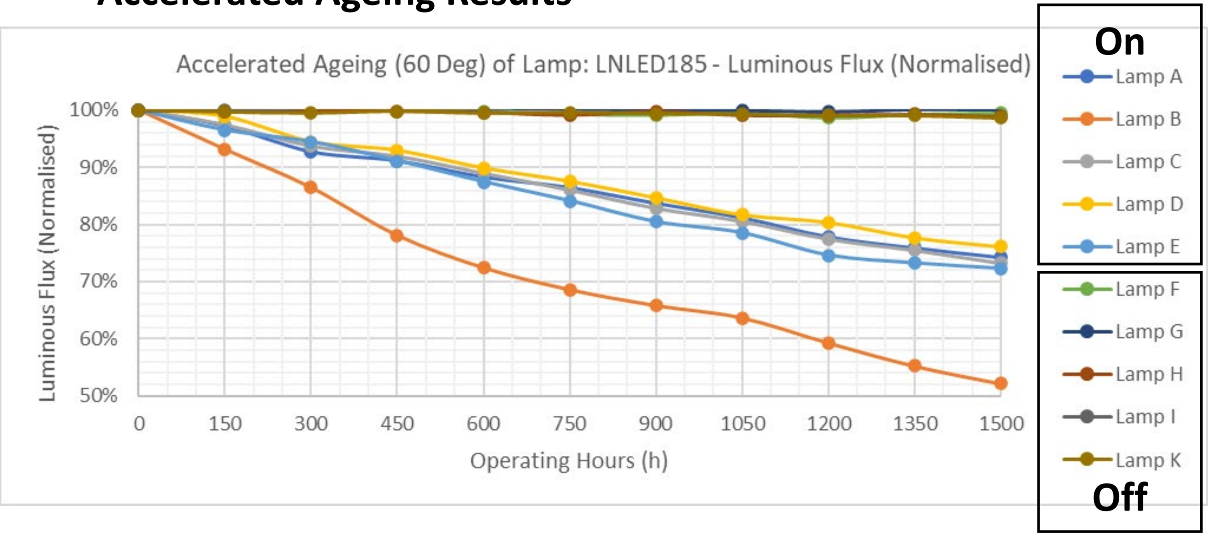
Five A-shape models (10 units of each)

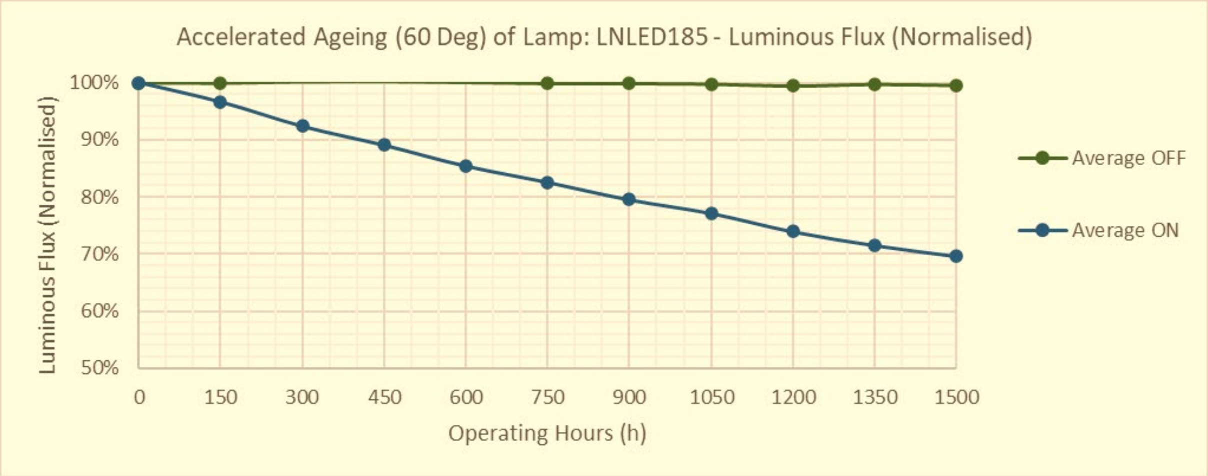
Do not want lamps to have early catastrophic failure. (not the purpose of this research).

LN Code	Lamp type	LED type	Dim	Rated Power	Rated Lumens	Rated (Tested) efficacy	Lifetime	CCT	Reason for selection	Unit Price
LNLED185	A80	COB	no	19	2300	121.1 (118.8)	10,000	6500	High powered lamp with low life yet still high efficacy claim.	€ 14.00
LNLED186	A60	COB	no	9	840	93.3 (99.1)	15,000	CW	Average efficacy and typical life claims	€ 2.50
LNLED187	A50	COB	no	6	470	78.3 (88.9)	15,000	WW	Very low efficacy claim but typical life claim	€ 4.50
LNLED188	A60	Filament	no	9.5	1350	142.1 (149.5)	15,000	WW	Expected filament efficacy claim but no life claim	€ 5.00
LNLED189	P40	Filament	yes	5	470	94.0 (86.7)	25,000	3000	Very low efficacy claim for filament LED and long life claim	€ 6.50

