Lighting Market Impact Evaluation Study

Modelling Assumptions Report

Prepared for NSW Office of Environment and Heritage

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DRAFT REPORT - V0.3

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1 Introduction

The purpose of this report is to outline the assumptions, their justification, and the data sources and approach taken to market modelling that was carried out as part of a Lighting Market Impact Evaluation Study (LMIES).

For the purpose of the modelling and the LMIES, lighting in NSW commercial buildings was split into the following 4 sectors:

- Residential: common areas of apartment buildings.
- Office.
- Non-office commercial: retail, education, health, accommodation, hospitality and leisure.
- Industrial: factories and warehouses.

The above 4 sectors represent the most granular level that commercial lighting was able to be dissected to, given the available market data. Note that road/outdoor lighting was not modelled in detail, as ESS activity in this sector has been negligible.

The key lighting upgrade types were modelled, and each was categorised by sector. The upgrade types modelled are listed below, and these are predominantly upgrades to LED technology (although some historical ESS upgrades to T5 and similar technologies did take place):

- Downlight upgrades in residential buildings (for common areas, which are covered by the ESS commercial lighting formula).
- Downlight upgrades in offices.
- Downlight upgrades in non-office commercial buildings.
- Fluorescent upgrades in offices.
- Fluorescent upgrades in non-office commercial buildings.
- Fluorescent upgrades in industrial buildings.
- HID upgrades in industrial buildings.
- HID upgrades in non-office commercial buildings.

Note that these are the key upgrades that have dominated the ESS. Small quantities of other upgrade types have also taken place however, for example downlight replacements in industrial premises, HIDs in offices, etc.

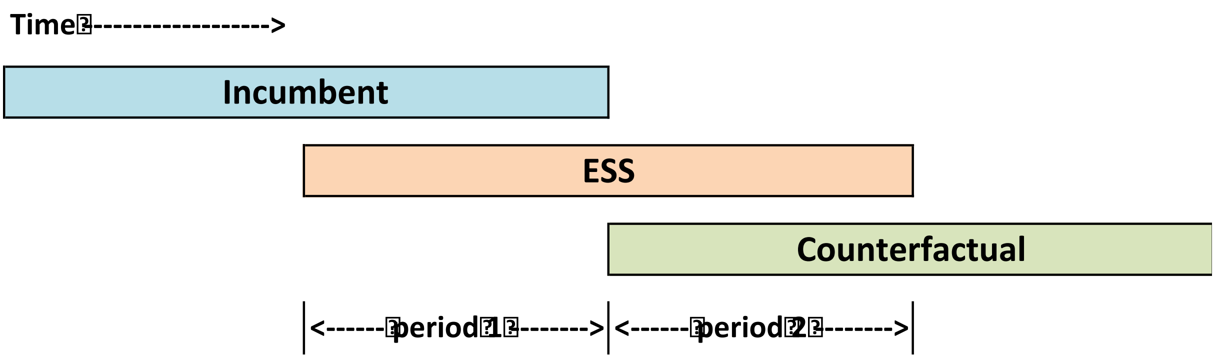
2 Approach

In order to accurately estimate the lifetime energy savings from upgrading a light (either an entire luminaire or simply a lamp-only replacement) logic dictates that we need to consider 3 different lights:

- The existing light which is replaced - the "incumbent". This is typically a halogen, fluorescent or HID.
- The light that is installed by an ACP - the "ESS" light. This is typically an LED.
- The light that *would have* replaced the incumbent, in the absence of the ESS, either when the incumbent fails or more likely when a major renovation of the space is undertaken. We call this light the "counterfactual". We cannot know what the counterfactual would have been, so this needs to be estimated using modelling and forecasting. Counterfactual installations are likely to include both LEDs and old technology (halogen, fluorescent, HID). Some building owners will fit LEDs when lights fail or the space is renovated, and some will opt to stay with old technology. The counterfactual is the *weighted average light that would have been installed* (weighted by quantities of installations).

Figure 1 below illustrates these three lights, on a time scale.

Figure 1 - sequence of lights used to calculate energy savings



In order to calculate the total energy savings from the installation of the ESS light, we need to calculate (and sum together) energy savings over the two distinct periods illustrated in the figure above: period 1 and period 2. To do this we need to calculate the following parameters:

- The duration of periods 1 and 2 - refer sections 3.1, 3.2 and 3.3.
- The electrical power of the incumbent, ESS and counterfactual lights - refer section 3.4.
- The annual operating hours of the lights - refer section 3.5.

The derivation of all the required parameters is discussed in the following sections.

3 Derivation of Required Parameters

3.1 Duration of Period 1 (Downlights)

Period 1 is the remaining life of the incumbent light - the length of time before it *would have been* replaced by the counterfactual (in the absence of the ESS). The assumption used is that the incumbent light is *half way* through its life, when the ESS unit is installed and period 1 commences. This assumption is intuitive - if you select a large quantity of lights at random, then on average they will be half way through their life.

Note however that lights targeted for replacement by ACPs are of course not selected at random, and technologies such as halogen are rapidly receding from the market (refer Figure 4 in Annex). Thus, halogen lights are likely to be more than half way through their life (e.g. remaining halogens are quite likely to be replaced by LED at the end of their life - intuitively this means that any remaining halogens are relatively old).

Thus, the assumption that the incumbent light is half way through its life will tend to over-estimate energy savings (by over-estimating the duration of period 1). However, in the absence of better data we have stayed with this 50% assumption.

The other piece of information we need to calculate the duration of period 1 is the total life of the incumbent (which we then halve, i.e. based on the 50% assumption).

For downlights (all sectors) one approach that can be taken is that halogen downlights can be easily replaced with LED lamps, i.e. the entire fixture does not need to be replaced in order to become LED. This is now common practice and effective and compatible LED replacement lamps are widely available.

Using this "lamp-only" replacement approach, halogen lamps have typical rated lives of 4,000-10,000 hours[1] and using operating hours of 3,000-5,000 hours, then we have an estimated average lamp life of 0.8 - 3.3 years.

An alternative approach is to assume that downlights are not likely to be replaced with LEDs until the space is renovated, at which time all the fixtures might be replaced with LEDs. Taking this approach, the total life of the incumbent would be much longer, i.e. in the order of 10 years.

Either of these approaches is possible, and on balance a hybrid of these approaches was used - 4 years was used for the life of the incumbent (meaning that 2 years was used for period 1, for downlights). This approach is closer to the first method - the "lamp-only" method, however this was simply the subjective view of the author (i.e. that the lamp-only approach to downlight replacement with LED was more common).

[1] Taken from manufacturer catalogues (Sylvania Lighting Australasia, Philips Lighting, GE Lighting)

3.2 Duration of Period 1 (Fluorescent and HID)

For fluorescent and HID lights, the assumption that the incumbent light is half way through its life remains. However, LED lamp-only replacements for these kinds of lights are less common than for halogen downlights. Thus, the approach taken was that total life of the incumbent is more likely to be the *mean time between major renovations* of the space in question. That is, lighting fixtures are typically replaced when the space is renovated.

