POLICY BRIEF // 0252016

SEAD | SUPER-EFFICIENT EQUIPMENT AND APPLIANCE DEPLOYMENT INITIATIVE

Governments Working Together to Save Energy.

Assessing Computer Energy Use in Voluntary and Mandatory Measures

May 2016

SEAD Computer Working Group

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Tenvic Ltd.

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CLEAN ENERGY MINISTERIAL
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Acknowledgments

The members of the SEAD Computer Working Group consisted of Mike Rimmer (Department for Energy and Climate Change (DECC)), Jenny Corry Smith (CLASP), Jason Lee (Department of Industry), Richard Collins (Punch Consulting), Paolo Tosoratti (European Commission), Naoko Doi (The Institute of Energy Economics, Japan (IEEJ)), Tohru Shimizu (The Institute of Energy Economics, Japan (IEEJ)), Hiroki Kudo (The Institute of Energy Economics, Japan (IEEJ)), Sang Hak Lee (Korea Electronics Technology Institute (KETI)), Robert Meyers (U.S. Environmental Protection Agency (EPA)), Jeremy Dommu (U.S. Department of Energy (DoE)), Augustine Orumwense (Natural Resources Canada (NRCan)), Katherine Delves (Natural Resources Canada (NRCan)), Patrick Roy (Natural Resources Canada (NRCan)), Micheline Brown (Natural Resources Canada (NRCan)), Ai Xin (China National Institute of Standardization (CNIS)) and Jonathan Wood (Tenvic Ltd).

The Department for Energy and Climate Change (DECC) in the UK, provided the majority of funding for the research behind this project.

Abstract

The levels of energy efficiency found amongst computers offering the same levels of functionality can be highly divergent. With this factor in mind computers have been addressed by many environmental initiatives around the world ranging from voluntary eco-labels to mandatory regulations. It is shown that even the most successful and widely known of these initiatives have not been able to fully maximise the energy efficiency savings opportunities of computers due to the fast moving nature of the product group often increasing efficiencies quicker than initiatives can refresh specifications. Despite the fast moving nature of energy efficiency improvements in computers it is shown that significant savings opportunities are still available within the computer area. Some of these savings opportunities are described and advice on how they could be further exploited by environmental initiatives is given.

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Introduction

Previous work undertaken under the SEAD computer working groups highlighted the differences and harmonisation opportunities amongst environmental initiatives that focus on computers.
This report investigates which aspects of energy use need to be assessed in order to determine the levels of efficiency that can be set out in existing and future voluntary or mandatory measures. In providing this information, the energy efficiency of current products on the market is assessed to identify where energy efficiency gains can be achieved. This includes an assessment of the energy efficiency potentials in key components such as central processing units (CPUs), graphics processing units (GPUs) and motherboards. Background data has been sourced from multiple data sources, including the EU and US ENERGY STAR programmes. Comparisons of current product performances against requirements in the EU Ecodesign Regulation and the ENERGY STAR v6.1 specification are made.

Results

Figure 1 and Figure 2 shows the results of the comparison of current product performances in the EU ENERGY STAR database against the EU Ecodesign Regulation requirements. The results clearly indicate that computers, on average, are performing significantly better that the EU Ecodesign Regulation requirements thereby suggesting the need for the EU Ecodesign Regulation to be updated.

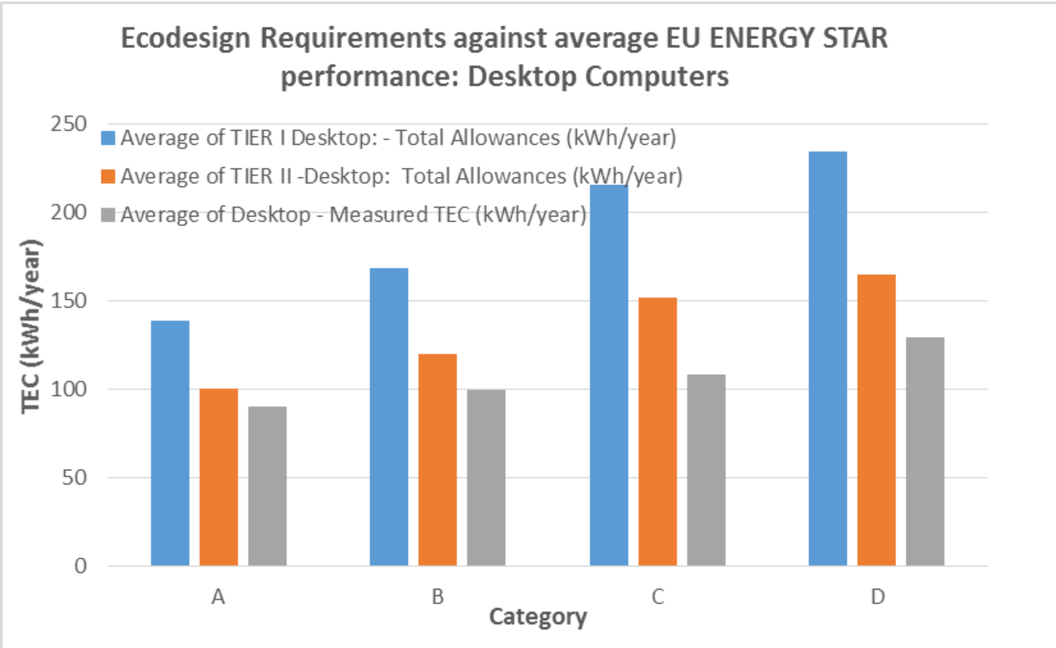

Figure 1 – Average TEC for Desktop Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

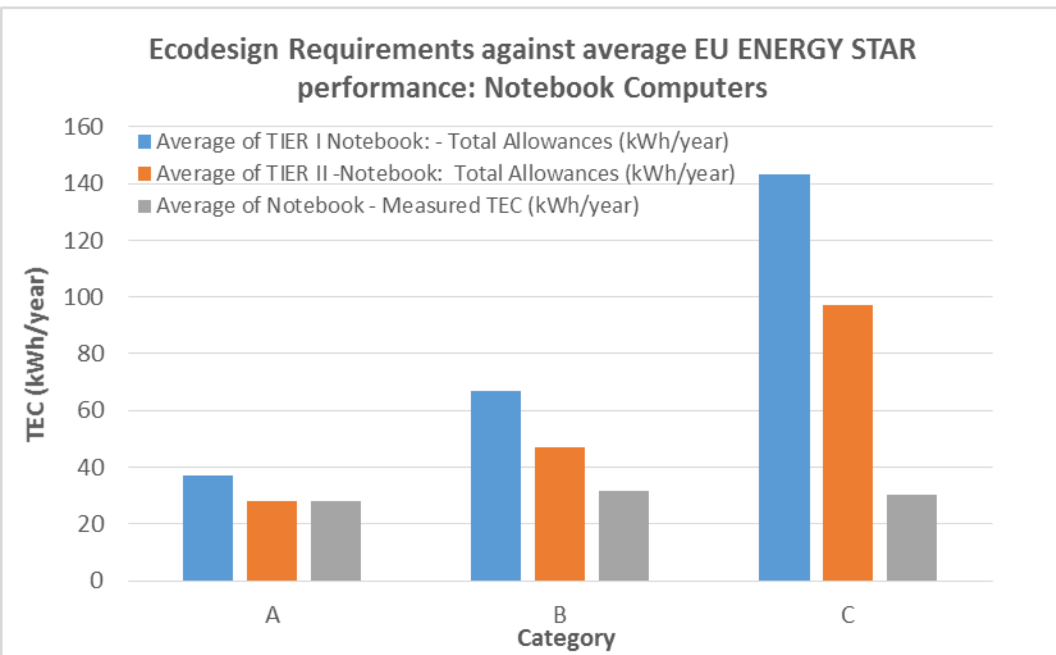

Figure 2 – Average TEC for Notebook Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

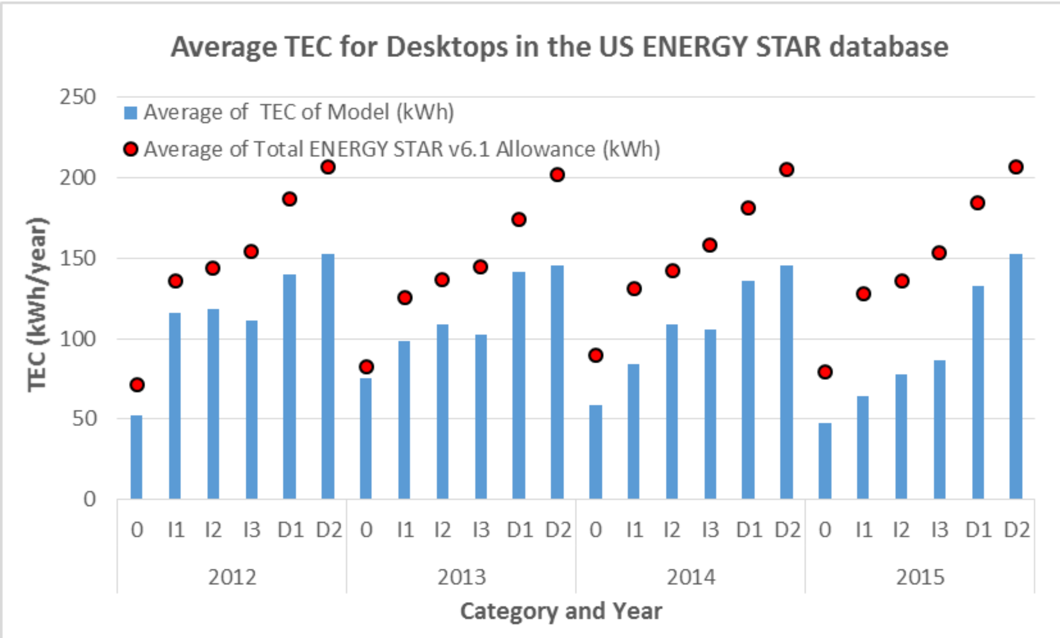

Figure 3 – Average TEC for Desktop Computers in the US ENERGY STAR database based on year first placed on the market against average ENERGY STAR v6.1 TEC allowance

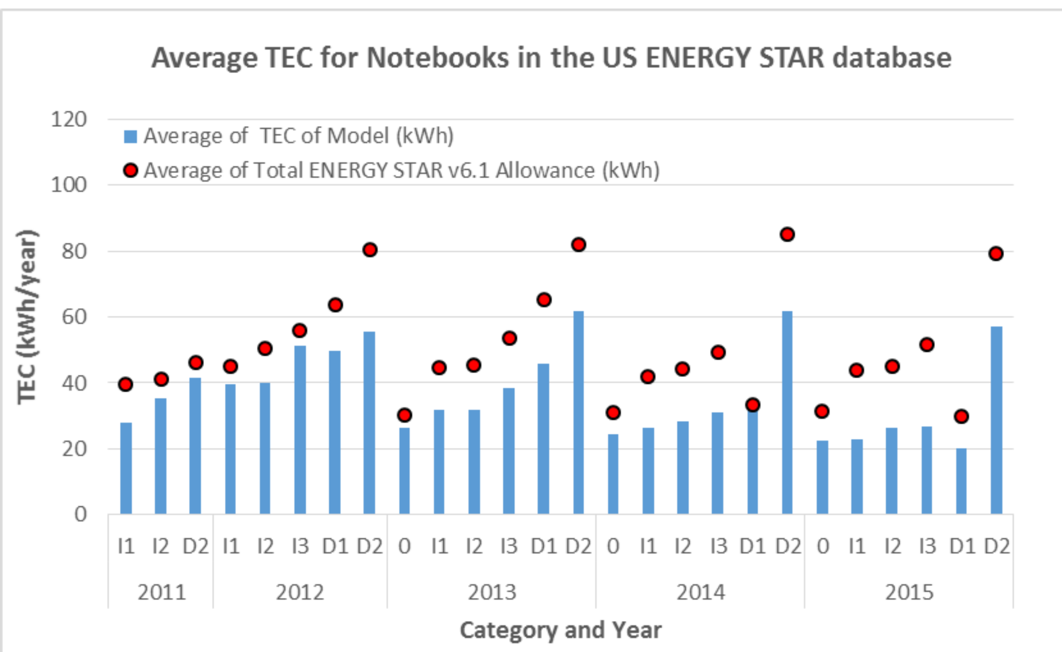

Figure 4 – Average TEC for Notebook Computers in the US ENERGY STAR database based on year first placed on the market against average ENERGY STAR v6.1 TEC allowance

Figure 3 and Figure 4 show the results of the comparison between the average performances of computers in the US ENERGY STAR v6.1 database with the ENERGY STAR v6.1 allowances. Again, the results clearly indicate that the average performance of products within the US ENERGY STAR v6.1 database is significantly below the ENERGY STAR v6.1 allowances suggesting that a refresh of the ENERGY STAR specification is warranted.

The results of the comparison between the EU Ecodesign Regulation requirements and ENERGY STAR v6.1 specifications against the current product performances suggested that additional analysis was necessary to understand why products were able to perform so far below the applicable energy efficiency levels of the two initiatives. To answer this question the energy efficiency levels of some of the most important components inside computer systems were reviewed.

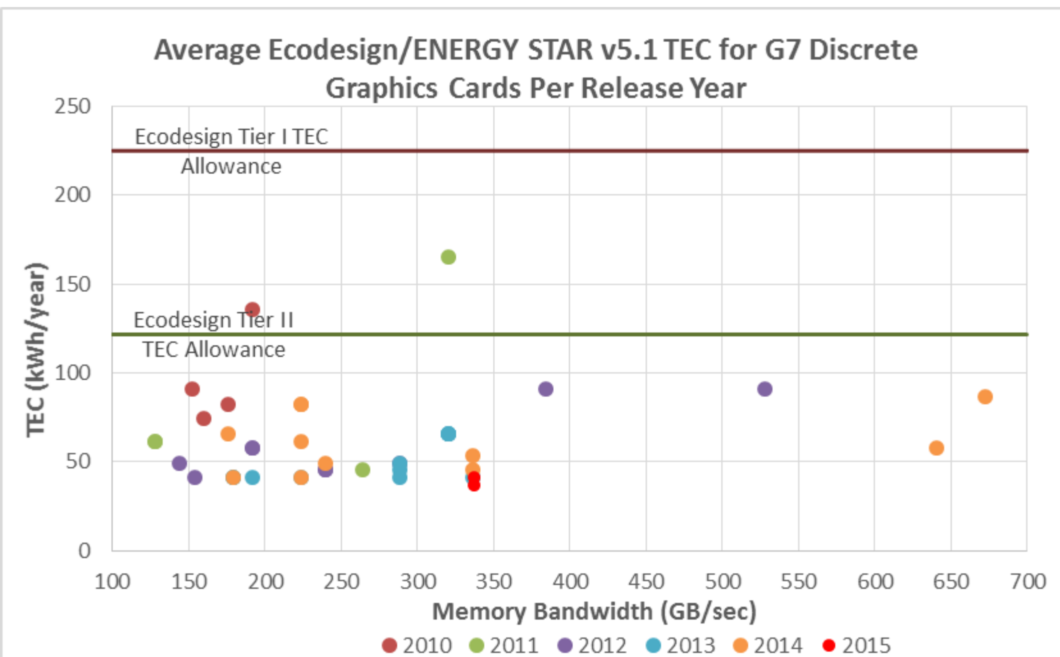

Figure 5 – Average TEC of High End Discrete GPUs per Year of Release Compared to the EU Ecodesign Allowances

Figure 5 and Figure 6 compare the EU Ecodesign Regulation and ENERGY STAR v6.1 allowances for high specification discreet graphic cards (dGfX's) against current product performances. Whilst it is recognised that the high specification dGfx's constitute a small proportion of the dGFx market the analysis shows that the allowances in both the EU Ecodesign Regulation and ENERGY STAR v6.1 are far too generous for these types of components.