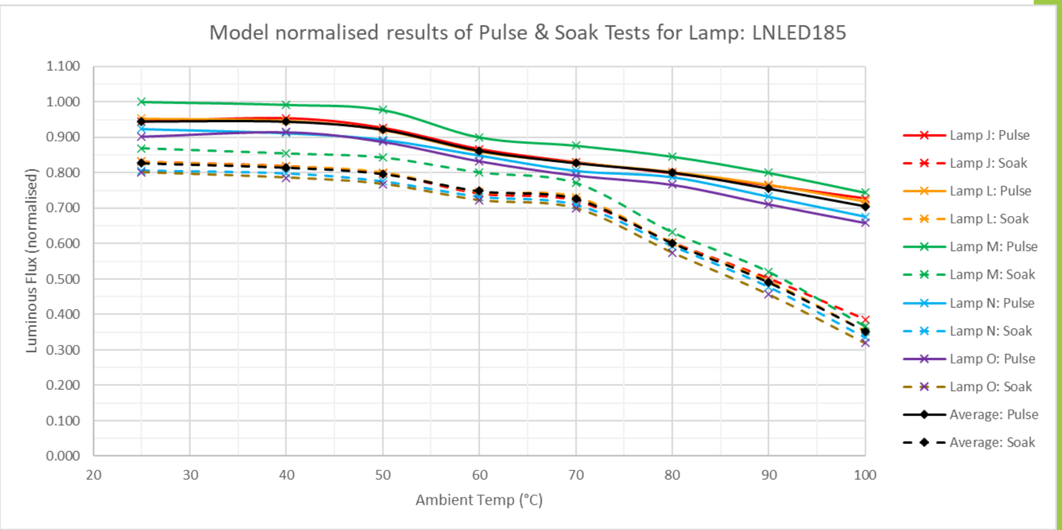
Measurements – LNLED 185 Luminous Flux

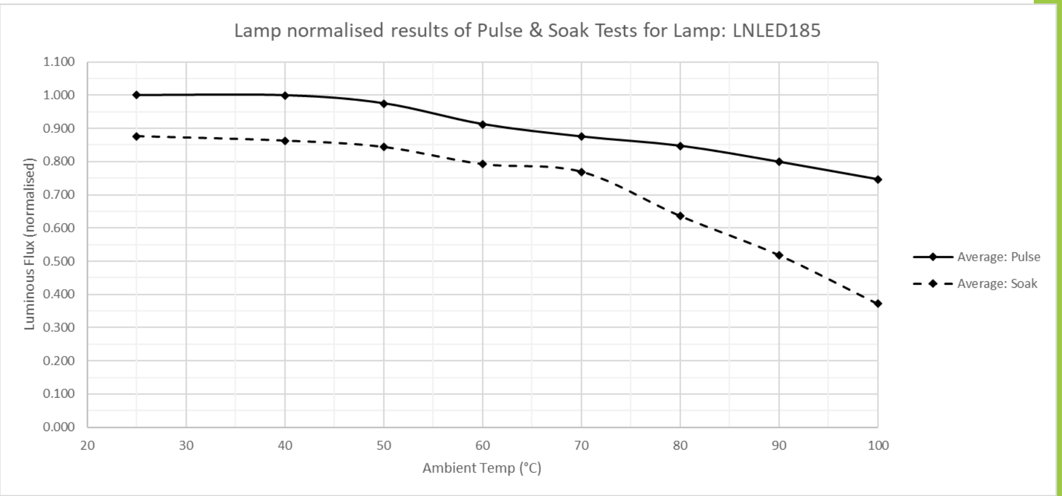
Accelerated Ageing Results





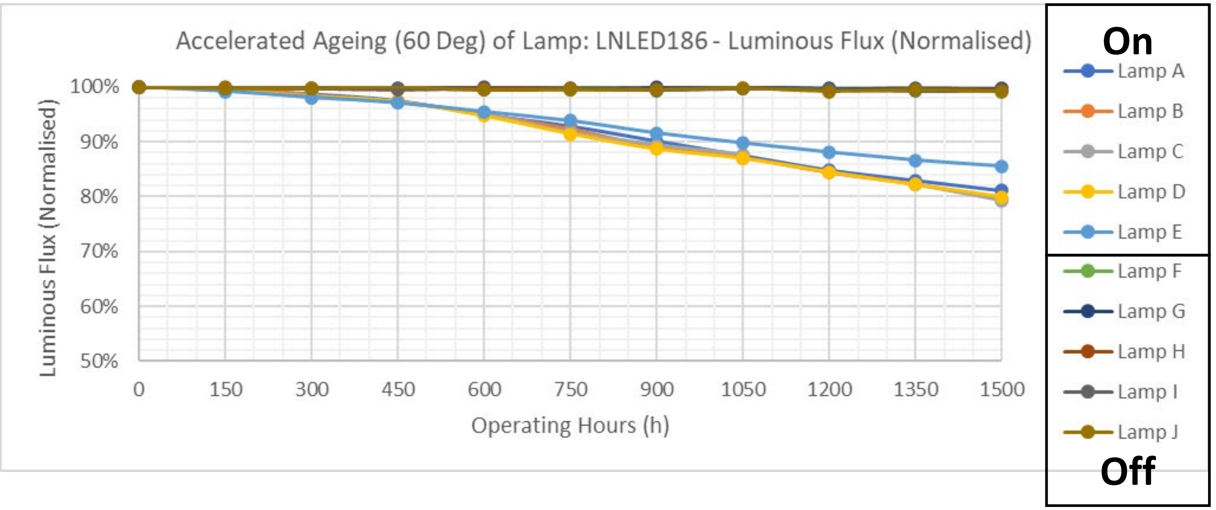
Pulse- Soak results

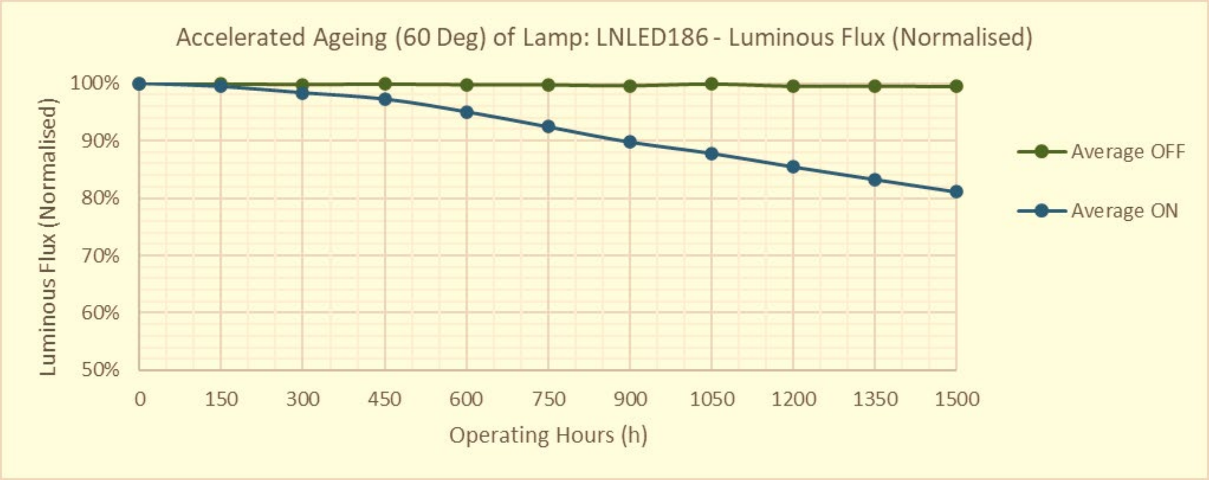




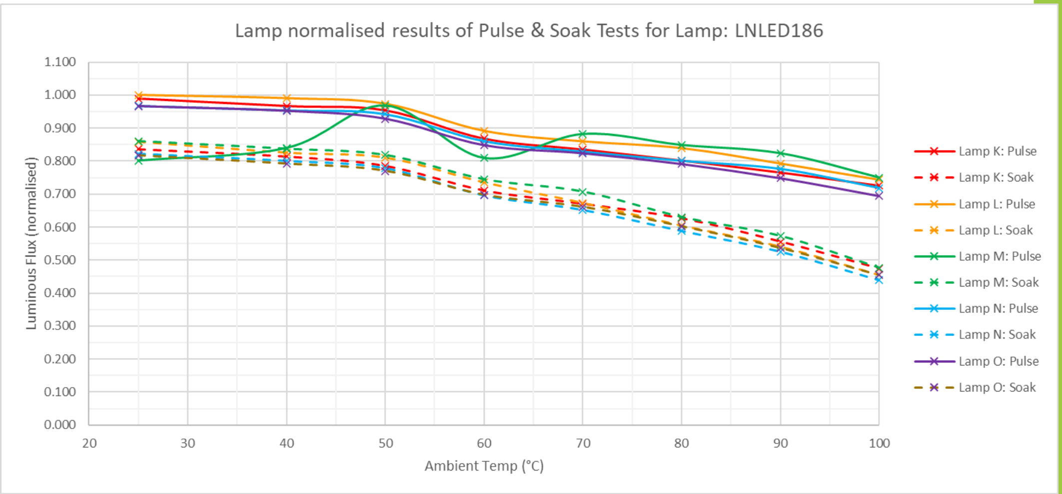