No data exists for the frequency of renovations. Thus, as part of stakeholder interviews for the LMIES, stakeholders were asked for their opinion as to how often various building types are typically renovated. On average, the responses were as follows:

- Office spaces: 10 years was widely touted, but noting that there is likely to be a very large range here - as low as 7 years for high quality office space, and much longer (e.g. 20 years) for low quality office space.
- Non-office commercial spaces: 15 years.
- Industrial spaces: 20 years.

These periods were then halved in order to calculate the duration of period 1. The results for all upgrade types are shown in Table 1.

Table 1 - values for duration of period 1

Upgrade Type	Life of incumbent (years)	Period 1 (years)
Downlights - residential (common areas)	4.0	2.0
Downlights - offices	4.0	2.0
Downlights - non-office commercial buildings	4.0	2.0
Fluorescent - offices	10.0	5.0
Fluorescent - non-office commercial buildings	15.0	7.5
Fluorescent - industrial	20.0	10.0
HID - industrial	20.0	10.0
HID - non-office commercial buildings	15.0	7.5

3.3 Duration of Period 2

Referring to Figure 1, Period 2 can be expressed as the life of the ESS installation minus the duration of period 1.

Logically, it can be argued that the life of the ESS installation is also equivalent to the mean time between renovations of the space in question, which is the approach used for Period 1. This also makes sense for LED downlights.

However, in the case of industrial buildings, it did not seem prudent to assign a life of 20 years to ESS installations. This would mean that installed LEDs would need to have lifetimes of 100,000 hours (operating 5,000 hours p.a. x 20 years). Thus, for industrial applications the life of the ESS installation was capped at 15 years.

The resultant ESS installation lives, and durations for periods 1 and 2, are shown in Table 2.

Table 2 - values for durations of periods 1 and 2

Upgrade Type	Period 1 (years)	ESS Installation Life (years)	Period 2 (years)
Downlights - residential (common areas)	2.0	10.0	8.0
Downlights - offices	2.0	10.0	8.0
Downlights - non-office commercial buildings	2.0	10.0	8.0
Fluorescent - offices	5.0	10.0	5.0
Fluorescent - non-office commercial buildings	7.5	15.0	7.5
Fluorescent - industrial	10.0	15.0	5.0
HID - industrial	10.0	15.0	5.0
HID - non-office commercial buildings	7.5	15.0	7.5

3.4 Electrical Power

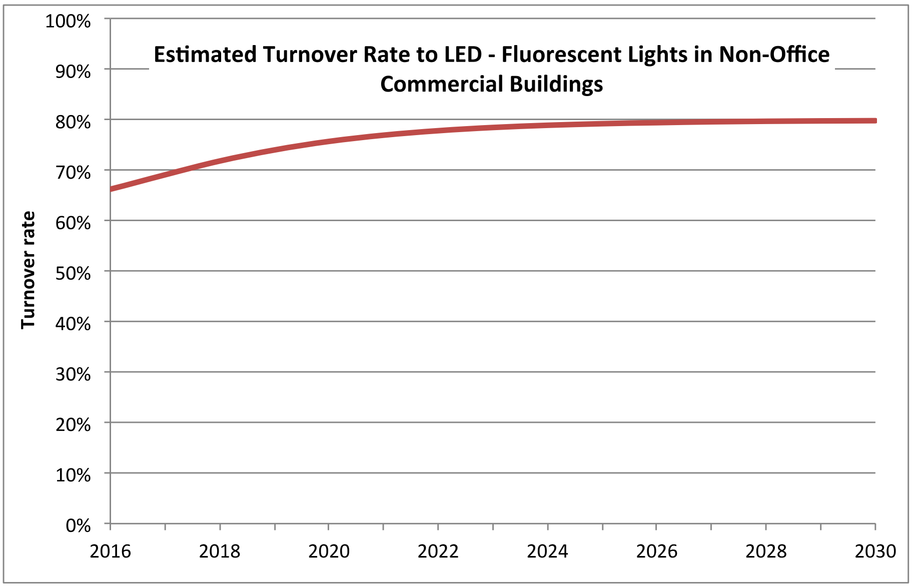
The historical electrical power of the incumbent and ESS lights are known, i.e. from ACP lamp circuit power (LCP) data.

The electrical power of the counterfactual is not known. To estimate this, we need to forecast the average quantities of LED and old-technology lights that we consider would have been installed at the end of the incumbent's life. We also need to estimate the electrical power for each, then take a weighted average - the *weighted average counterfactual*.

The power of the old-technology lights was assumed to remain static, as lighting manufacturers are not investing in making these technologies more efficient. LEDs are, however, becoming more efficient and this is expected to continue. A future forecast of LED efficacy was taken from a US study (US DoE 2016[A]) and from this the power of LEDs was forecast.

Extensive modelling was undertaken to forecast the following important metric: the *estimated turnover rate*, which is the *percentage of retirements of incumbent lights that transition to LED*. The modeling was based primarily on ABS lamp import data (ABS 2017[B]) (refer Figure 4) with trends extrapolated into the future. The Annex contains multiple graphs for this metric, but Figure 2 below shows an example - the estimated turnover rate for fluorescent fixtures in the non-office commercial sector.

Figure 2 - estimated turnover rate to LED, for fluorescent lights in non-office commercial sector



From the figure above we can see that, in 2016, an estimated 67% of remaining fluorescent fixtures are being replaced with LED fixtures, when they reach the end of their life (i.e. when the space is renovated). It is important to keep in mind that this percentage does pertain to what happens during major renovation, when luminaires are typically replaced. In this case, two thirds of fluorescent lights are replaced with LED lights, <u>when the space is upgraded</u>.

During interviews conducted for the LMIES, many (but not all) lighting suppliers stated that they now sell only LED luminaires. Whilst it is unlikely that 100% of new luminaire sales are now LED, the 67% estimate above does appear conservative in light of the information provided by lighting suppliers, as does the assumption that the rate does not increase beyond 80% in future.

Graphs for all the upgrade types/sectors can be seen in the Annex.