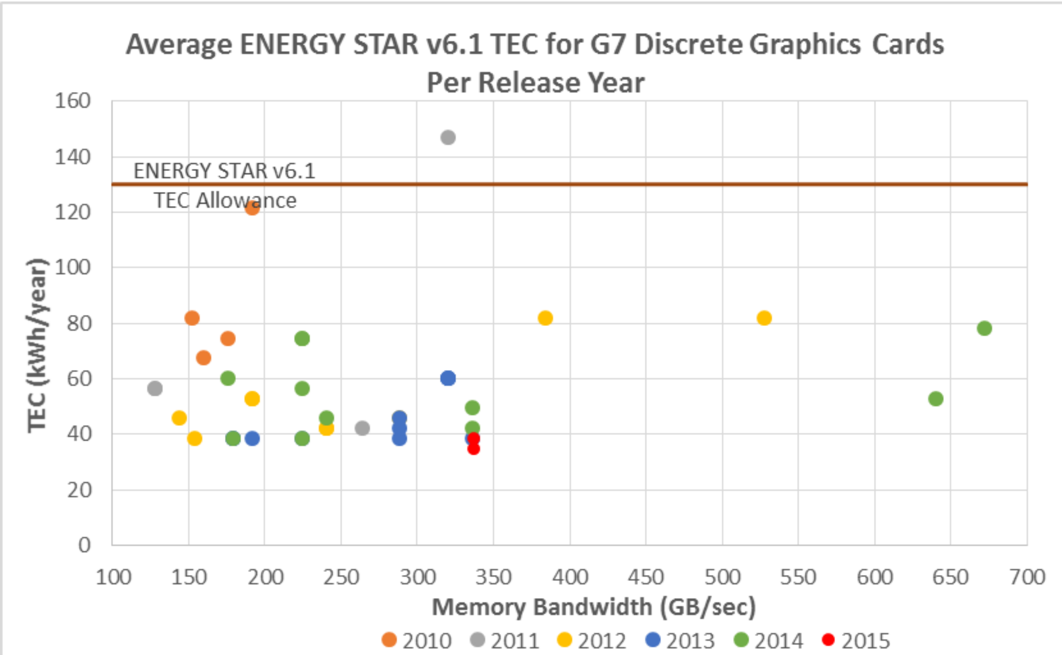

Figure 6 – Average ENERGY STAR v6.1 based TEC of High End Discrete GPUs per Year of Release Compared to the ENERGY STAR v6.1 allowances

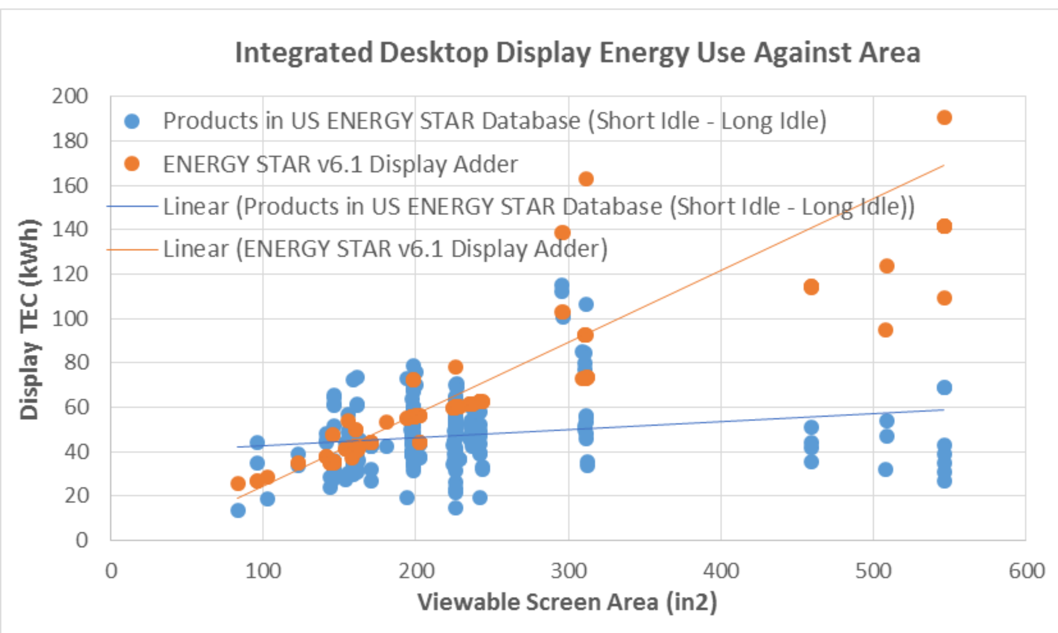

Figure 7 – Estimated ENERGY STAR v6.1 TEC of Displays and Allowances in Integrated Desktop Computers Listed in the US ENERGY STAR database (May 2015) against Viewable Screen Area

The results of an investigation into the ENERGY STAR v6.1 allowances for integrated displays, shown in Figure 7, demonstrate that the integrated displays in many products currently on the market are significantly more energy efficient that the requirements laid down under ENERGY STAR.

Additional energy efficiency improvements in computers could be made through enhancing the energy efficiency requirements of internal PSUs, storage devices and RAM memory. In addition, extra energy savings could be achieved by initiatives paying closer attention to the energy efficiency of motherboards and by including enhanced power management requirements on computers.

Conclusions

The above results show that there is still a large opportunity for increased energy efficiency in computers currently on the market. The results of the investigation do not suggest any failings on behalf of the EU Ecodesign Regulation or the ENERGY STAR v6.1 specification, rather that the energy efficiency of current products on the market has improved significantly since the requirements behind both initiatives were developed. Given the divergence between the allowances in both the EU Ecodesign Regulation and the ENERGY STAR v6.1 with current performances of products on the market it is suggested that both initiatives need to be refreshed. It is also suggested that both initiatives could take the bold step of breaking from the traditional of setting separate specifications for stationary and mobile computers and instead set specification based on computational performance regardless of form factor.

1. Introduction

There are a number of initiatives around the world that attempt to increase the energy efficiency of domestic and office computers either through voluntary or mandatory measures. Of particular importance are the ENERGY STAR voluntary initiative and the EU Ecodesign Regulation on computers as these two cover the world's largest markets.

This document investigates the current performances of domestic and office desktop computers and highlights areas for further consideration when refreshing the requirements behind the two main energy efficiency initiatives.

2. Current Performances

In order to provide context on how desktop and notebook computers currently on the market are performing it is necessary to track performance over time. A review of the EU ENERGY STAR database was conducted to understand how the energy efficiency performance of computers has changed over time. The analysis involved merging snapshots of the EU ENERGY STAR database from different periods in time. The delay in adoption of the ENERGY STAR v6.1 specification within the EU allowed for comparative analysis over a much greater period of time than normal.

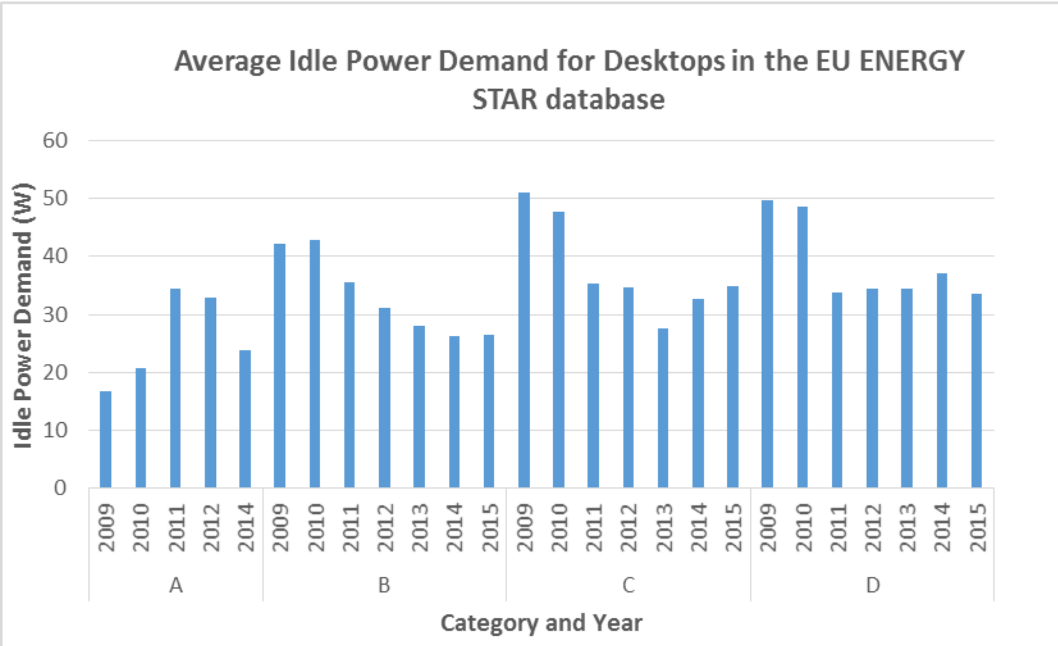

Figure 1 – Average ENERGY STAR v5.1 based Idle Mode Power Demand of desktop computers in the EU ENERGY STAR database

Figure 1 shows the results of the analysis on the EU ENERGY STAR database for desktop computers. It is clear that energy use of category B, C and D ENERGY STAR qualified desktop computers has fallen since 2009. However, it is also clear that average energy use of category A desktop computers has increased on average since 2009. Energy use of category C ENERGY STAR qualified desktop computers also appears to have increased in 2014 and 2015 compared to the 2013 lowest levels. Similarly, average energy use of category D products seems to have fallen significantly since 2009 and 2010 but improvements have not continued into 2015. It should be noted that as the data was collected in June 2015 then the data does not encompass the full range of products that would be registered in 2015.

Figure 2 shows the results of the same analysis but for integrated desktop computers. There were significant gaps in the data for integrated desktop computers and so analysis is not as complete as for the traditional desktop computer form factor. However, it is clear that the average energy use of category B integrated desktop computers qualified under the EU ENERGY STAR fell from 2009 to 2013 but then rose in 2014 only to fall back slightly in 2015. Average energy use of all other categories of Integrated computers have fallen since 2009 but a similar rise in average energy use is seen in category D products which have 2014 and 2015 average energy values higher than in the period 2011 to 2013.

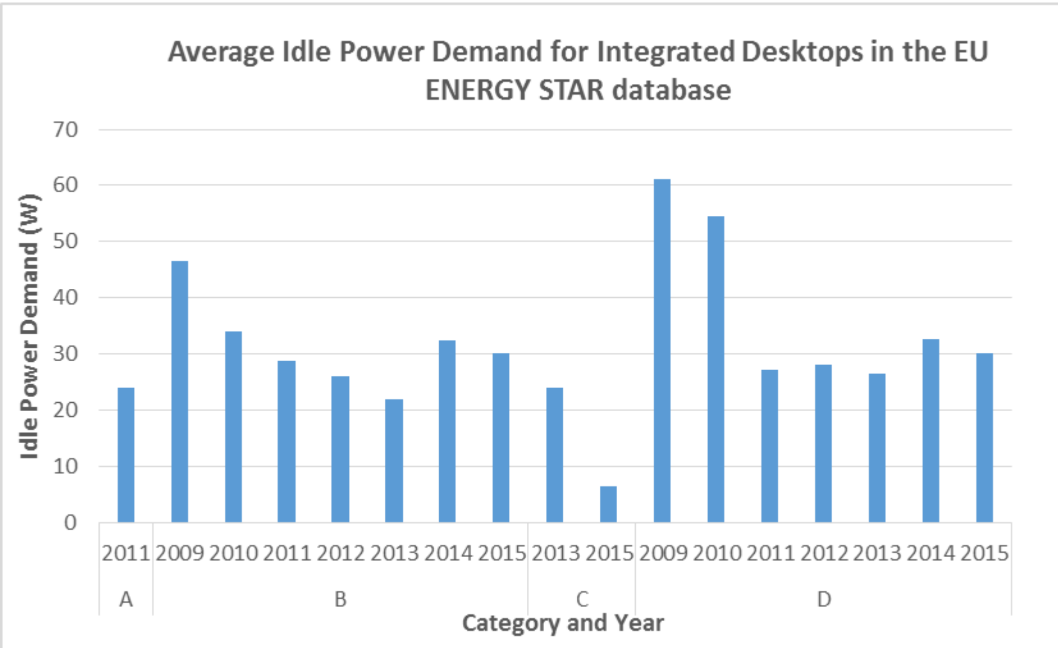

Figure 2 – Average ENERGY STAR v5.1 based Idle Mode Power Demand of integrated desktop computers in the EU ENERGY STAR database

Figure 3 illustrates the average energy use of notebook computers registered as ENERGY STAR over the period 2009 to 2015. The graph clearly shows that the average energy use of category A notebook computers has fallen since 2009. The same is not true for category B products which show an upturn in average energy for 2014 and 2015. Category C average energy use has increased in 2015 relative to 2014. Again it should be noted that as the data was collected in June 2015 the 2015 do not represent a full year's worth of product data which could impact results.