Measurements – LNLED 186 Luminous Flux

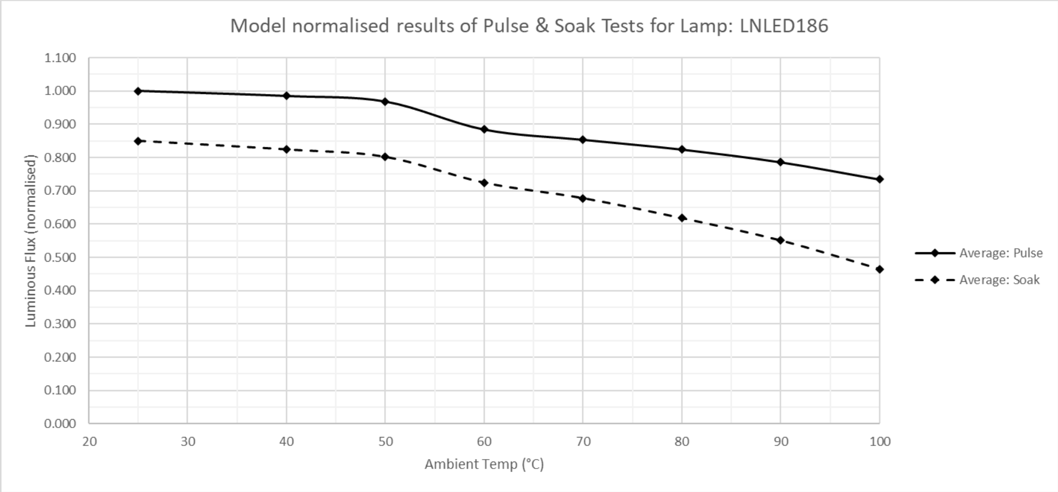
Accelerated Ageing Results





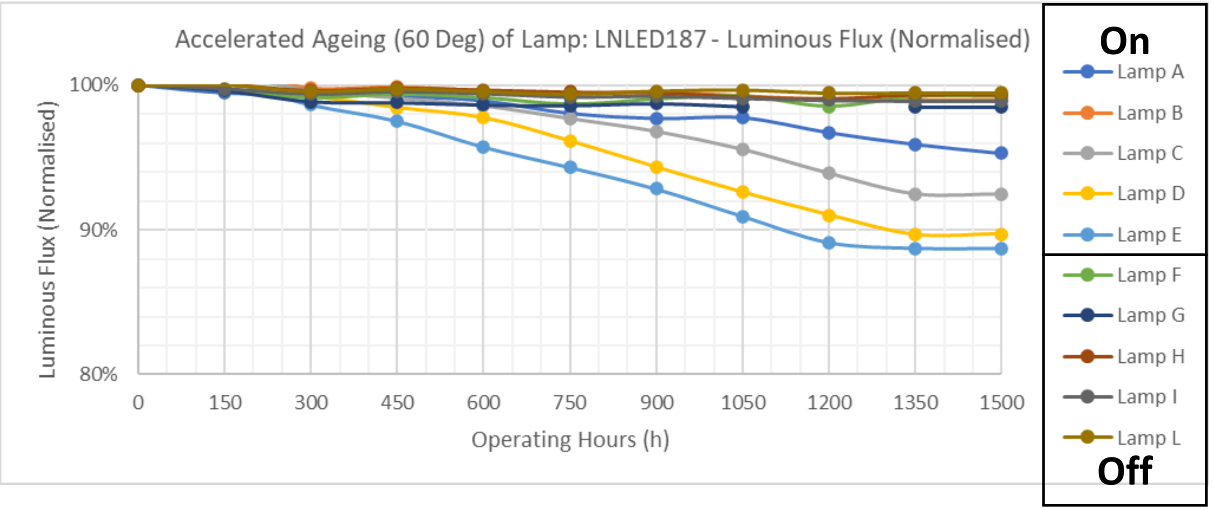
Pulse- Soak results

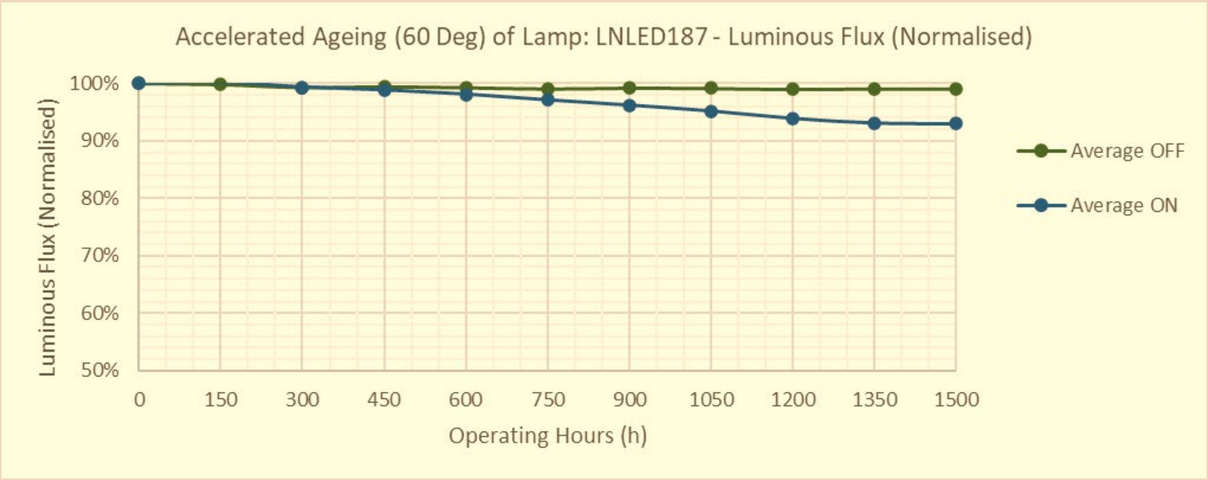




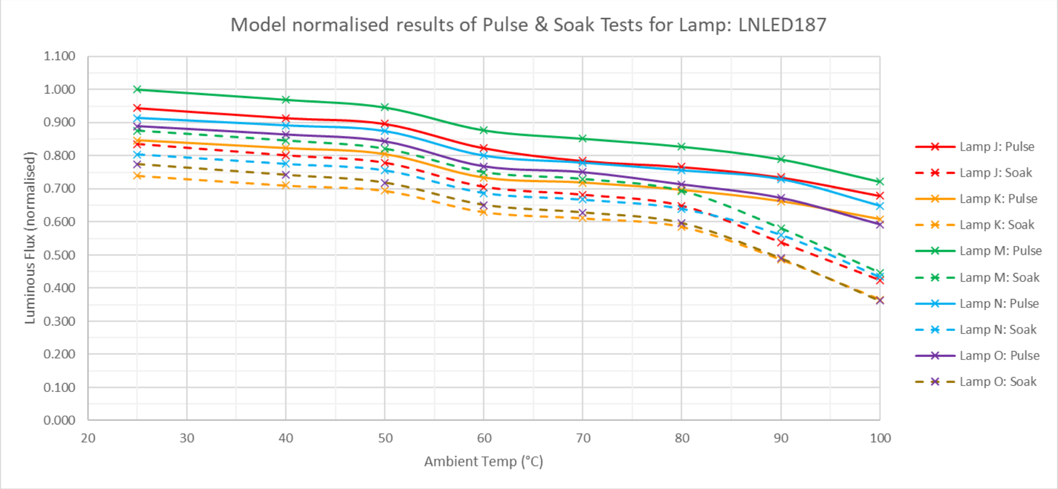