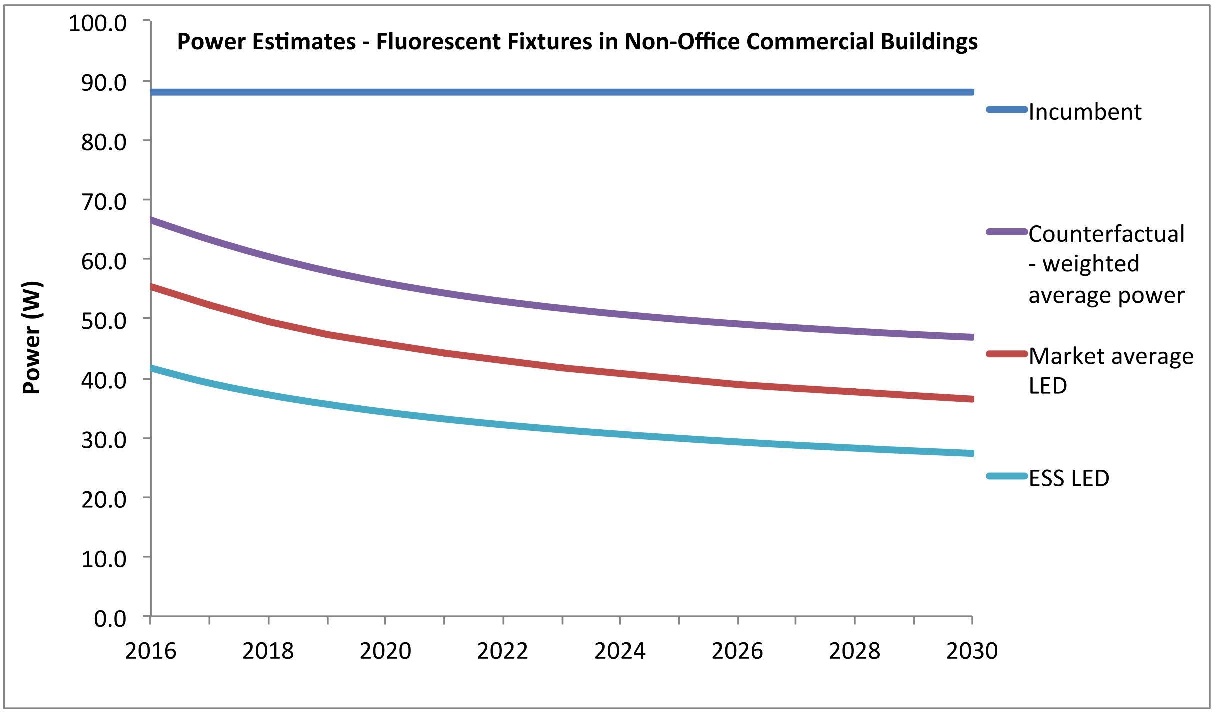
From this estimated turnover rate, and from forecasts of LED efficacy into the future, we can then calculate the *weighted average power of the counterfactual*. Figure 3 below charts the results of this modelling for the same example used above. It shows the following power values (for typical twin 4-foot fluorescent fixtures used in non-office commercial buildings):

- Incumbent - twin 36W lamp fixture with magnetic ballast, power = 88W (from ESS formula).
- Counterfactual - the calculated weighted average of the incumbent technology and the market average LED (weighted using the estimated turnover rate described above). i.e. some fixtures will be replaced like-for-like (fluorescent replacing fluorescent) and some will upgrade to LED.
- Market average LED - the forecast power of the market average LED fixture.

- ESS LED - the forecast power of the ESS LED installed (assumed to be 25% more efficient than the market average LED, due to the inherent incentive for ESS lights to be more efficient).

Note that, throughout this report, these figures represent typical averages - there will of course be installations that are larger and smaller than those shown in these graphs.

Figure 3 - forecast power values for fluorescent lights in non-office commercial sector



From the figure above we can derive the following, for a typical ESS installation undertaken in 2016:

- The incumbent was an 88W fixture.
- It was replaced with an ESS LED of 42W.
- The counterfactual fixture *would have been installed in 7.5 years time (2024)* and it's power would have been around 55W (the purple line in year 2024).

Graphs for all the upgrade types/sectors can be seen in the annex.

3.5 Operating Hours

Operating hours, for the various sectors modelled, were taken from the ESS Rule.

4 Data Issues and Uncertainties

The calculation approach outlined in previous sections is based on a number of assumptions, and also uses imperfect data. These issues are discussed in this section.

Lighting is complex. In Australia, there are around *half a billion* lights installed (E3 2016a[C]). There are many different lighting technologies installed in many different types of buildings and sectors, and we are in the middle of an unprecedented period of change in the available types, efficiencies and costs of lights.

To estimate the energy savings available from lighting upgrades, we need to examine the lighting *stock* - that is the quantities of the various types of lights actually installed in buildings. However for various reasons very little data exists related to lighting stock. Counting of the stock of lights is occasionally undertaken by various organisations - for example a modest residential stock count (E3 2016b[D]) was undertaken in 2016, with results being normalised using ABS household information. The challenges involved when counting lighting stock levels include:

- Lighting technologies are changing rapidly, meaning that counts become obsolete very quickly.
- Lighting technologies can be can be difficult to identify in situ.
- Counting of a representative sample is a comprehensive and expensive exercise.
- Non-residential lighting stocks are considered more difficult to count, due to the wide variations in types of buildings, market sectors and lighting applications involved.

Given these realities, we are forced to rely on desktop modelling for the commercial lighting sector, and this requires a large number of assumptions.

In contrast to *stock* data, excellent data does exist for product *sales* - we have access to lamp import data[2] (used a proxy for sales as no lamps are manufactured in Australia, and we don't have access to sales data). These import data exist as a time series (refer Figure 4). However they do include limitations that they exists only at the national level - there is no available, state-level breakdown of commercial lighting market data, either for sales or stock.

However, this import data series remains the best available time-series dataset for lighting. To take advantage of this rich data source, we need to convert *sales* data into *stock*, and for this was done using a "stock-and-sales" model. The resultant model that was constructed for this project is considered to be the best available lighting dataset ever developed for New South Wales, although **it does contain unavoidable uncertainty**. From the model we also derive the estimated turnover rates of lighting types, as these are critical inputs to calculations of energy savings from lighting upgrades.

ACP commercial lighting data was also collected from a number of ACPs, in order to estimate the types and quantities of lighting being installed as part of the ESS. However this data only covered around 12% of the total ESS commercial lighting market. It was assumed that all ESS commercial lighting activity occurred in the same proportions as this ACP data.

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[2] For conventional lamp types only - LEDs were not included in these data until January 2017.

To conclude , the key data issues and uncertainties can be summarised as follows:

- Predictions were made about the future efficacies of various LED lights, based on US DoE 2016[A].
- A number of assumptions were made about the durations of various lighting installations, based on interviews with stakeholders.
- The ACP commercial lighting installation data covered only around 12% of the ESS commercial lighting market.
- The ABS import lamp data, from which future trends regarding the uptake of LEDs were extrapolated, exists only at the national level.

References

[A] US DoE 2016, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared for the U.S. Department of Energy Solid-State Lighting Program, September 2016, Prepared by Navigant.

[B] ABS 2017, Australian Bureau of Statistics, lamp import data, purchased from the Australian Bureau of Statistics.

[C] E3 2016a, Consultation Regulation Impact Statement - Lighting, Regulatory reform opportunities and improving energy efficiency outcomes, Energy Efficient Equipment Committee, November 2016.