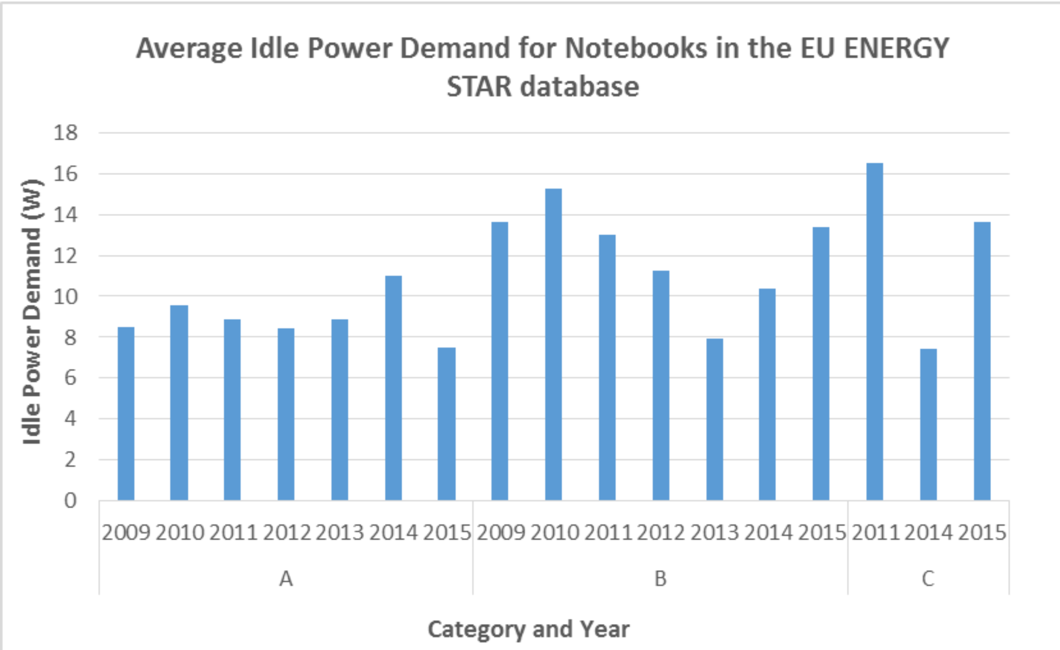

Figure 3 – Average ENERGY STAR v5.1 based Idle Mode Power Demand of notebook computers in the EU ENERGY STAR database

Energy use of computers is often cited to be directly correlated to computational performance. Whilst the ENERGY STAR v5.0/5.2 categories provide some grouping of performance there can still be considerable differences in performances even within a category. The ENERGY STAR v6.1 specification uses CPU performance as the primary indicator (along with GPU performance) of computer performance. CPU performance is calculated as the number of CPU cores multiplied by the CPU clock speed (GHz). To try to understand whether the average energy usage results were impacted by improvements in performance it was necessary to investigate changes in levels of performance.

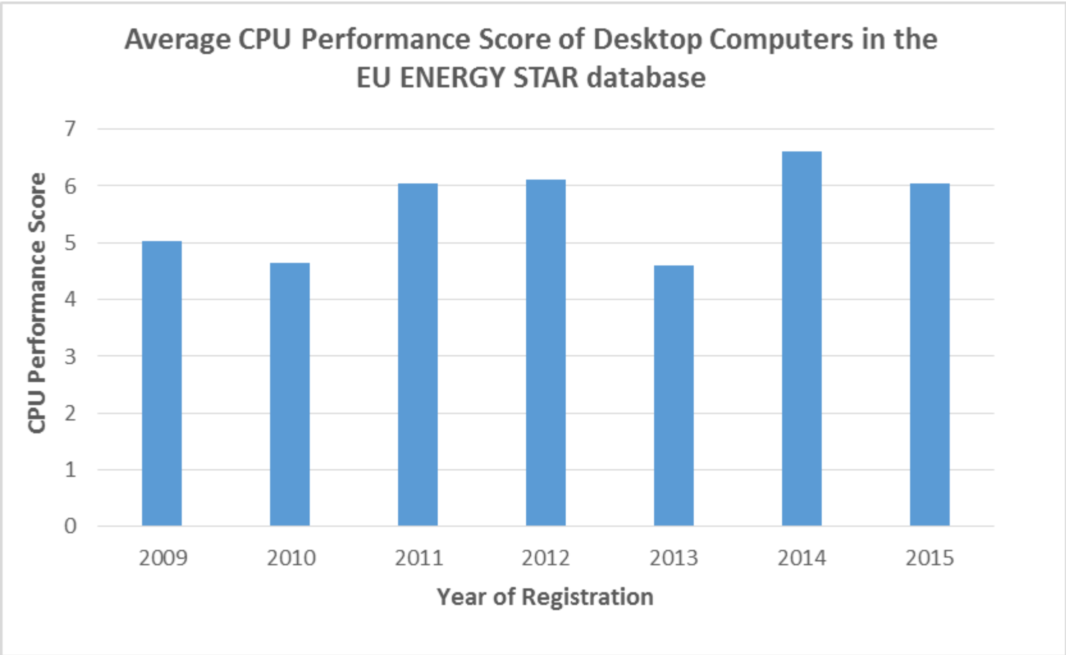

Figure 4 – Average CPU Performance Score for Desktop Computers in the EU ENERGY STAR database over time

Figure 4, Figure 5 and Figure 6 show the changes in CPU performance score for desktop, integrated desktops and notebook computers respectively that were registered under the EU ENERGY STAR scheme between 2009 and 2015. CPU performance for desktop PCs has increased from 2009, with a slight reduction in 2013. The CPU performance figures for 2015 are slightly below the levels for 2011 to 2014 but this could be somewhat explained by the smaller number of products being registered in 2015. Interestingly, CPU performance of integrated desktop computers has been decreasing since 2009. This suggests that on average integrated desktop computers are being shipped with lower performance CPUs.

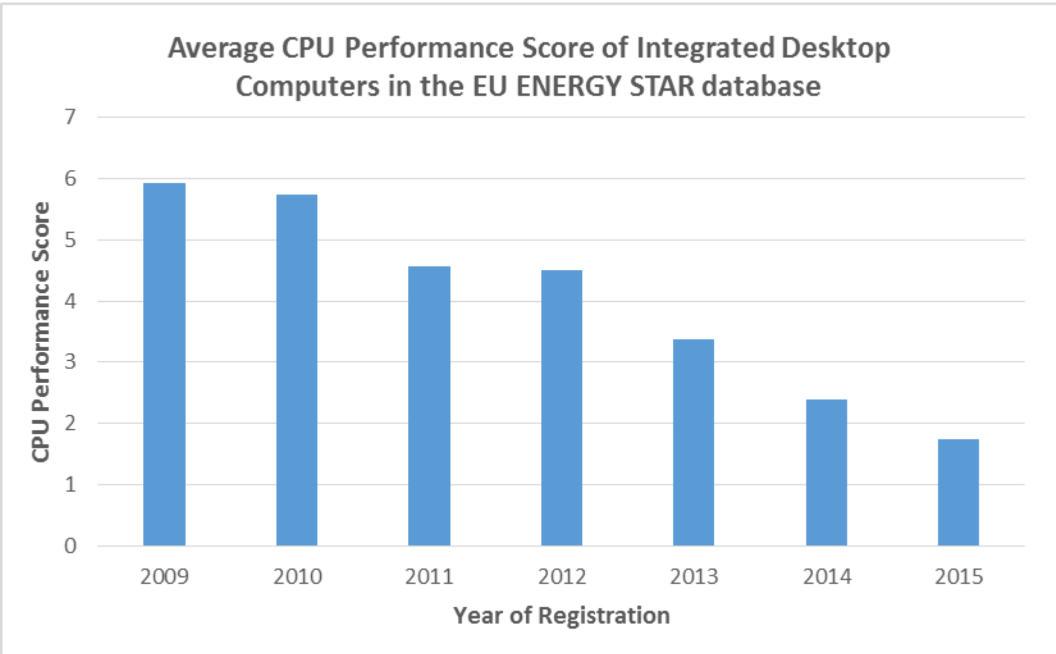

Figure 5 – Average CPU Performance Score for Integrated Desktop Computers in the EU ENERGY STAR database over time

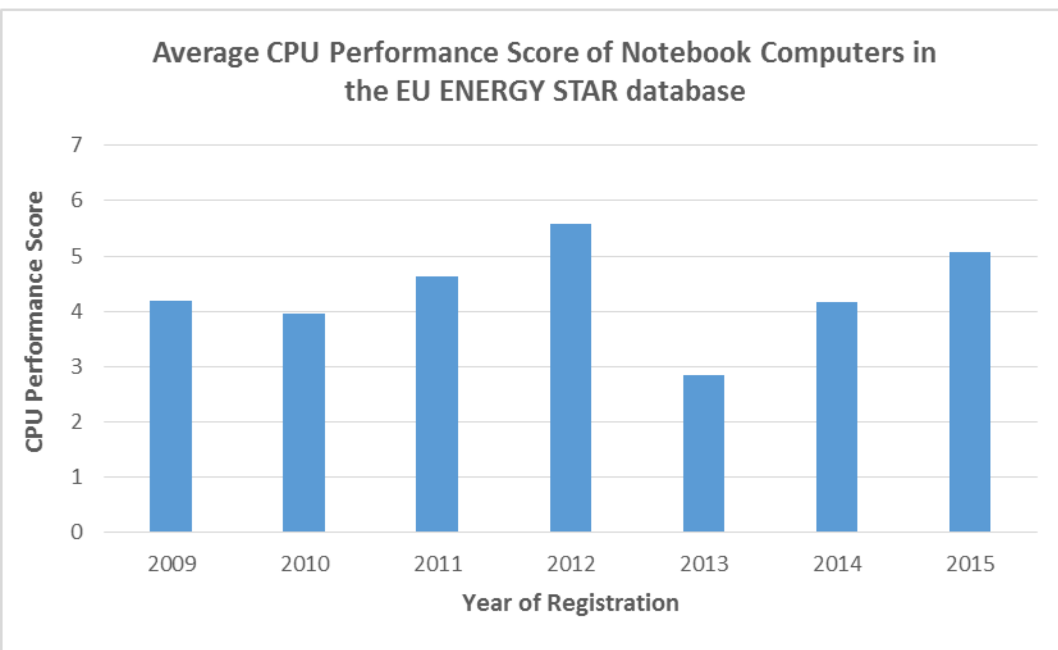

Figure 6 – Average CPU Performance Score for Notebook Computers in the EU ENERGY STAR database over time

Annual average CPU performance amongst EU ENERGY STAR qualified notebook computers appears to have been more mixed with a general increase seen to 2012 followed by a decrease in 2013 and then a further increase into 2014 and 2015. The non-constant growth in average CPU performances seen in desktop, integrated desktop and notebook computers could be due to a number of factors including:

- The ENERGY STAR v6.1 CPU performance metric not be adequately reflecting CPU performances resulting in results which suggest that CPU performance is not increasing over time. That is, CPU performance can be impacted by other factors such as how much work can be done by the CPU in each clock cycle. CPU work per clock cycle is measured in instructions per cycle (IPC). The CPU cache memory performance also has a large impact on overall CPU performance. A CPU cache is a cache used by the central processing unit (CPU) of a computer to reduce the average time needed to access data from the main memory. Fast access to memory is therefore an important component of CPU performance efficiency. It is suggested that in future energy efficiency initiatives should take a closer look at how other factors other than just CPU frequency and number of cores affect overall CPU performance to better categorize products based on performance.
- CPU performance is likely to be highest in category D desktops (and integrated desktops) and category C notebooks whilst lowest in category A computers. Different distributions of products categories throughout the years studied could impact the overall average CPU performance values.
- Changes in the way in which products are designed could also have had a big impact on the average CPU performances. For example, integrated desktop computers now typically include components primarily designed for mobile products whereas in 2009 that may have contained components designed for desktop computers.

In order to investigate the correlation between CPU performance and energy use further Category D and category B desktops were isolated for further analysis. These categories were chosen as category D for desktop computers reflects the category with the highest performance computers. Whilst category B products were assessed because they represent the most desktop computers registered under ENERGY STAR. The results of the analysis for desktop computers can be seen in Figure 7. The results show that there is a general increase in idle mode as CPU performance increases. However, the analysis also shows that for products registered with the EU ENERGY STAR initiative in 2011 there was an inverse correlation between idle mode power and CPU performance. It is likely that this inverse relationship is due to the fact that the highest CPU performance found in an EU ENERGY STAR qualified product in 2011 was 14.4 and that most performances were clustered between 10 and 13.6. It is suggested that this is not a big enough spread of performances to gain a full understanding of the correlation between idle mode power demand and CPU performance. It is also clear that the highest CPU performances were seen amongst products registered in 2013, 2014 and 2015. What is less clear from the results is why there was a stronger correlation between CPU performance and idle power demand in 2014 than in 2013. This seems to suggest that CPUs were more efficient in 2013 than in 2014. It is likely that other product technical features such as discrete GPUs (which may or may not be present in category D desktops) are impacting these results meaning that the results do not accurately reflect changes in the relationship between CPU performance and idle mode power.

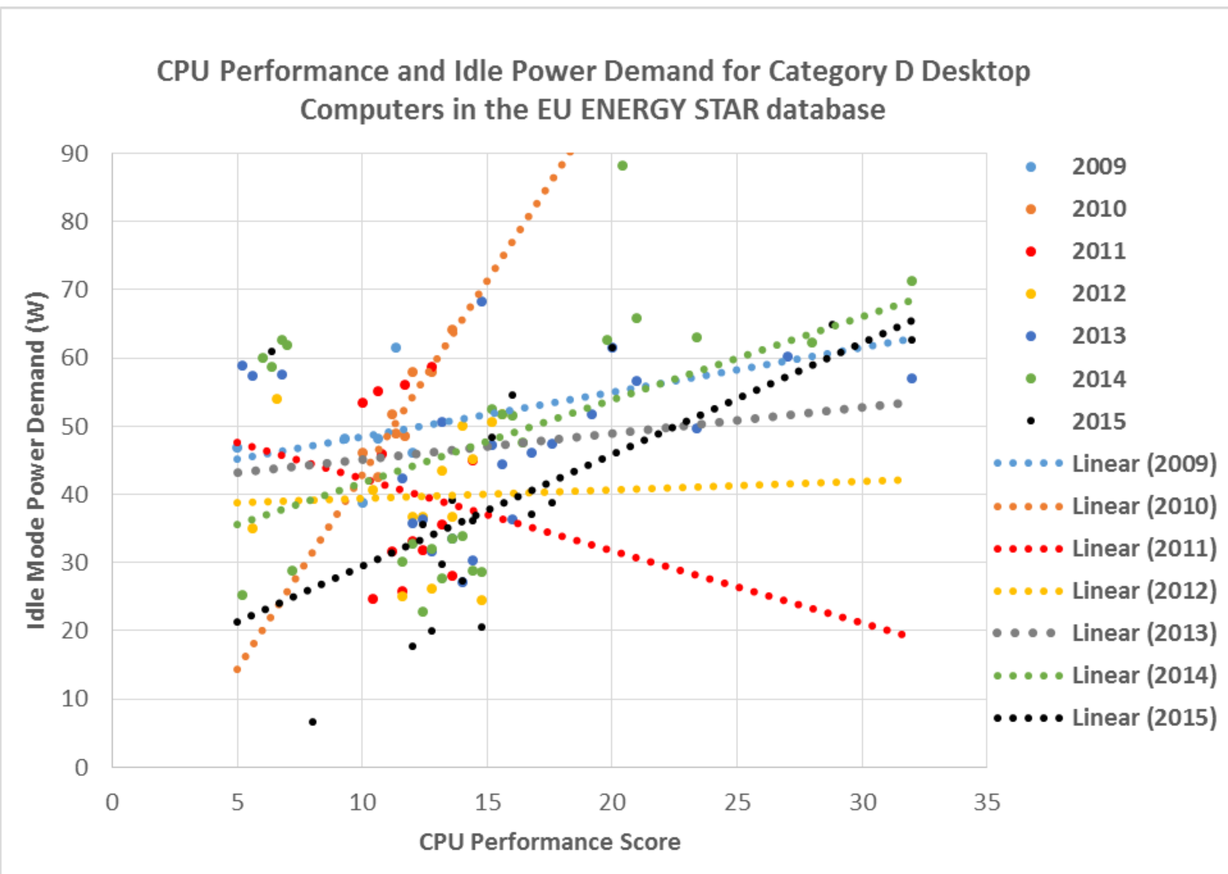

Figure 7 – Average Idle Mode Power Demand for Category D Desktop Computers in the EU ENERGY STAR database against CPU Performance

Figure 8 shows the same analysis of the relationship between CPU performance and idle power but for category B desktop products. The results clearly indicate that there is a strong correlation between increasing CPU performance and increasing idle mode power. This relationship is most evident for the products registered in the EU ENERGY STAR database during 2014. What is also clear from the graph is that the average energy efficiency of CPUs appears to have been improving constantly since 2011 as witnessed by the linear trend lines becoming lower over time.