Measurements – LNLED 187 Luminous Flux

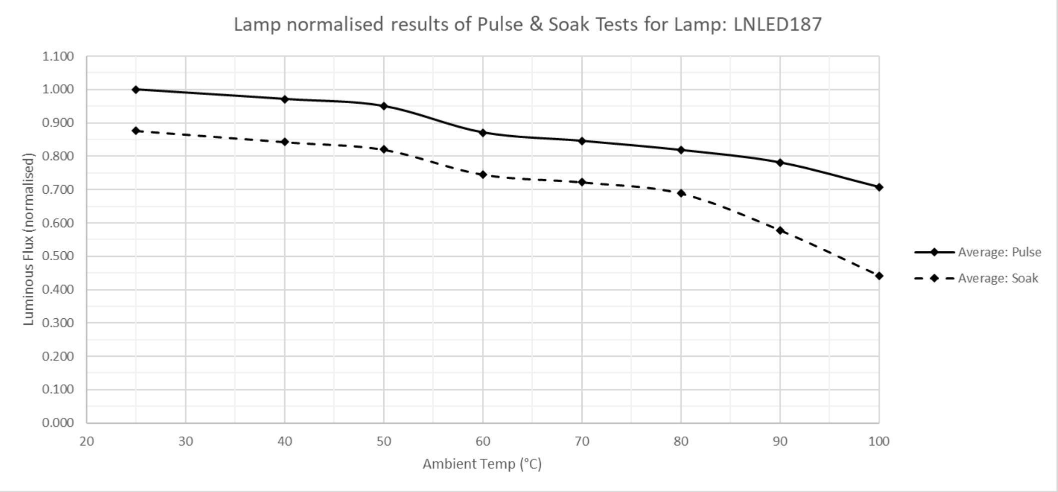
Accelerated Ageing Results





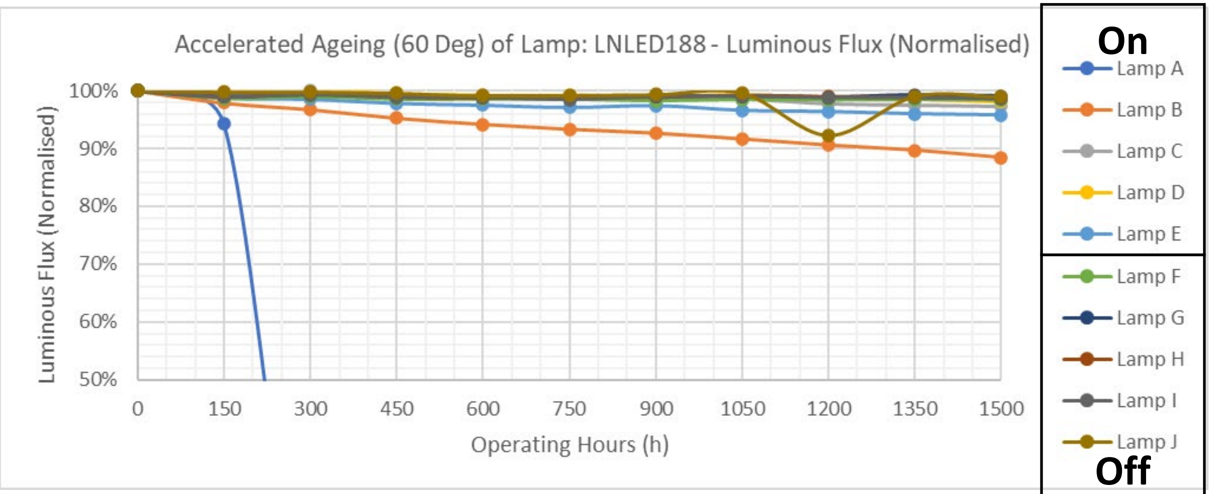
Pulse- Soak results

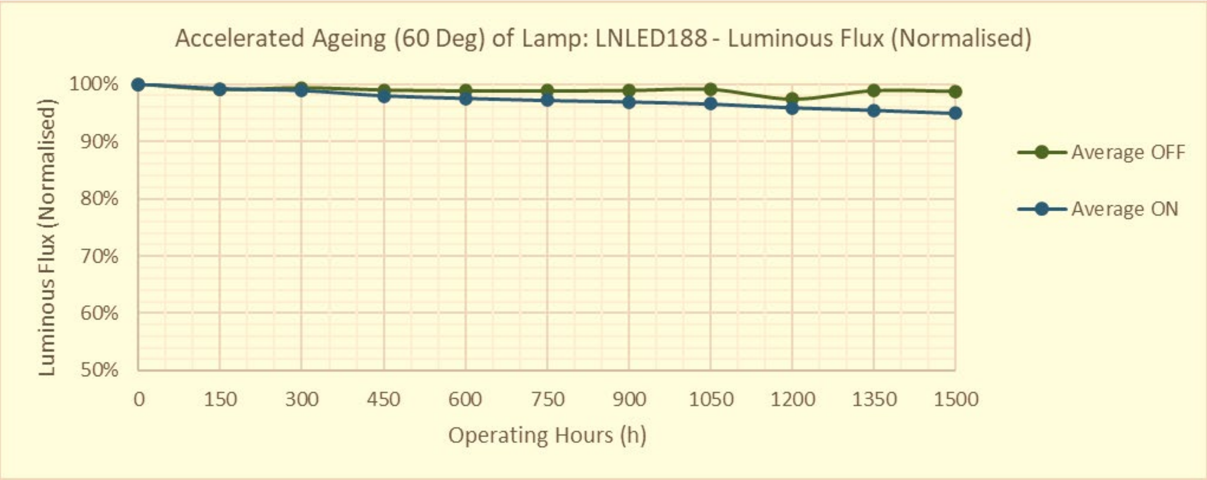




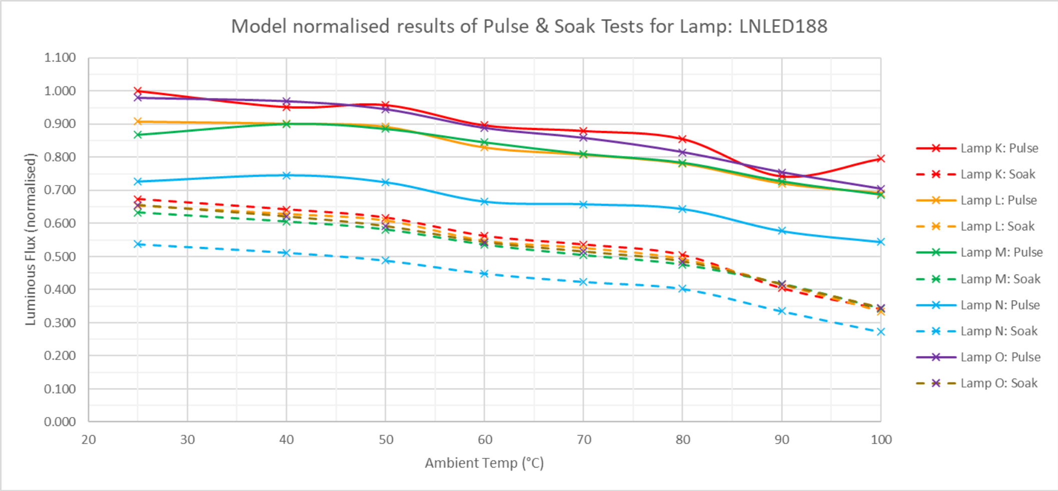
Measurements – LNLED 188 Luminous Flux