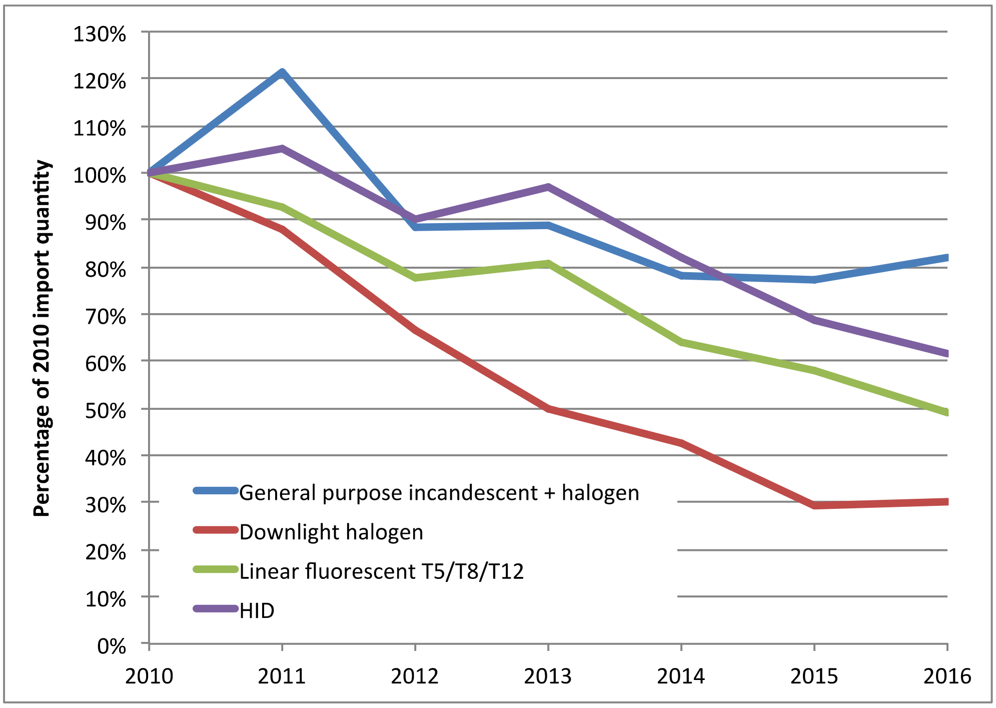
[D] E3 2016b, 2016 Residential Lighting Report, Results of a lighting audit of 180 Australian homes, Energy Efficient Equipment Committee, June 2016.

Annex - Graphs

ABS Data

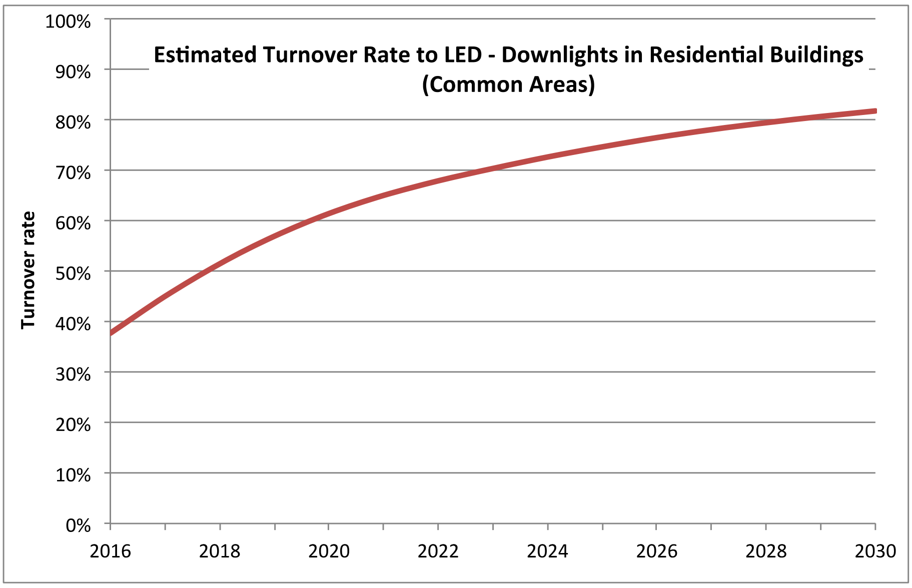
Extensive modelling was undertaken to forecast the following important metric: the *estimated turnover rate*, which is the *percentage of retirements of incumbent lights that transition to LED*. The modeling was based primarily on ABS lamp import data (ABS 2017[B]) (refer Figure 4 below) with trends extrapolated into the future.

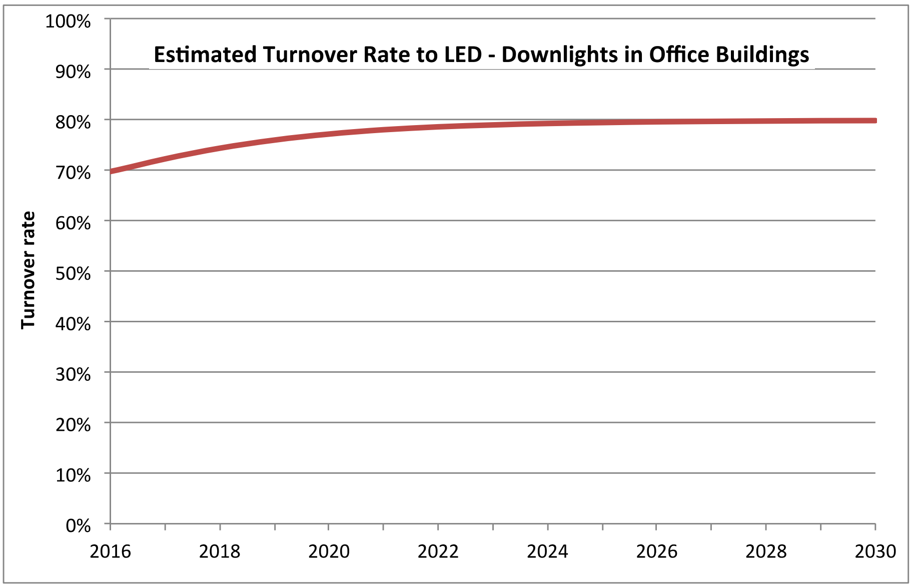
Figure 4 - Import quantities of conventional lamp types, relative to 2010 quantities (source: ABS 2017[B])