It is recognised that the above analysis only covers products that are included within the ENERGY STAR database and as such skews the analysis towards the more efficient products on the market. However, CLASP recently conducted research on the whole Chinese market where a Government database is used to support a Regulation on computer energy efficiency[1]. The CLASP research showed that a large percentage (i.e. almost a half of desktops and more than half of notebooks) of products on the Chinese market would likely meet the ENERGY STAR v6.1 specification limits. Given that CLASP had downloaded the Chinese database in late 2013 it is safe to assume that Chinese whole market ENERGY STAR v6.1 coverage rates in 2015 would be significantly higher than the report suggested. As such, results at the market level are likely to be similar to those found in the EU ENERGY STAR database.

1 CLASP, 2014, "Energy Consumption of Computers in the Chinese Market", available from http://clasp.ngo/en/Resources/Resources/PublicationLibrary/2014/Data-on-China-Computer-Market-Reveals.aspx

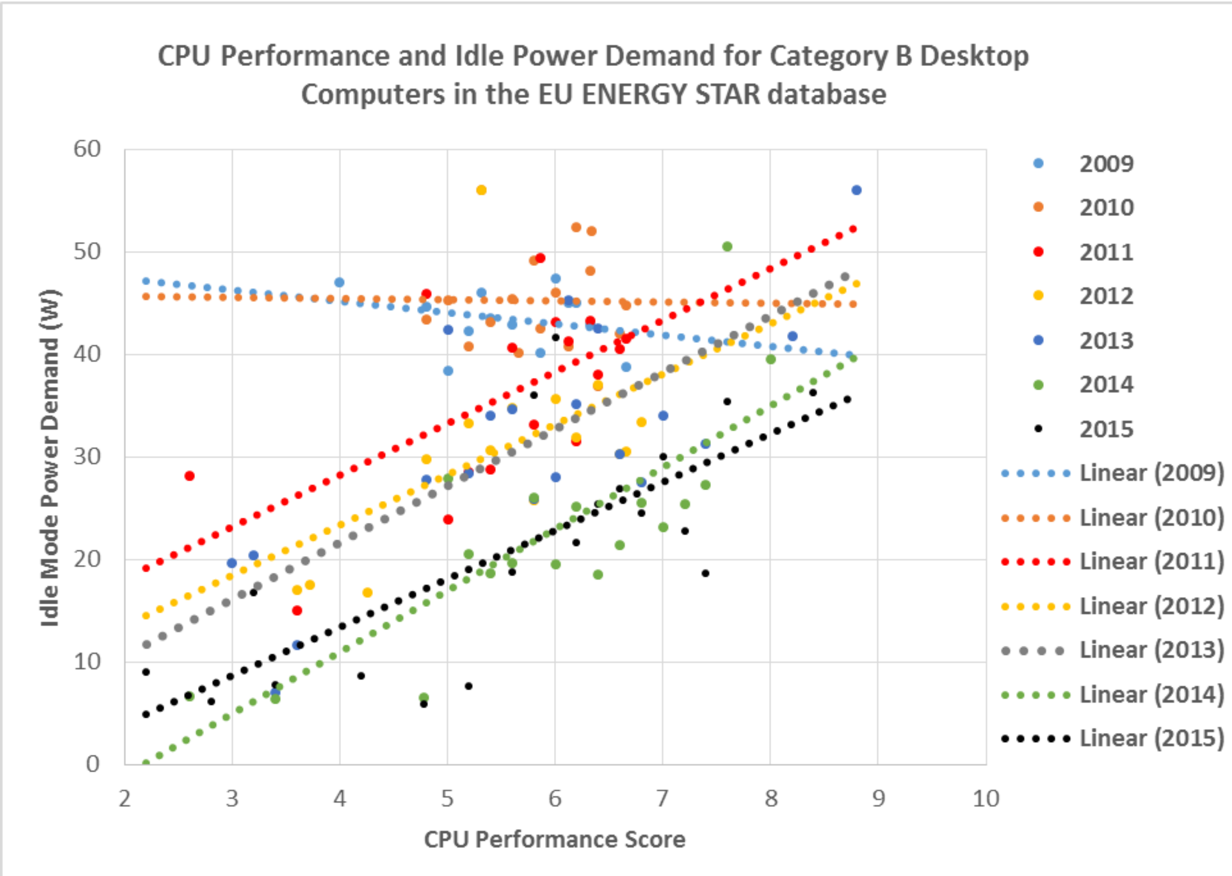

Figure 8 – Average Idle Mode Power Demand for Category B Desktop Computers in the EU ENERGY STAR database

3. Improvement Opportunity

Having investigated the current levels of performance for products in the EU ENERGY STAR database in the previous section of the report, this section investigates the potential for further improvements in the energy efficiency of desktops, integrated desktops and notebook computers. Analysis of future energy efficiency opportunities is conducted at the whole product level for desktop, integrated desktop and notebook computers followed by more in-depth analysis of efficiency possibilities in individual product components. In conducting this analysis, the report provides evidence for existing and future energy efficiency initiatives to develop ambitious requirements on these product types.

Figure 9 to Figure 12 compare the average TEC values of computers registered in the EU ENERGY STAR database during 2014 and 2015 against the TEC requirements laid down in the EU Ecodesign Regulation on computers[2]. The EU Ecodesign Regulation on computers lays down mandatory TEC requirements on desktop, integrated desktop and notebook computers placed onto the EU market. The first tier of EU Ecodesign requirements came into force on the 1st July 2014 with the second tier due to come into force on the 1st January 2016.

Figure 9 illustrates that there is a considerable difference between the average EU Ecodesign Tier I Requirements and the average measured TEC for desktop computers in the EU ENERGY STAR database. This is especially evident for category C and category D products for which the average measured TEC in the EU ENERGY STAR database is around 50% less that the tier I EU Ecodesign requirements. Whilst the delta between the Tier II EU Ecodesign Requirements and the average TEC of EU ENERGY STAR Products is much smaller it illustrates that already during mid-2015 that the average performance of EU ENERGY STAR registered desktops is well below the forthcoming January 2016 Tier II requirements. This suggests

2 Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers, available from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32013R0617

that the Tier II EU Ecodesign Requirements may have a limited impact on desktop computers already on the market.

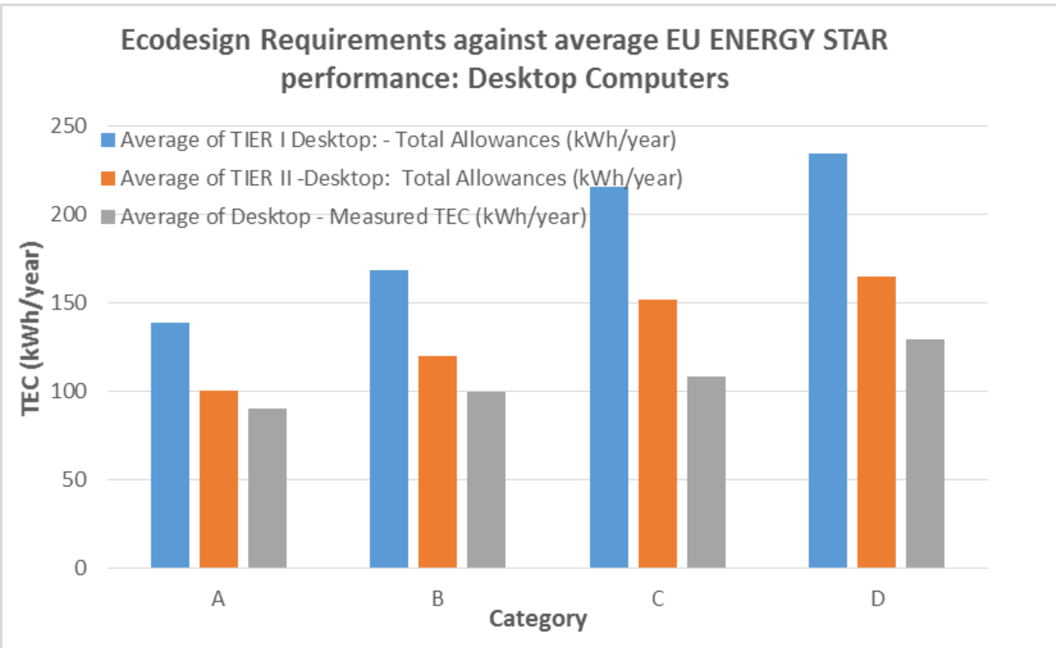

Figure 9 – Average TEC for Desktop Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

Figure 10 includes the same comparison between average measured TEC for EU ENERGY STAR notebooks and the average Tier I and Tier II EU Ecodesign Requirements for each product category. The graph shows that the delta between the average measured TEC and the Tier II requirements for category A notebook computers is extremely small. This suggests that the Tier II EU Ecodesign requirement is probably set at approximately the correct level of ambition (given that not all ENERGY STAR qualified products will be able to meet the Tier II requirements). However, it is clear that the Tier I and Tier II EU Ecodesign requirements are significantly too lenient for category B and, especially, category C notebook computers.

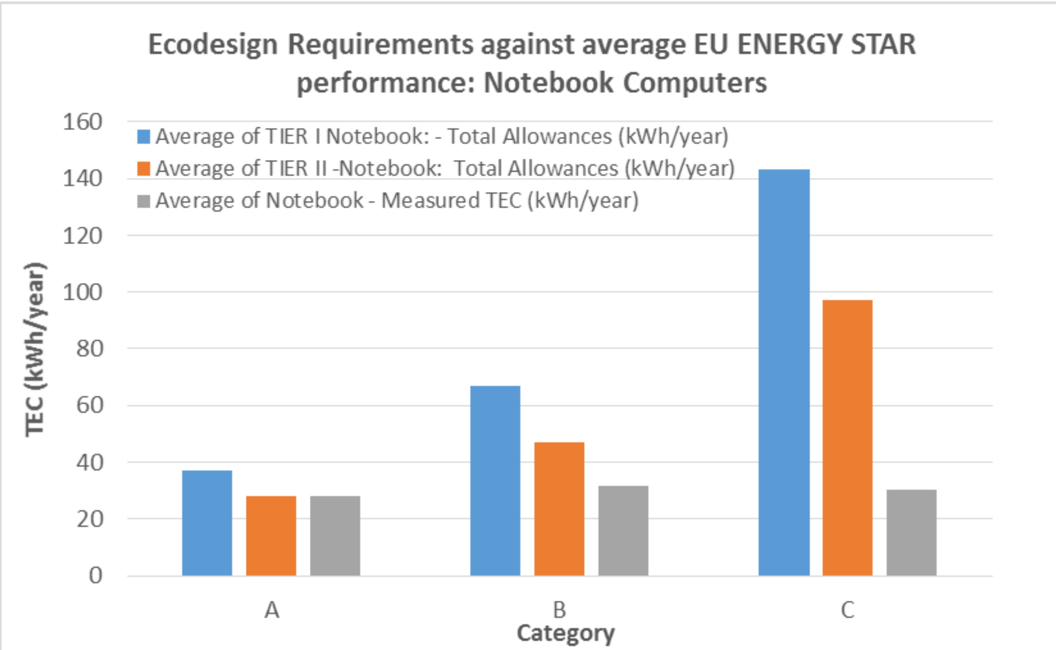

Figure 10 – Average TEC for Notebook Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

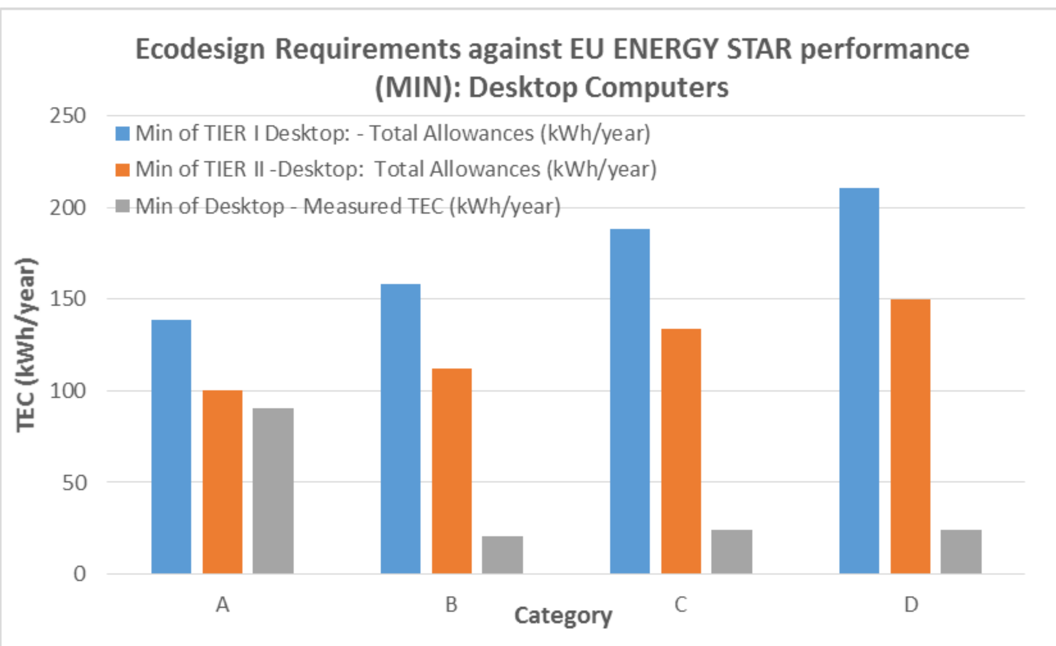

Figure 11– Minimum TEC for Desktop Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

Figure 11 shows the results of an extended analysis into the current best performances of EU ENERGY STAR registered desktop computers against the lowest EU Ecodesign allowances (i.e. base allowance plus the minimum of the extra allowances used in that product group by ENERGY STAR registered products). It is clear from the analysis that in most product categories, with the exception of category A, there are products on the market can meet the EU Ecodesign requirements by a very large margin. This suggests that when energy efficiency initiatives either refresh or develop requirements on desktop computers they should carefully assess what is currently technically possible in terms of energy efficiency.