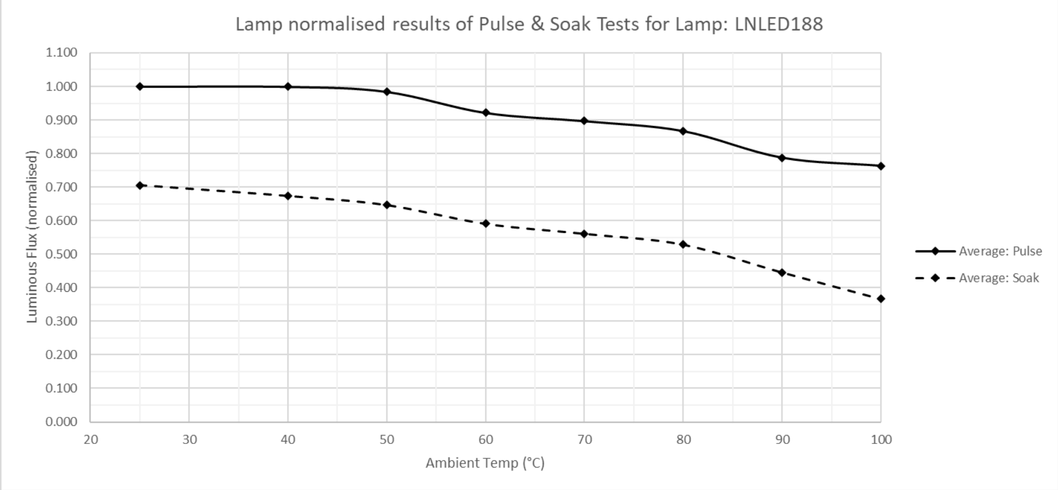
Accelerated Ageing Results





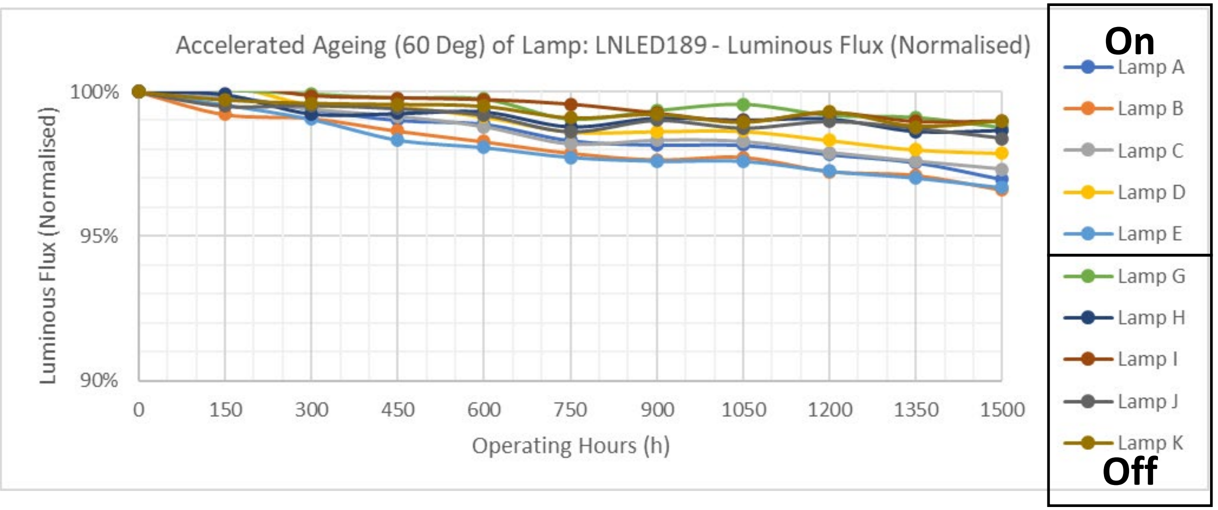
Pulse- Soak results

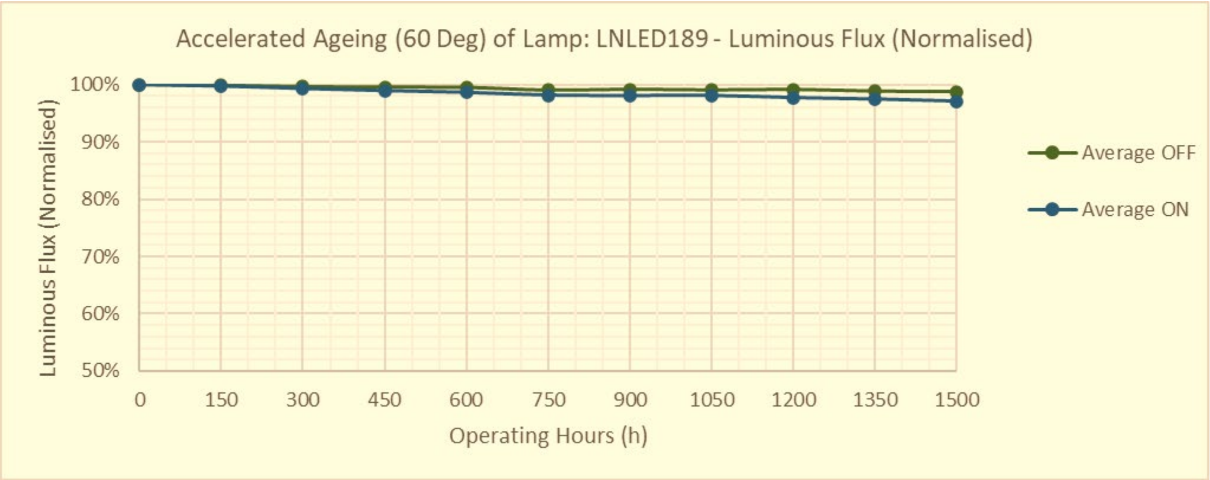




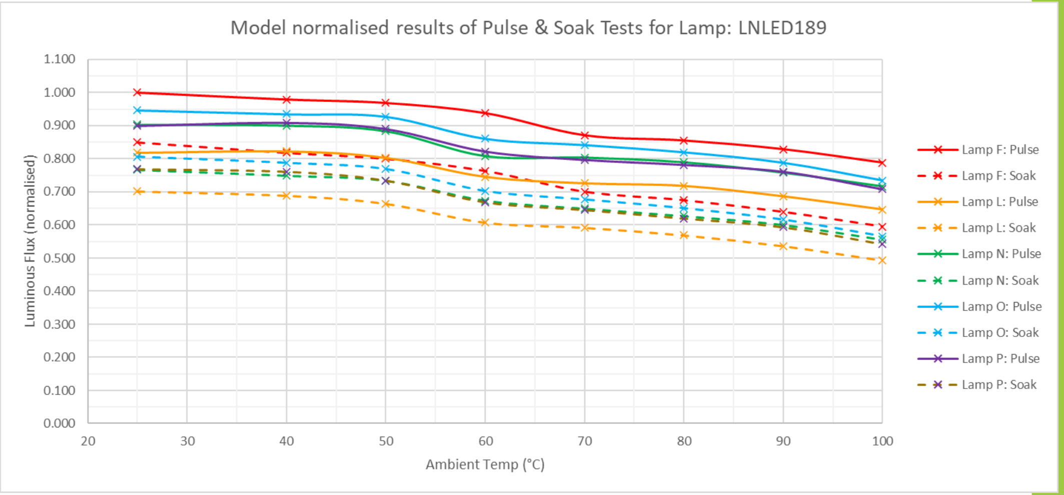
Measurements – LNLED 189 Luminous Flux