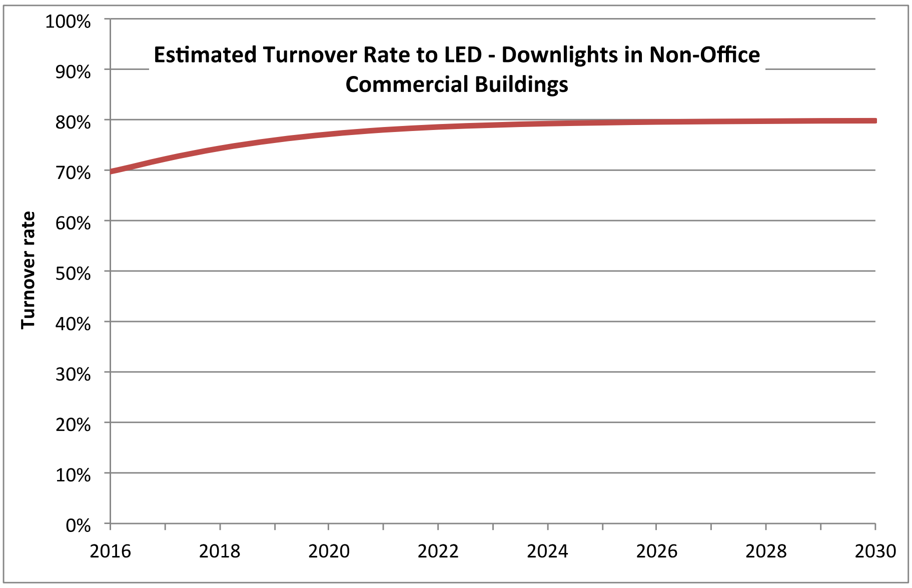


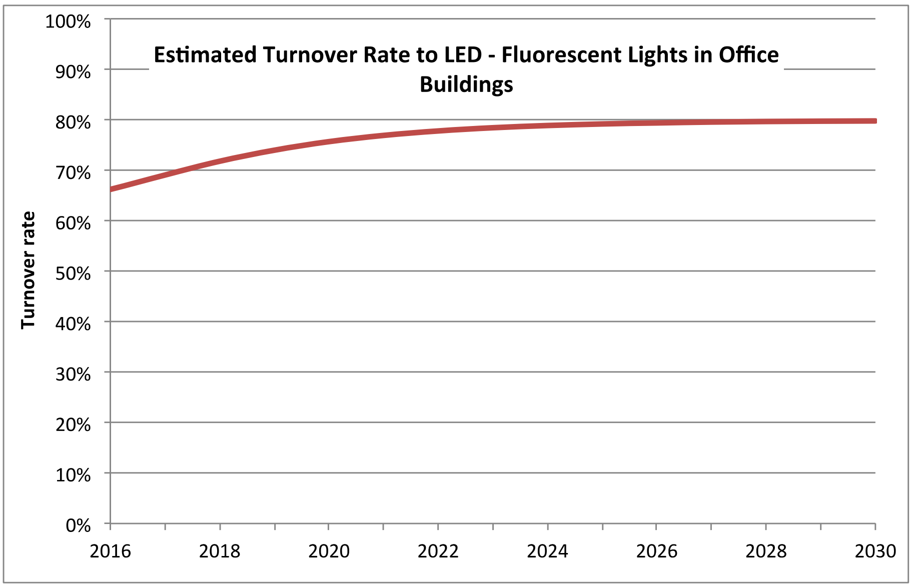
Graphs for Turnover Rates

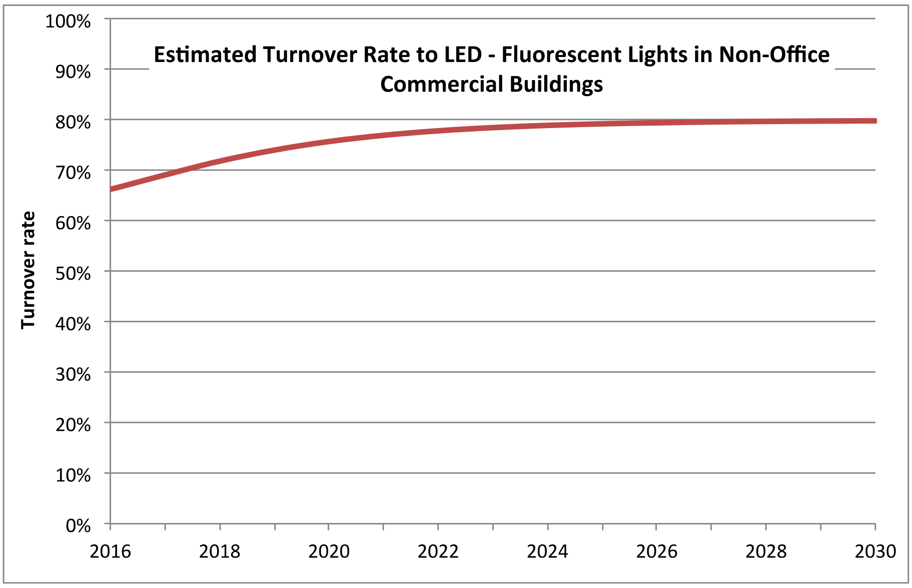
Below are graphs of “turnover rates” for all upgrade types. This is the same type of graph as used as an example in Figure 2 in the main body of this report.

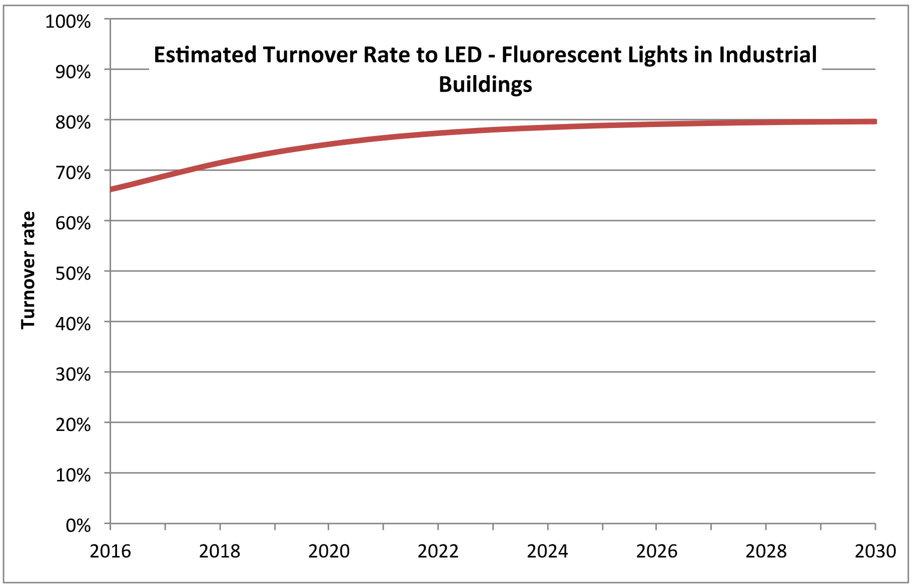

Estimated Turnover Rate to LED - Downlights in Residential Buildings (Common Areas)
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030

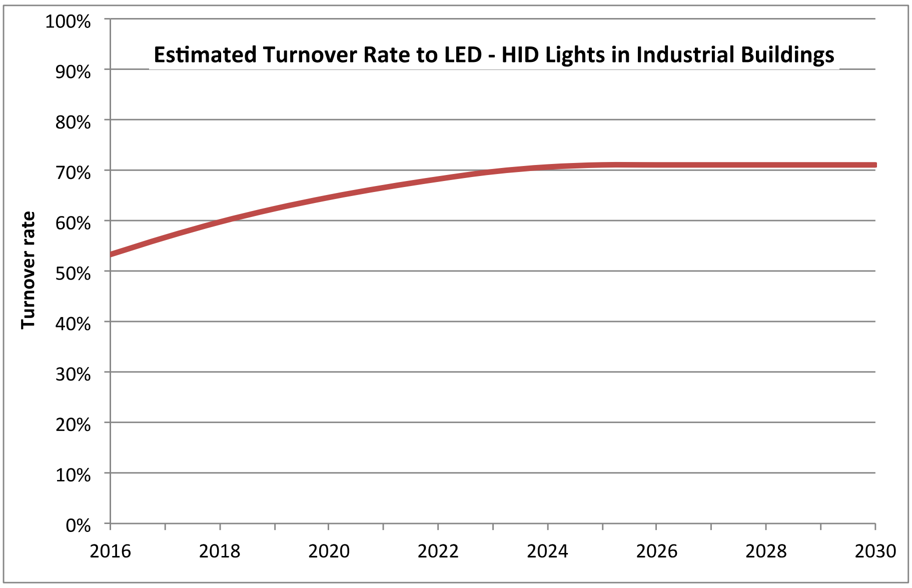

Estimated Turnover Rate to LED - Downlights in Office Buildings
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030