Figure 12 shows the results of the same analysis on minimum EU Ecodesign requirements and best performances within the EU ENERGY STAR database but for notebook computers. Again, it is clear that there are notebook computers on the market, within each category, that can perform significantly below both the Tier I and Tier II EU Ecodesign requirements. As with the desktop computers, any energy efficiency initiatives should pay close attention to how products which offer similar levels of performance can achieve significantly better on energy efficiency attributes.

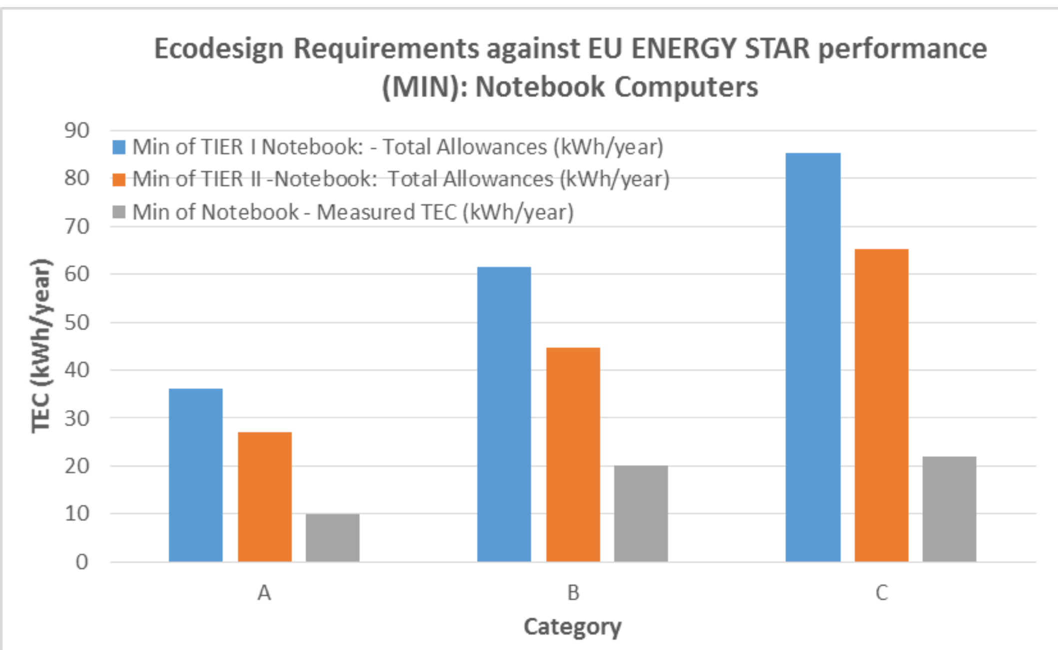

Figure 12 – Minimum TEC for Notebook Computers in the EU ENERGY STAR database over time compared to the EU Ecodesign Requirements

It should be pointed out that future energy efficiency initiatives are more likely to use the ENERGY STAR v6.1 test procedure rather than the older ENERGY STAR v5.0/5.2 test procedure that it used to support the EU Ecodesign Regulation on computers. As such, analysis has also been conducted on the US ENERGY

STAR database to see how products are performing against the ENERGY STAR v6.1 specification for computers. This specification was implemented in the US on the 10th September 2014.[3,4]

Figure 13 shows the average TEC for each category of desktop computer registered under the US ENERGY STAR programme per year that the product was first placed on the market. The graph shows that the amount of energy used, on average, by products in most categories has reduced over time. The exemption are the D1 and D2 categories for which energy use appears not to have decreased significantly over time. Much of this is likely due to the fact that these are higher specification products where average functionality may have also increased over time. However, it is clear that products are on average performing well below the ENERGY STAR v6.1 specification thresholds. This suggests that future energy efficiency requirements on desktop products could likely be significantly more stringent without significantly reducing the number of products on the market.

Figure 14 shows the results of the same average analysis but for integrated desktop computers. Whilst the deltas between the average ENERGY STAR TEC allowance and the average measured TEC for products in the US ENERGY STAR database mostly appear smaller than for desktops much of this is due to scaling issues in the graph resulting from the high ENERGY STAR allowance for D2 products. This high allowance is a result of high GPU allowances plus high allowances for the integrated display. For most products, apart from the category 0 products, there is still a large delta between the average ENERGY STAR allowance and the average measured TEC. This confirms the early assumption that more stringent energy efficiency criteria could be developed for integrated desktop computers whilst still allowing a significant number of products to pass.

3 US EPA and DoE, ENERGY STAR® Program Requirements for Computers, available from http://www.energystar.gov/products/certified-products/detail/7629/partners

4 The ENERGY STAR v6.0 specification went into effect on the 2nd June 2014 in the US. The scope of the v6.0 specification was increased to cover Slates/Tablets, Portable All-In-One Computers and Two-In-One Notebooks resulting in the designation of the v6.1 specification.

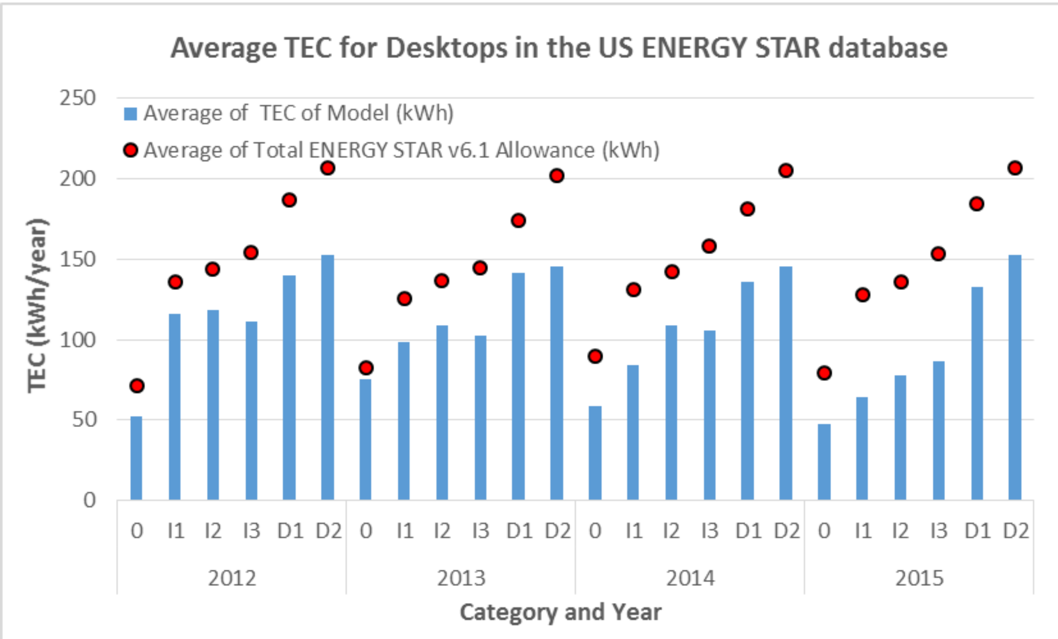

Figure 13 – Average TEC for Desktop Computers in the US ENERGY STAR database based on year first placed on the market against average ENERGY STAR v6.1 TEC allowance

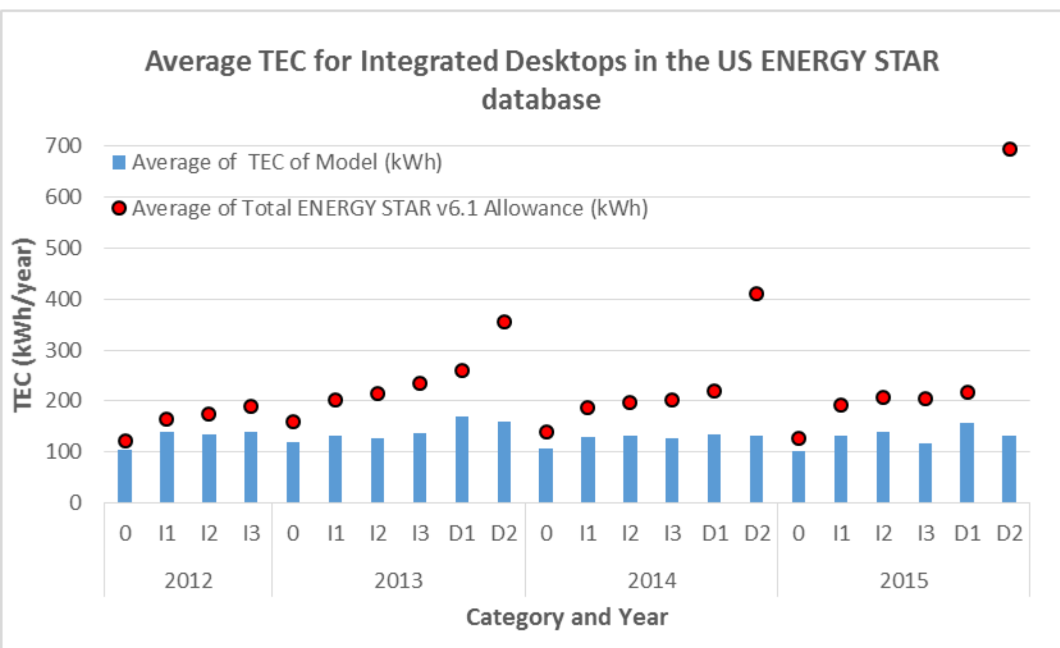

Figure 14 – Average TEC for Integrated Desktop Computers in the US ENERGY STAR database based on year first placed on the market against average ENERGY STAR v6.1 TEC allowance

Figure 15 shows the deltas between the average ENERGY STAR v6.1 TEC allowance and average measured TEC for products registered to the US ENERGY STAR database according to the date which they were first placed on the market. The graph clearly shows that the average delta has increased over time meaning that the average amount of energy used per notebook computer has been reducing. Further analysis should be conducted to identify why the delta for category 0 and D1 products is significantly smaller on average than for other types of notebook computer.

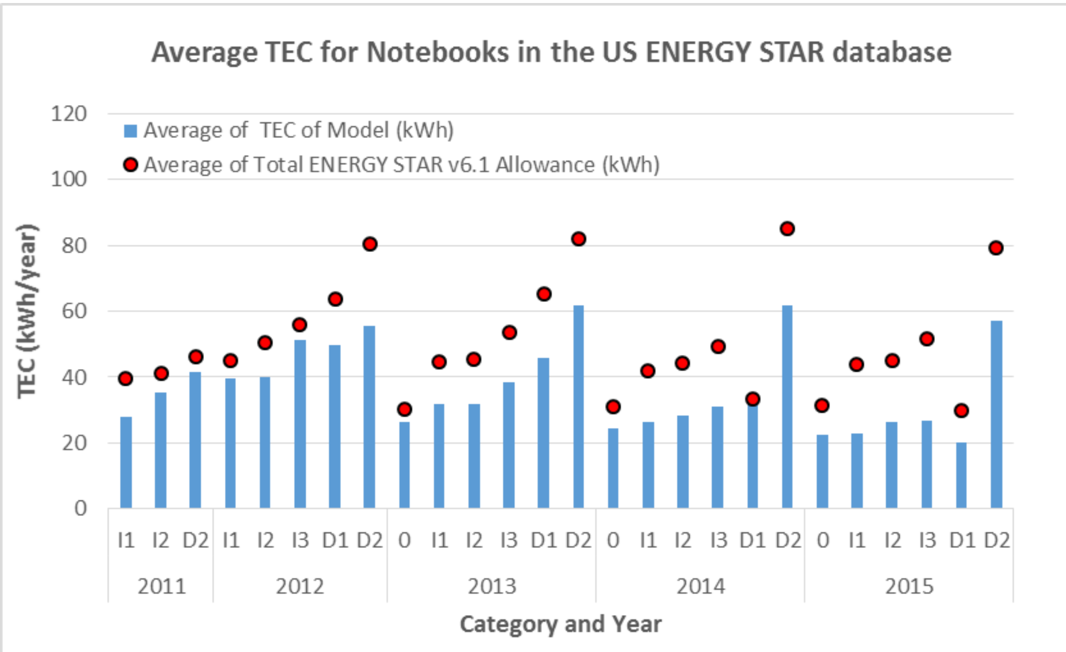

Figure 15 – Average TEC for Notebook Computers in the US ENERGY STAR database based on year first placed on the market against average ENERGY STAR v6.1 TEC allowance

The graphs above gave a good indication of the average deltas between the ENERGY STAR v6.1 specification limits and the measured TEC for products registered in the US ENERGY STAR database. The analysis therefore provided a good indication of how products are performing on average. To understand what is technically feasible in terms of energy efficiency performance within each ENERGY STAR v6.1 category it is necessary to look at the minimum reported TEC within each category. Figure 16 shows how the minimum reported TEC (i.e. the minimum amount of energy used by a registered product) compares against the maximum ENERGY STAR v6.1 specification allowance in that same category. Whilst the large deltas for the D1 and D2 categories can be partly explained by the large differences in GPU allowances (i.e.

GPUs can be allocated between 30 and 136 kWh/.year depending on their G1 to G7 performance rating) the deltas for the other product categories show that there are products on the market that can perform well below the ENERGY STAR v6.1 allowances.

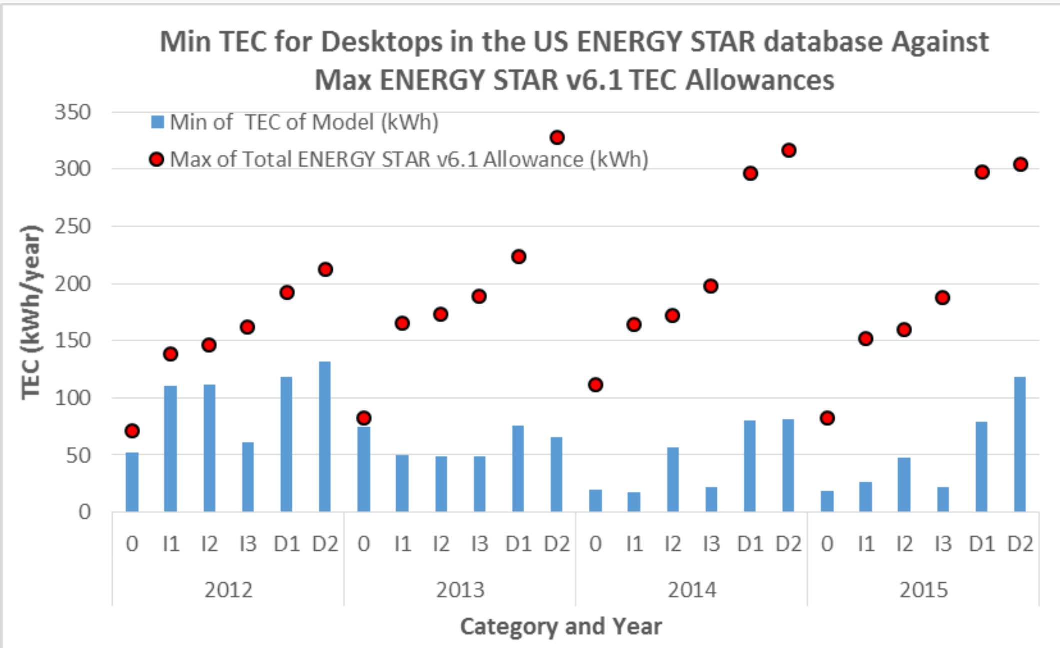

Figure 16 – Minimum TEC found for Desktop Computers in the US ENERGY STAR database based on year first placed on the market against the maximum ENERGY STAR v6.1 TEC allowance found

Figure 17 demonstrates the deltas between the minimum measured TEC for ENERGY STAR registered integrated desktop computers and the maximum ENERGY STAR v6.1 allowance per category. Again it is clear that there are very large differences between how products can perform in terms of energy efficiency and how much energy they are allowed to consume under the ENERGY STAR v6.1 specification. As an example of the extent of this delta, the most efficient I2 product sold in 2014 used eight times less energy than was allowed for that category under ENERGY STAR. Much of this large delta is likely due to over generous allowances for the integrated display and, for the D1 and D2 products, over generous allowances for any discrete GPUs.