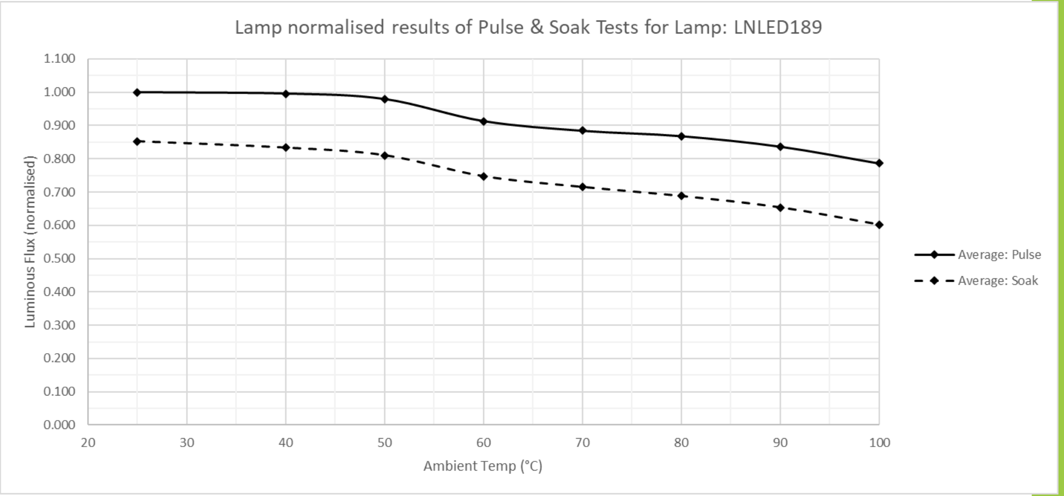
Accelerated Ageing Results





Pulse- Soak results

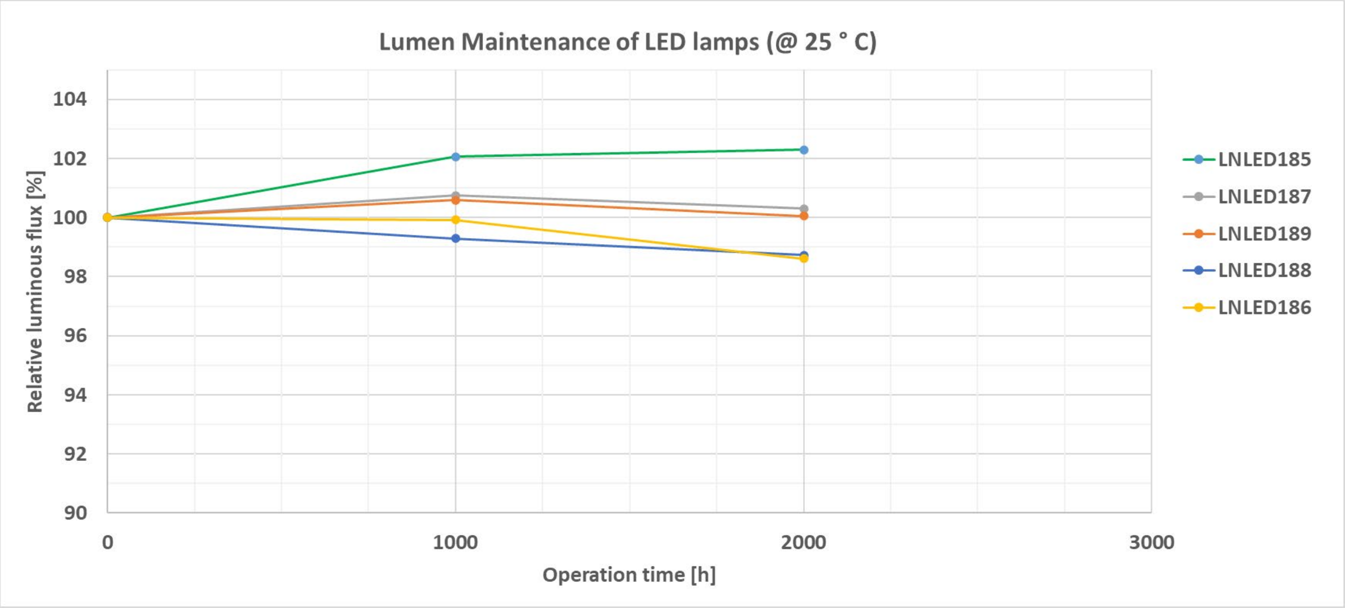




First Stage Results: Prediction based on ADT & Pulse Soak Tests

	$A_{60°}$	$\beta_{60°}$	K_T	K_{iT}	$L_{70,60°}$	Predicted $L_{70,25°}$	Rated $L_{70,25°}$
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

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



Smart Sustainability in Lighting and Controls SSLC

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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

Acknowledgements

Thanks are due to

Yoshi Ohno, and Jiaye Li, NIST

Gillian Isoardi, Light Naturally

Jun-Seok Oh, KIEL Institute

EUDP for supporting our work, j.no 64018-0534

Thank you for you attention

Questions are welcome

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