Estimated Turnover Rate to LED - Downlights in Non-Office Commercial Buildings
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030


Estimated Turnover Rate to LED - Fluorescent Lights in Office Buildings
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030

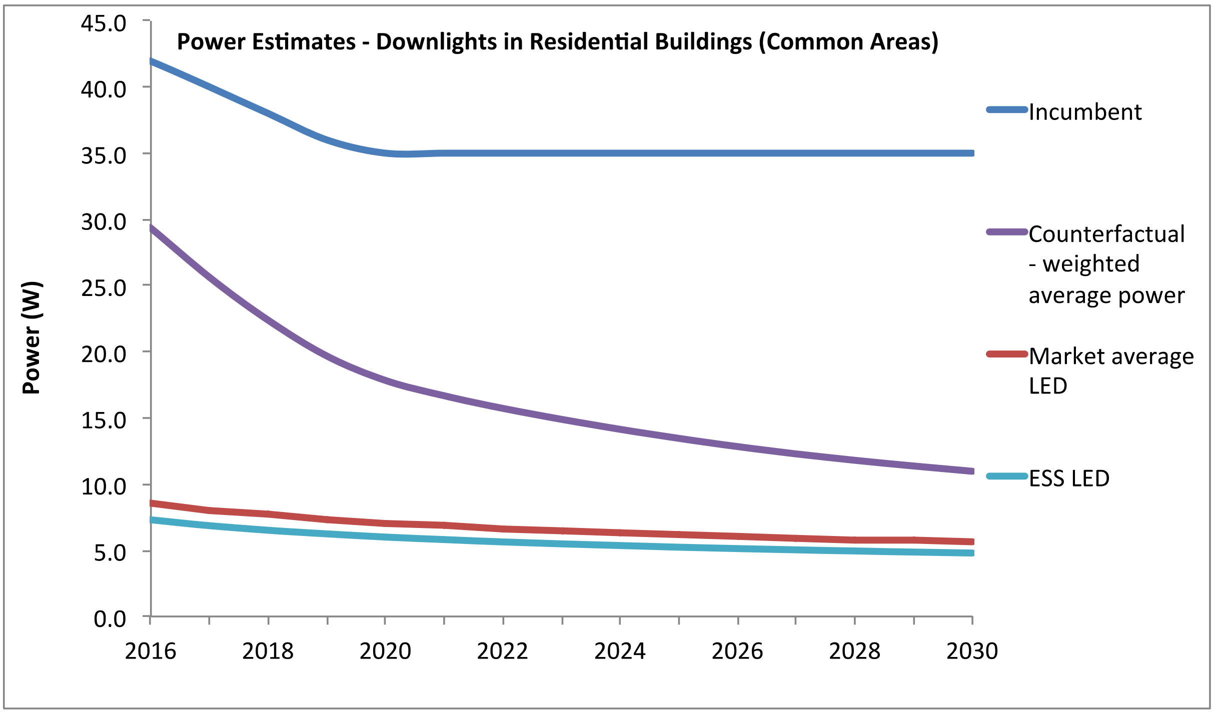

Estimated Turnover Rate to LED - Fluorescent Lights in Non-Office Commercial Buildings
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030

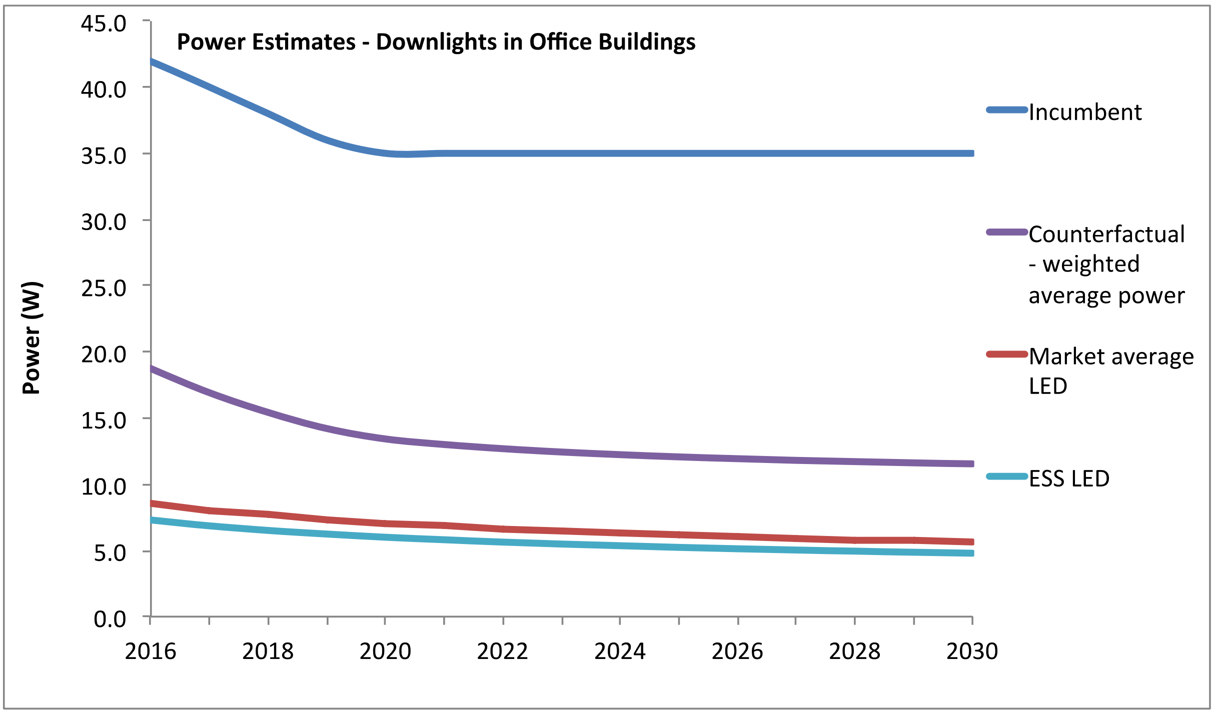

Estimated Turnover Rate to LED - Fluorescent Lights in Industrial Buildings
Turnover rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2016
2018
2020
2022
2024
2026
2028
2030