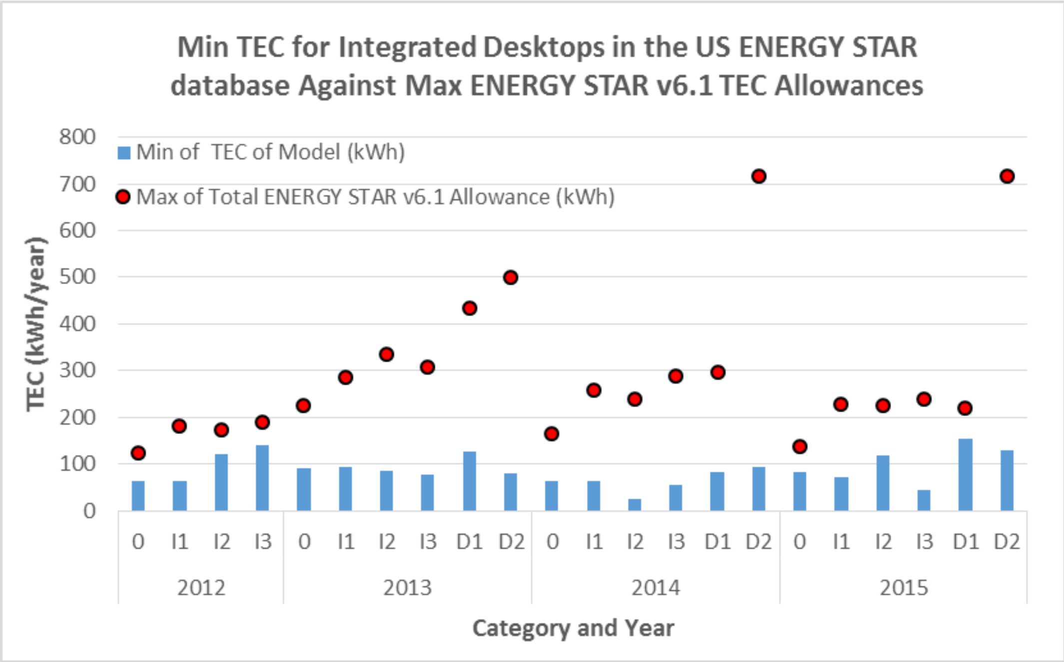

Figure 17 – Minimum TEC found for Integrated Desktop Computers in the US ENERGY STAR database based on year first placed on the market against the maximum ENERGY STAR v6.1 TEC allowance found

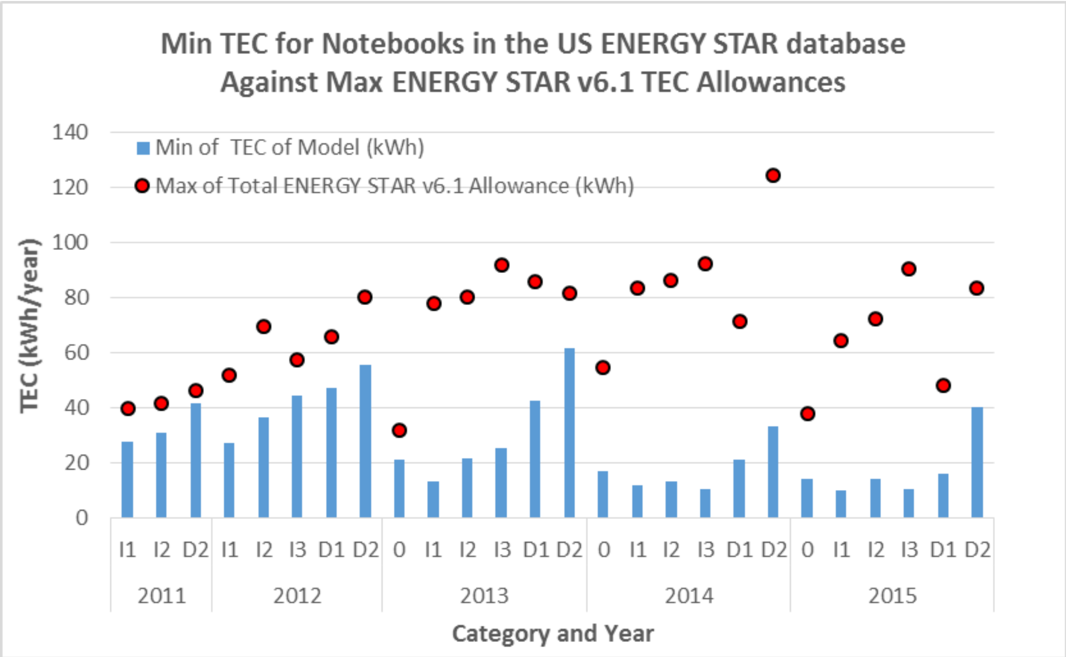

Figure 18 – Minimum TEC found for Notebook Computers in the US ENERGY STAR database based on year first placed on the market against the maximum ENERGY STAR v6.1 TEC allowance found

Figure 18 reveals the deltas between the minimum measured TEC for ENERGY STAR registered notebook computers and the maximum ENERGY STAR v6.1 allowance per category. Once again it is clear that there are some very large differences between the measured TEC values and the ENERGY STAR allowances for each category. The open ended ENERGY STAR v6.1 display allowances are providing a significant amount of allowance for some notebooks with either large displays or high resolution specifications (or both) meaning that the maximum allowance reflect products with high specification displays. Nevertheless, the size of the deltas suggests that the ENERGY STAR v6.1 speciation could probably be significantly more stringent whilst still reflecting currently available performances.

It is clear that there are a significant number of desktop, integrated desktop and notebook computers within the US ENERGY STAR v6.1 database that are performing well under the ENERGY STAR v6.1 specification limits. This serves to illustrate that the ENERGY STAR v6.1 specification is not necessarily reflecting the most energy efficient products on the market.

Given that there was a change in the test procedure between ENERGY STAR v5.0/5.2 and ENERGY STAR v6.1 and the fact that ENERGY STAR v6.1 has not yet been implemented in the EU, analysis has also been conducted to identify how products registered to the US ENERGY STAR v6.1 database perform against the EU Ecodesign Regulation requirements. To undertake this analysis it was necessary to make a small amendment to the measured long idle power demand of integrated desktops and notebook computers in the US ENERGY STAR v6.1 database as long idle under ENERGY STAR v6.1 does not match the idle power mode used under the Ecodesign Regulation. The amendment involved adding a small amount of extra power to the measured long idle power demand to account for a HDD that would need to be active under the EU Ecodesign Regulation testing procedure.

Figure 19 to Figure 21 show the maximum, average and minimum reported TEC values (based on the EU Ecodesign Regulation test procedure) for desktop computers, integrated desktop computers and notebook computers registered in the US ENERGY STAR v6.1 database compared to the average Tier I and Tier II EU Ecodesign Regulation allowances. For all computers, it is clear that the average measured TEC values for products in the US ENERGY STAR v6.1 database are significantly below both the Tier I and Tier II EU Ecodesign Requirements. Whilst there are clearly desktop and notebook computers products that do not meet the EU Ecodesign Tier II limits (represented by the grey bar column) there are products, within each computer type and category, on the market that can perform well under the Tier II allowance limits (represented by the dark blue bar column).

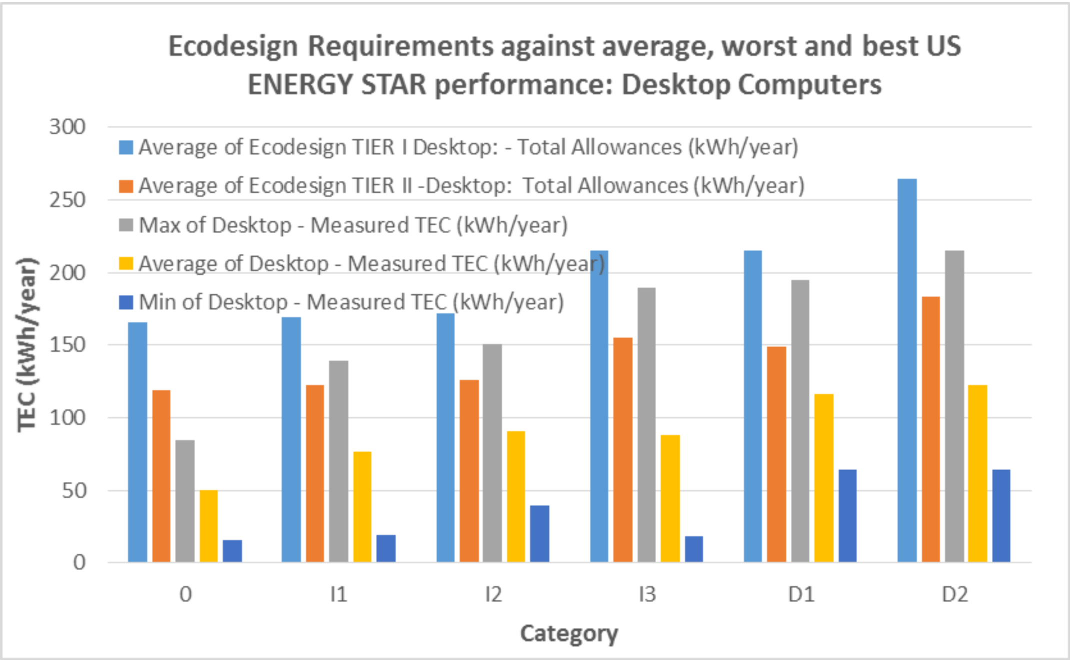

Figure 19 – Average EU Ecodesign Regulation TEC requirements for Desktop Computers in the US ENERGY STAR database against average, maximum and minimum TEC values

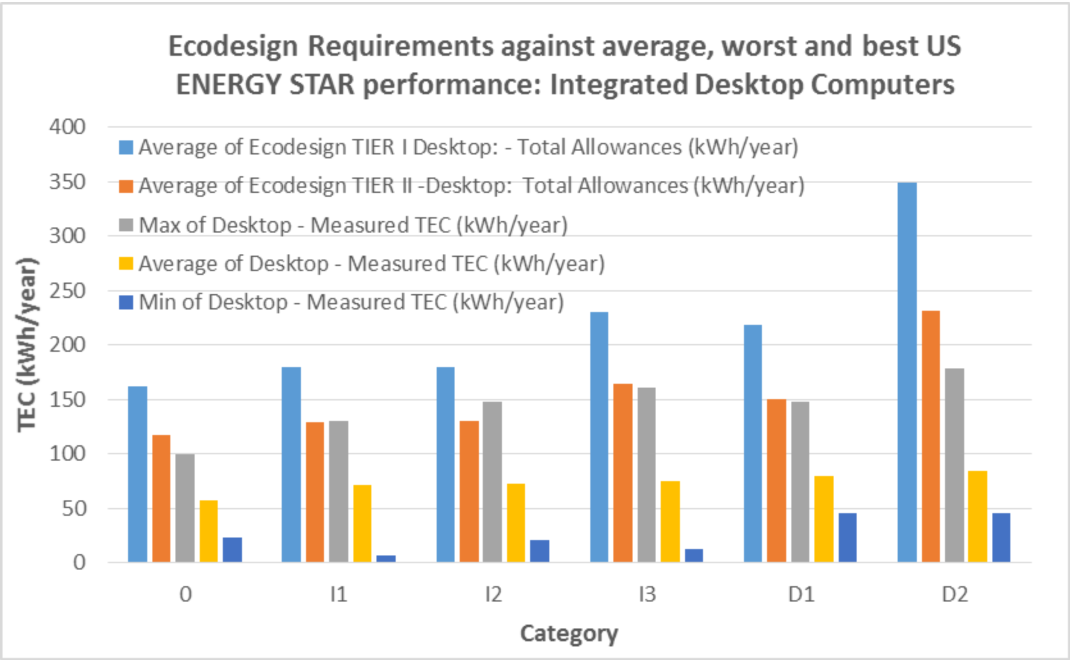

Figure 20 – Average EU Ecodesign Regulation TEC requirements for Integrated Desktop Computers in the US ENERGY STAR database against average, maximum and minimum TEC values

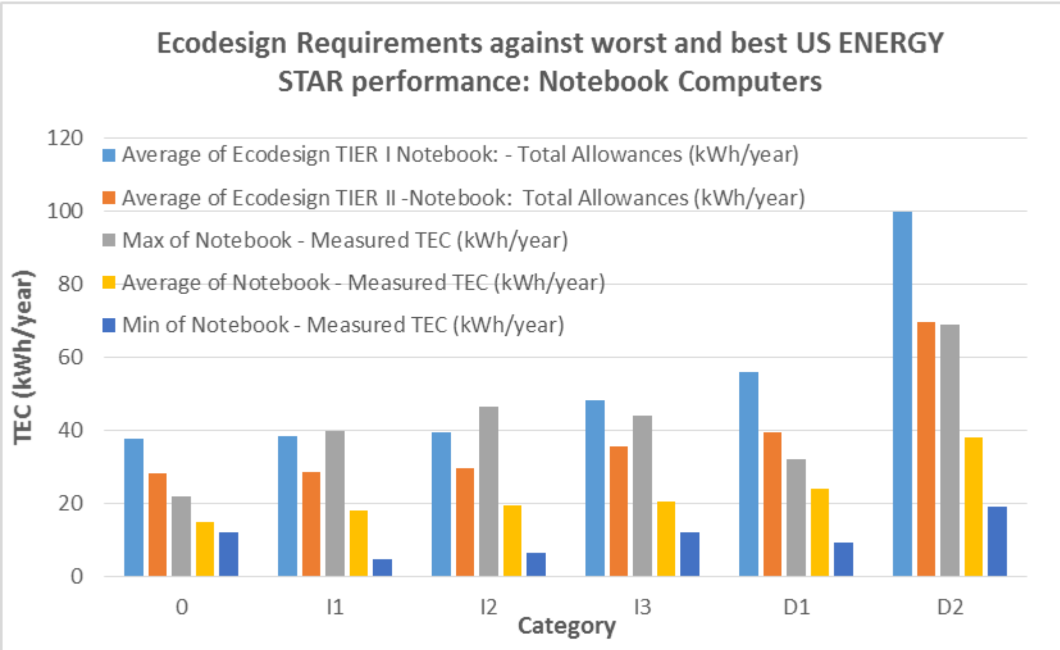

Figure 21 – Average EU Ecodesign Regulation TEC requirements for Notebook Computers in the US ENERGY STAR database against average, maximum and minimum TEC values

The section of the report has shown that products in the EU ENERGY STAR database and within the more up to date US ENERGY STAR database can easily meet both the EU Ecodesign Regulation requirements and the ENERGY STAR v6.1 specification. The next section of the report builds on these findings by assessing which computer components and power modes could be covered by more ambitious energy efficiency specifications.

4. Future Opportunities

It is clear that the two largest energy efficiency programmes focusing on desktop, integrated desktop and notebook computers are not necessarily reflecting best practice in terms of computer energy efficiency performance. It is important to note that this is not a criticism of either initiative rather an observation of current product performances. It is not uncommon for energy efficiency initiatives that focus on computers to quickly appear unambitious due to the fact that the energy efficiency levels of computers on the market can change quickly.

This section of the report identifies how some of the extra energy efficiency opportunities clearly available from computers could be obtained by refreshes to existing, or the development of new, specifications within energy efficiency initiatives.

Power Demand per Component

Computers contain many different components all of which have different power demands. The share of the total computer power demand allocated to each of the main computer components can vary widely based on the configuration of any one particular product. Typically the following components constitute the greatest share of total power demand in a computer system so will be subject to further discussion in this report:

- Central processing Units (CPUs)
- Motherboards
- Graphics processing cards
- Internal Power Supply Units (PSUs)
- Integrated displays
- Random Access Memory (RAM)
- Storage devices (e.g. hard disk drives (HDDs) or Solid State Drives (SSDs))

CPUs

The CPU in computers has traditionally been seen as the highest power demanding component of a computer system. However, CPU manufacturers have taken extensive steps to reduce the idle and sleep mode power demands of their products and also sought to increase the energy efficiency of their products whilst in use (i.e. active mode). These energy efficiency benefits have come about due to improvements in the manufacturing processes of the CPUs as well as conscious efforts by the manufacturers to reduce energy consumption (most often in order to increase battery life in mobile products).

Reductions in the power demand of CPUs have often come about as a result of die shrinkage. Die shrinkage refers to the ability of manufacturers to use more advanced fabrication processes to shrink the size of transistors in a CPU (i.e. often called the "process size" and measured in "nm"). Die shrinkage allows more processor dies to be manufactured on the same piece of silicon wafer resulting in lower costs whilst at the same time reduces the power demand of each during switching.

Whilst die shrinkage has advantages in terms of cost, performance per area and generally lower power demands it does cause issues with current leakage. Current leakage results is extra energy being required in all power modes as electrons leak through insulating layers and as the insulating layers become thinner leakage can increase. Much of the leakage problem in current CPUs on the market has been solved with improvements in the materials used for insulating materials but it remains to be seen if leakage will become a significant issue as process size continues to shrink.

Whilst the process size of CPUs, and their levels of functionality, can greatly impact the energy usage of these components there are other technologies that manufacturers can employ to reduce overall power demands of CPUs. These include:

- ### Dynamic voltage and frequency scaling

  Dynamic voltage and frequency scaling (DVFS) scaling involves scaling the CPU core voltage, clock rate, or both, based on computational demand to decrease power demand. This technology can be employed in real time to optimise the power-performance trade-off (since scaling CPU voltage and clock rate can impact performance). DVFS is not CPU specific but is based on a statistical model that predicts what voltage level a CPU will need to operate at a given frequency. DVFS is designed to incorporate a significant amount of overhead as a CPU's operating temperature will affect voltage requirements and this overhead can result in wasted energy (compared to a perfect solution). It is estimated that a 10% increase in voltage can result in a 20% increase in power demand.

- Adaptive Voltage and Frequency Scaling

  Adaptive Voltage and Frequency Scaling (AVFS) is a relatively new technology in which on-die hardware mechanisms manage the voltage through real-time monitoring of the junction temperature and current frequency. This method eliminates the need for an overhead voltage and therefore further reduces power demand. AVFS also promises to improve wafer yields as the technology can compensate for nominal differences in the make of individual chips.

- Clock gating

  Clock gating is a well understood and used technique for reducing power demand in CPUs. Clock gating works by disabling portions of the circuitry that are not needed during CPU operation.

- Integration of the voltage regulator

  Recently manufacturers have integrated the voltage regulator onto the CPU die instead of relying on a motherboard voltage regulator to produce the necessary voltage to different parts of the CPU. This has resulted in a decrease in idle mode power demand but a slight increase in active mode power demand.

- S0i3 states

  Newer CPUs support enhanced power management functions which allow CPUs to power down into a low power mode called "S0i3" whilst the computer is an idle mode. This technology has the added advantage of significantly reducing idle mode power demand without impacting user experience due to quick wake times. It has been shown that the inclusion of S0i3 states in computers can significantly reduce power demand.[5]

The above, and any additional, CPU power management functionalities should be considered when either developing or refreshing existing specifications within energy efficiency initiatives. That is, when reviewing

5 Anandtech, October 2012, "Intel's Haswell Architecture Analyzed: Building a New PC and a New Intel", available from http://www.anandtech.com/show/6355/intels-haswell-architecture

product energy efficiency performance the occurrence of these power management technologies should be considered. Where products are below average in terms of energy efficiency it should be investigated as to whether or not they include the above listed power management technologies.

Motherboards

The power demand of motherboards inside of desktop, integrated desktop and notebook computers can vary significantly even when functionalities are similar. Figure 22 shows idle mode power demand for an example small dataset of Z97 chipset based motherboards where all other components are standardised.

CLASP have also conducted a significant amount of research into the power demand of desktop motherboards which provides further insights into the different power demands of these computer components.[6]

Manufacturers have made some steps to reduce the power demand of motherboards. Some of these initiatives have been at the hardware level with reduction on process size bringing about some savings. Other manufacturers have taken additional steps to reduce power demand through innovative technologies which allow motherboard components to enter lower power modes during periods of lower utilisation.

When setting energy efficiency requirements for computers extra attention should be paid to the motherboards included in products as they can significantly impact overall energy use which is not necessarily warranted by an increase in computational or technical performance.

6 CLASP, October 2014, "Energy Consumption of Gaming Computers in the US Relative to the ENERGY STAR Version 6 Benchmark", available from http://clasp.ngo/en/Resources/Resources/PublicationLibrary/2014/Highest-Performance-Gaming-Computers.aspx

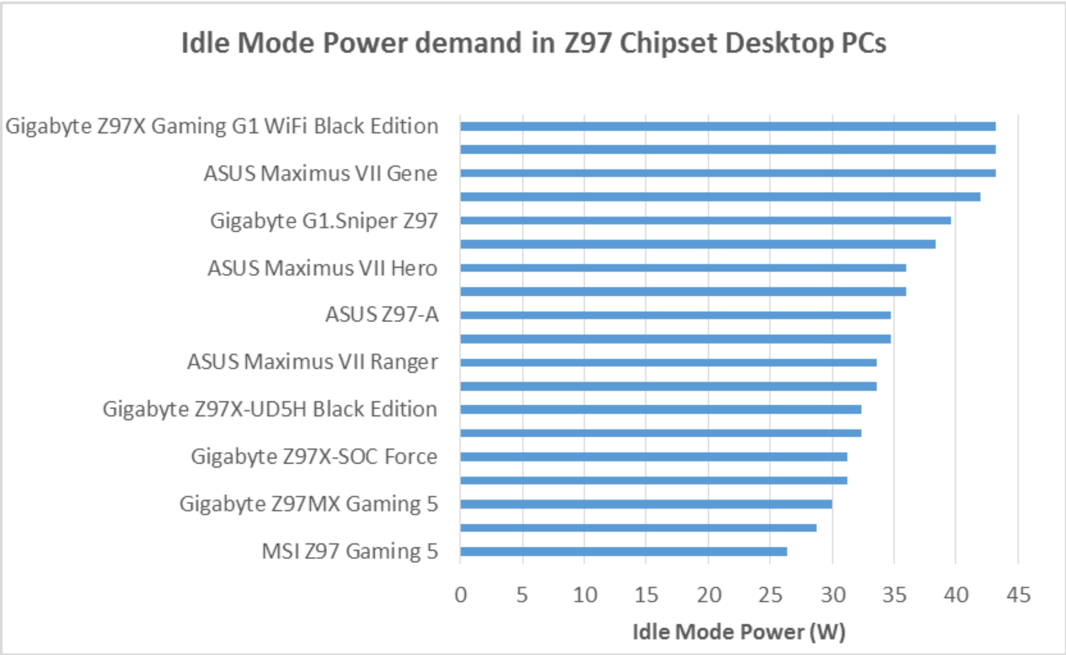

Figure 22 – Idle Mode Power demand of Z97 Chipset Motherboards[7]

Active mode

The active mode of computers has typically not been covered by initiatives which deal with the energy efficiency of computers. The lack of coverage of active mode under initiatives such as ENERGY STAR and the EU Ecodesign Regulation is likely largely due to concerns over impacting computer performance and assumptions that computers only spend a small amount of time in active mode resulting in low overall energy use in this mode. Concerns surrounding the impact on functionality are partially well founded because computation performance and power demand are still strongly correlated. However, power demand in active mode can vary even for products providing the same level of performance and so additional savings could be achieved by setting energy efficiency requirements on this power mode. It is often claimed that computers spend little time in active mode as they quickly power down to idle states after brief periods of inactivity. However, recent research suggests that computers can actually spend a considerable amount of time in active mode with estimates as high as 20% of on time being in active

7 Hardware Info, May 2014, "19 Intel Z97 chipset motherboards review: testing the new generation", available from http://us.hardware.info/reviews/5385/50/19-intel-z97-chipset-motherboards-review-testing-the-new-generation-power-consumption-idle-avg-over-5-minutes

mode. If these research findings are correct then active mode could be having a large influence on the overall energy use of computers. Table 1 below illustrates an example calculation of total energy use for some example high performance gaming desktop computers. It is clear from the analysis that if high end desktop computers spend 20% of their time in active mode then that mode accounts for significantly more overall energy use than all other power modes combined (when using an adapted ENERGY STAR v6.1 spread of times for each use profile).

Power Mode	Average Power Demand (W)	Estimated % Use Time	Energy Use (kWh/year)
Active	209.0	20%	366.2
Short Idle	73.6	21%	135.4
Long Idle	71.9	9%	56.7
Sleep	4.0	5%	1.8
Off	1.0	45%	3.9

Table 1 – Average Power Demands and Energy Use seen in High End X99 based Desktop Personal Computers[8]

Consideration of the active mode of computers is a significant issue that deserves further consideration than is possible in this report. The active mode of desktops, integrated desktops and notebook computers will be discussed in detail within a following separate SEAD report.

Power Management

Most desktop, integrated desktop and notebook computers have had power management functionality available for many years. The most widely known power management technology is the Advanced Configuration and Power Interface (ACPI) specification which provides an open standard for device configuration and power management by the operating system. Most energy efficiency initiatives which address desktop, integrated desktops and notebooks include requirements on both the presence of power management functionality and specific power management settings. Power management controls the ability of a computer to power down into another power mode with a lower power demand (e.g. idle mode

8 Power demand values sourced from http://www.anandtech.com/show/8978/msi-x99s-mpower-review/5

to sleep mode) after a defined period of user inactivity (e.g. 20 minutes) thereby saving energy. There is often a fine balance between setting short power down times (i.e. the amount of time before the computer powers down) to encourage maximum amount of time in a lower power demanding mode and not impacting user experience of the computer (i.e. functionality in lower power demanding modes such as sleep mode is very limited). Whilst the length of time it takes a computer to wake from sleep mode is often fast (e.g. 5 seconds) frequent power down periods can significantly impact user experience.

However, newer power management technologies available in some products already on the market allow a computer CPU to power down in millisecond intervals when not being used.[9] The technology is fast enough to allow the computer CPU to power down in-between keystrokes without impacting user behaviour. This technology has been explored in detail by energy efficiency commentators.[10]

These newer power management technologies should be investigated in significantly more detail when either developing or refreshing energy efficiency specification within initiatives. It is suggested that these technologies could be employed in other products already on the market without significantly impacting costs as it is likely that current hardware architecture could support this functionality.

Graphics Solutions

All desktop, integrated desktop and notebook computers require a graphics processing capabilities in order to render images to a display. This graphics functionality is normally delivered via an integrated graphics processing unit (iGfx), which is either located on the motherboard or recently more commonly on the CPU die or through a dedicated discrete GPU (dGfx) which is normally connected via a PCie slot on the motherboard within desktop computers and attached directly to the motherboard in notebooks (dGfx) in integrated desktop computers may be connected via either route).

Discrete graphics processing cards (dGfx) include several physical features (e.g. dedicated memory and sophisticated graphics processing units (GPUs)) that enable them to provide higher levels of graphics performance than iGfx. With this higher graphics performance and discrete component format comes increased power demand. However, the distinction between dGfx's and iGfx's performance levels is

9 https://www.apple.com/macbook-pro/environment/

10 http://switchboard.nrdc.org/blogs/pdelforge/new_study_reveals_computer_ins.html blurring as newer higher specification iGfx with dedicated memory are being developed and promoted by the manufacturers as offering significantly higher levels of graphics performance comparable to lower specification dGfx's (i.e. graphics performance is heavily dependent on memory bandwidth which is normally restricted by shared memory in iGfx's). These higher specification iGfx's are likely to be able to deliver good levels of graphics performance whilst using significantly less energy than comparable dGfx's.

As well as improvements in the graphics performance of some iGfx's other technologies have also been developed in reduce the extra power demand required by products which provide enhanced levels of graphics performance.

Many notebook computers now on the market include both an iGfx and a dGfx with the ability for either the user and/or the computer to switch between the two graphics solutions depending on the level of graphics performance needed at any one time. These "hybrid" or "switchable graphics" solutions as they are known enable the provision of both high graphics performance and lower powered graphics functionality where this provides enough performance. These switchable/hybrid graphics solutions have been developed for notebook computers because they allow for the use of high performance graphics when required (or when plugged into a mains outlet) and the ability to use a less powerful, and hence lower powered, iGfx to extend battery life. These switchable graphics solutions have been developed by both GPU manufacturers and general computer manufacturers, meaning that there are a multitude of solutions available in the marketplace.