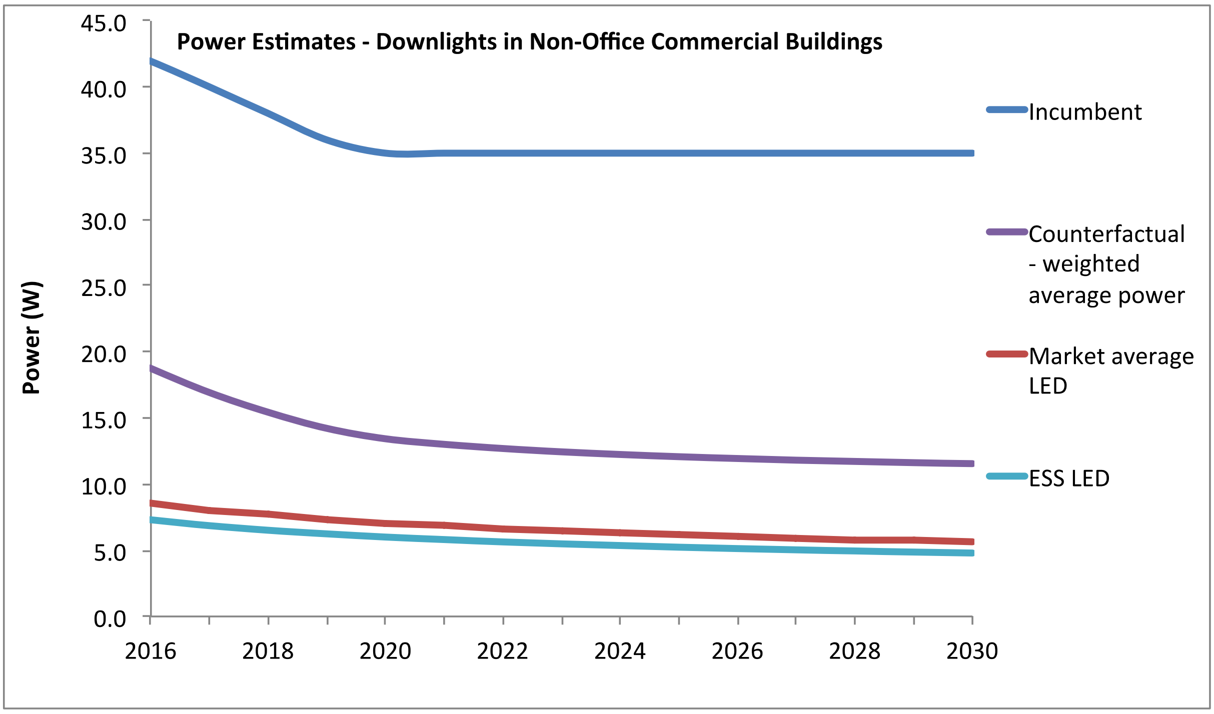


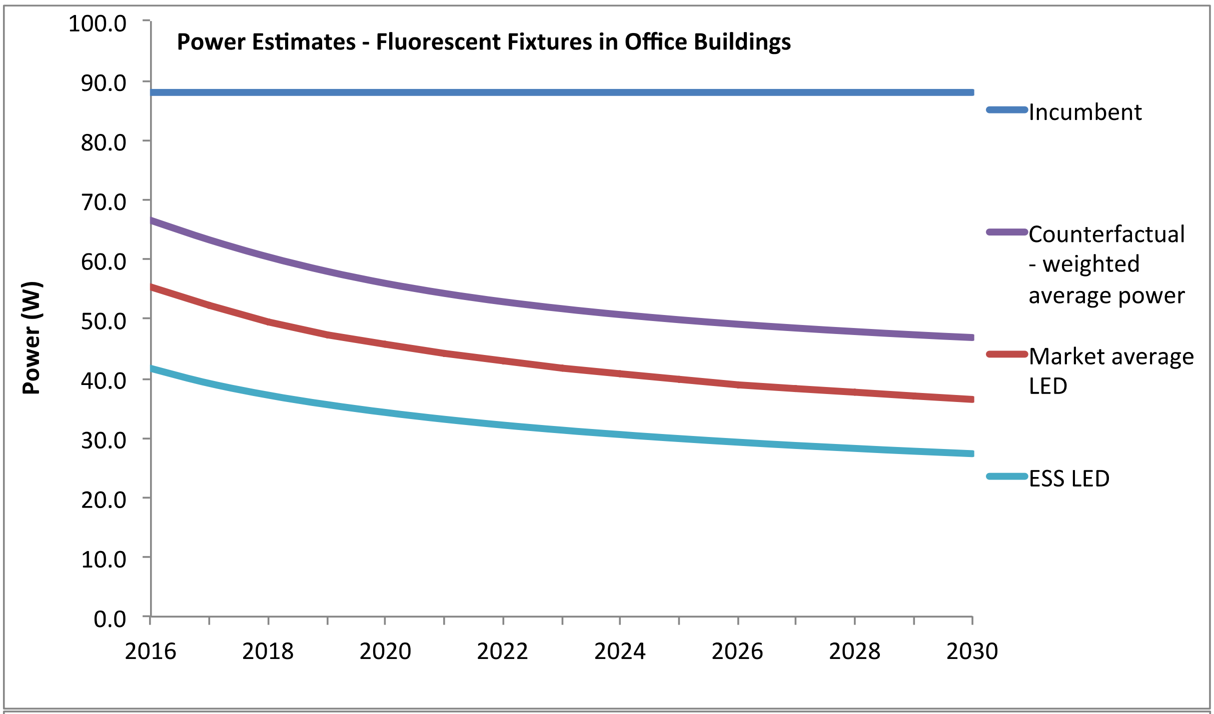
Graphs for Power Values

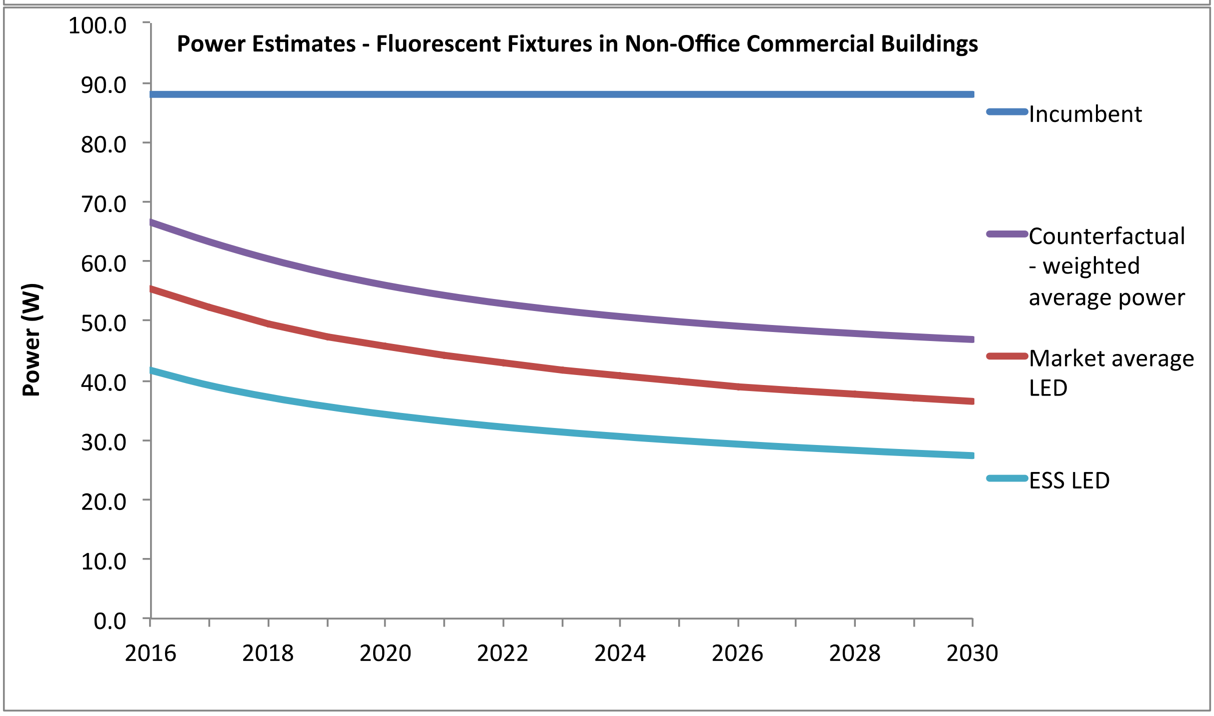
Below are graphs of average power values for all upgrade types. This is the same type of graph as used as an example in Figure 3 in the main body of this report.

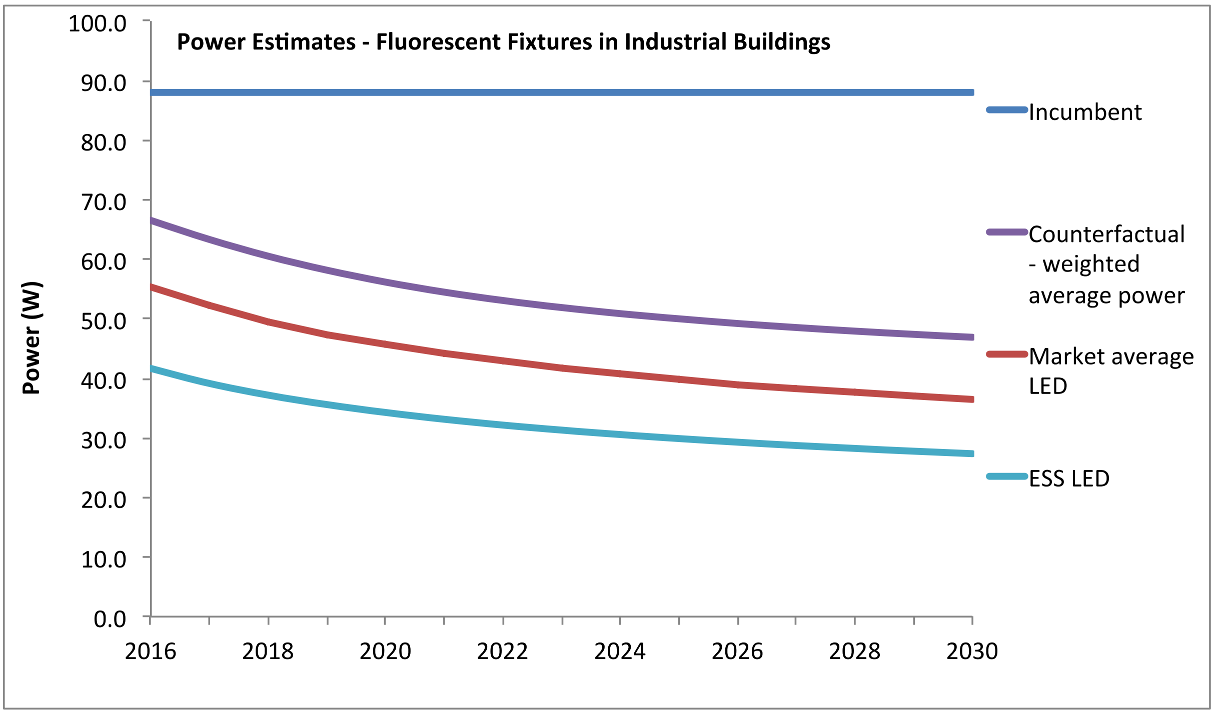


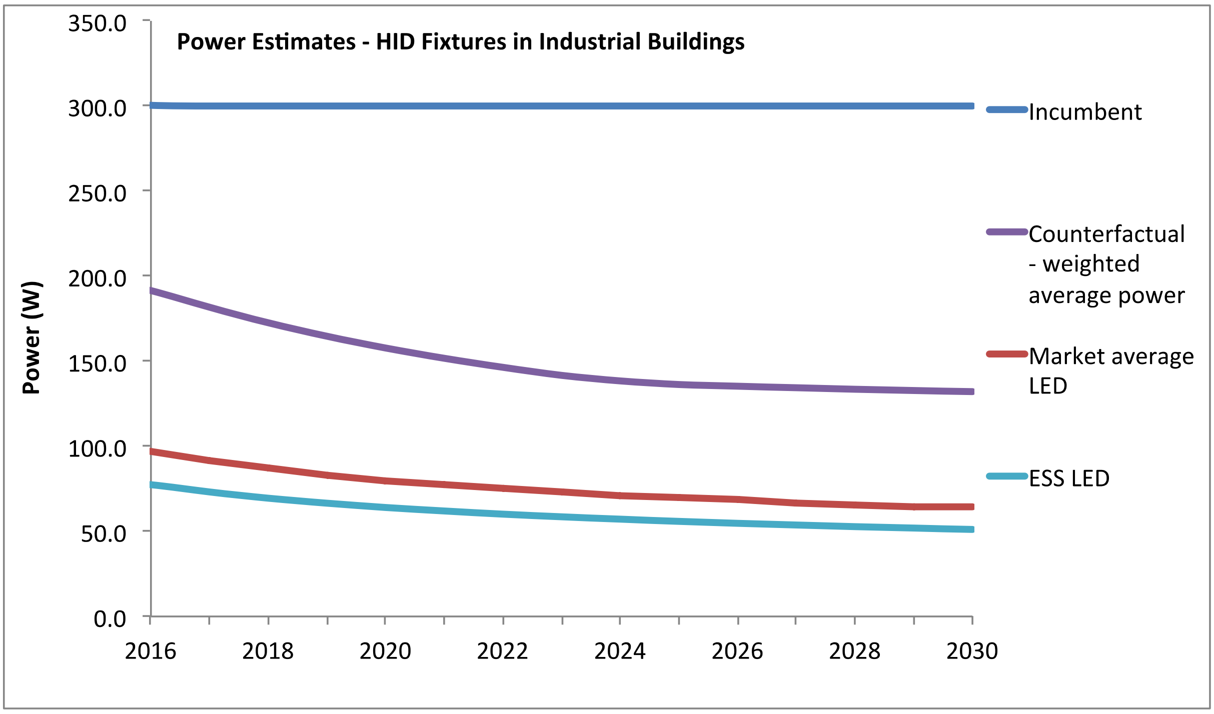

Power Estimates - Downlights in Office Buildings
Power (W)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED


Power Estimates - Downlights in Non-Office Commercial Buildings
Power (W)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED


Power Estimates - Fluorescent Fixtures in Office Buildings
Power (W)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED


Power Estimates - Fluorescent Fixtures in Non-Office Commercial Buildings
Power (W)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED


Power Estimates - Fluorescent Fixtures in Industrial Buildings
Power (W)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED


Power Estimates - HID Fixtures in Industrial Buildings
Power (W)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2016
2018
2020
2022
2024
2026
2028
2030
Incumbent
Counterfactual - weighted average power
Market average LED
ESS LED