Switchable graphics technologies have not found their way into desktop computers in any meaningful amounts. There have been various examples of this functionality being used in desktops in the past, and within some newer desktop computers, but uptake remains low. This low uptake in desktop switchable graphics is likely a result of two main issues. Firstly, manufacturers are not encouraged to reduce the power demand of desktop computers to the same extent that they are incentivised to reduce power demand in notebook computers as they do not need to consider battery life. Secondly, most desktop computers are based on an open format architecture meaning that components can be changed or upgraded relatively easily by users. This open architecture means that dGfx's are largely separate components from any iGfxs included on either the motherboard or on the CPU die. This separation means that external displays can either be connected to the dGfx outputs or the outputs of the motherboard.

Within the notebook architecture the same output is used regardless of whether the dGfx or the iGfx is being used. However, some manufacturers have tried to include switchable graphics into open format desktop computers. It is accepted that these technologies are in their infancy but energy efficiency initiatives could seek to encourage the adoption of these technologies through either mandatory requirements or incentives. One particular technology that could be used to support switchable graphics in desktop computers known as Panel Self-Refresh (PSR) is discussed later in this report.

DGfx's performance is most often described in terms of frame buffer memory bandwidth which is measured in GB/s. There are a wide range of GB/s performances within dGfx's on the market and there is often, although less so in recent years, a strong correlation between performance and idle mode power demand. A grading system for dGfx's was developed by ECMA which has been adopted by many environmental initiatives including the EU Ecodesign Regulation and ENERGY STAR v6.1. The ECMA 383 classification of G1 to G7 is shown in

Table 2 below.

GPU Category	GPU performance banding		Bit Width (bits)
	FB_BW Min (GB/s)	FB_BW Max (GB/s)	
G1	0	16	-
G2	16	32	-
G3	32	64	-
G4	64	96	-
G5	96	128	-
G6	128		<192
G7	128		≥192

Table 2 – Classification of dGfx's based on Memory Bandwidth

Manufacturers do not often communicate power demand data for dGfx's and so data is normally gathered from other sources where products have been tested for other purposes such as performance reviews. These independent performance reviewers do not often test dGfx's in the range of G1 to G6 as G7 dGfx's as their main source of interest given their higher performances. Given that the power demand of G7 dGfx's is the highest then G7 data is very relevant to energy efficiency initiatives.

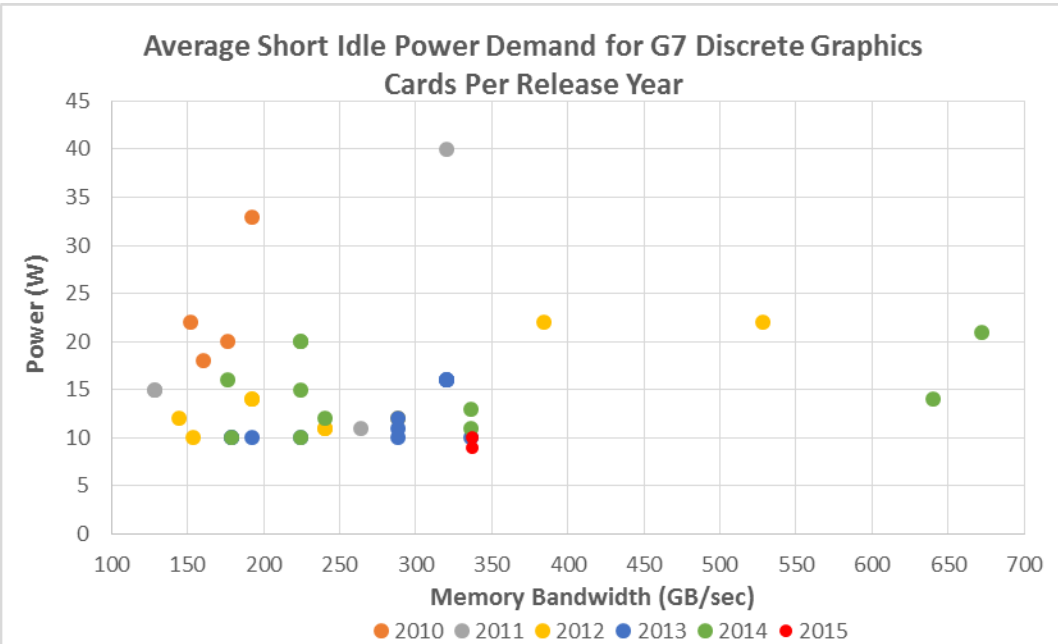

Figure 23 – Average Short Idle Power Demand in High End Discrete GPUs per Year of Release

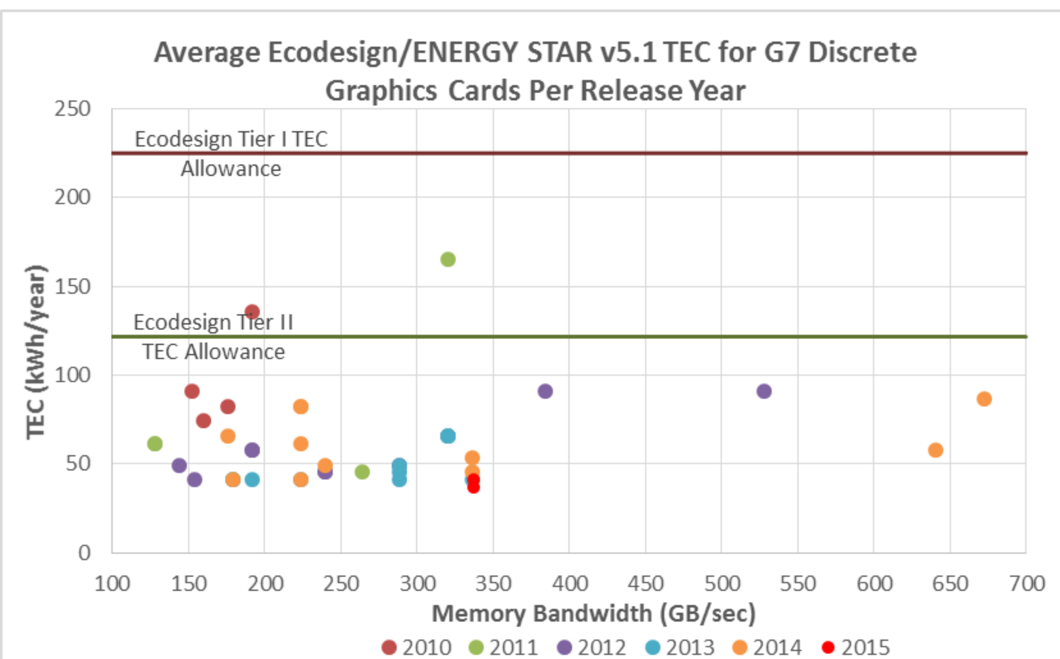

Figure 24 – Average TEC of High End Discrete GPUs per Year of Release Compared to the EU Ecodesign Allowances

Figure 23 illustrates the short idle power demand for a range of desktop G7 dGfx's placed on the market since 2010.[11] The results clearly indicate that since 2010 there has been a general trend towards high performances but with lower idle mode power demands. This shows that dGfx manufacturers have taken steps to decouple performance from idle mode power demand. Indeed, GPU manufacturers have employed many of the power demand reducing technologies that were described earlier for CPU's.

The efforts that manufacturers have taken on dGfx idle mode energy efficiency have meant that EU Ecodesign Regulation allowances on G7 dGfx's are now far too generous, as illustrated in Figure 24. Indeed, only two of the G7 dGfx's in the SEAD analysis would fail to meet the Tier II EU Ecodesign Regulation allowances. This is a significant issue for the EU Ecodesign Regulation since the dGfx allowances aren't ring fenced meaning that any excess allowance can be used to compensate for inefficiencies in the rest of the computer. In addition the EU Ecodesign Regulation includes an exemption for desktop computers which include a G7 dGfx that has a frame buffer bandwidth above 320 GB/s (N.B exempted desktop computers must also include A CPU with a minimum of six physical cores, a minimum 16 GB of system memory (RAM) and an internal power supply (PSU) with a rated output power of at least 1,000 W). The SEAD analysis shows that 14 desktop G7 dGfx's on the market would already meet this exemption limit and this does not count desktop computers which have multiple lower specification G7 dGfx's installed. It is therefore clear that both the G7 dGfx allowances and the exemption limits included under the EU Ecodesign Regulation need to be reviewed.

Conducting analysis against the ENERGY STAR v6.1 specifications was slightly more complex because the ENERGY STAR specification uses short idle (as with the EU Ecodesign Regulation) but also long idle for which there are no widely published values. As such, it was necessary to estimate long idle values so that TEC values could be calculated and then compared to the ENERGY STAR v6.1 allowances. During the ENERGY STAR v6.1 development process it was assumed that long idle values for dGFx were 66% of the short idle values. This same conversion factor was used for the SEAD analysis with the findings shown in Figure 25. As can be seen only 1 dGfx from 2011 cannot meet the ENERGY STAR v6.1 allowances. As with the EU Ecodesign Regulation these allowances are not ring fenced for the dGfx so any unused allowance

11 Data from: TOMSHARDWARE, May 2015, Nvidia GeForce GTX 980 Ti 6GB Review, available from http://www.tomshardware.co.uk/nvidia-geforce-gtx-980-ti,review-33214-7.html

can be used to compensate for other inefficiencies in a desktop computer. It is therefore clear that the G7 dGfx allowances under ENERGY STAR need to be reviewed as they are currently far too generous.

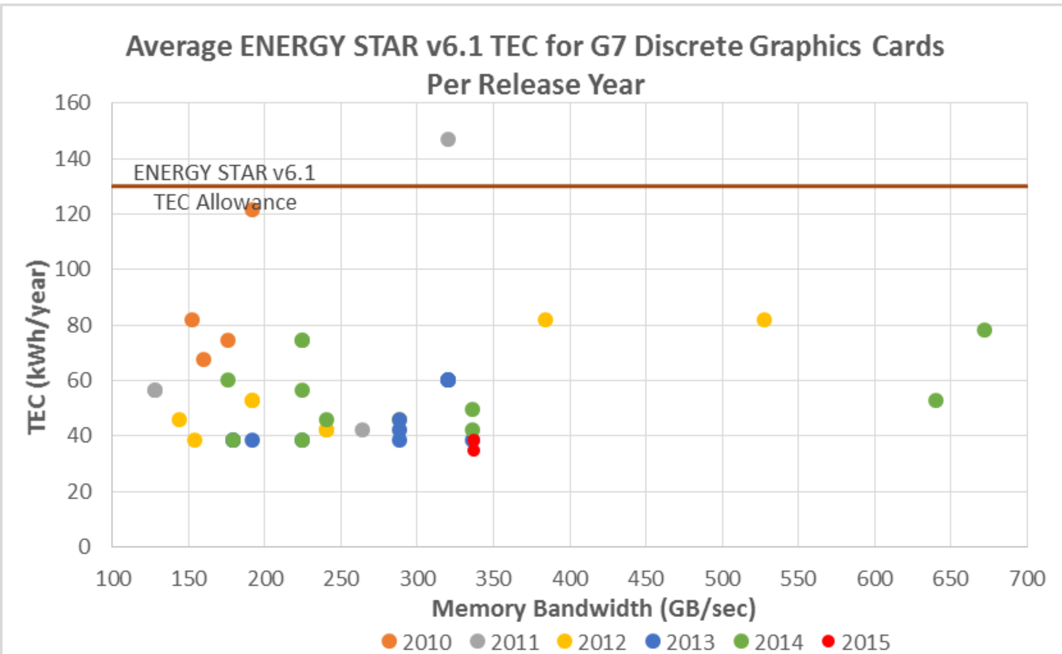

Figure 25 – Average ENERGY STAR v6.1 based TEC of High End Discrete GPUs per Year of Release Compared to the ENERGY STAR v6.1 allowances

It has been shown that the power demand of G7 dGfx's has reduced significantly since 2010 to the point where they are performing significantly under the EU Ecodesign Regulation and the ENERGY STAR v6.1 specification allowances. However, less attention has been paid to the active mode power demand of the G7 dGfx's on the market. The measured active mode power demands of a large range of G7 dGfx's is shown in Figure 26[12]. It is clear that active mode power demand of G7 dGfx's can be very significant (i.e. the maximum value in the dataset was 428W) but can also vary significantly (i.e. the minimum value in the dataset was 99W). It is also very evident that there is a very strong correlation between increasing active mode performance and increasing active mode power demand, although some variability does exist.

12 Data from: TOMSHARDWARE, May 2015, Nvidia GeForce GTX 980 Ti 6GB Review, available from http://www.tomshardware.co.uk/nvidia-geforce-gtx-980-ti,review-33214-7.html

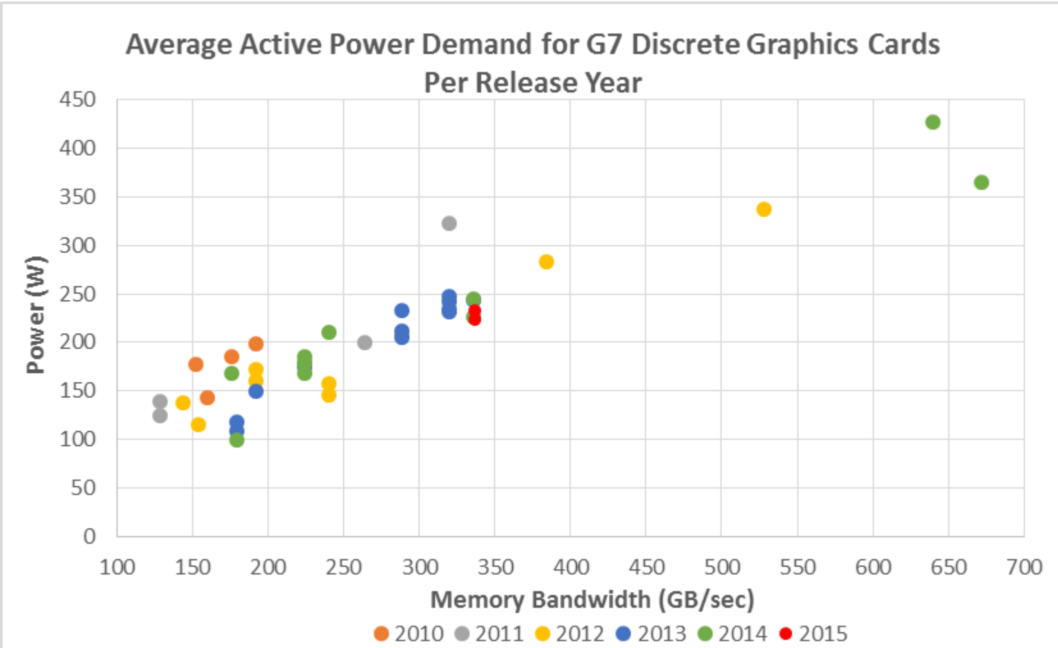

Figure 26 – Average Active Mode Power Demand in High End Discrete GPUs per Year of Release

To provide context to the active mode power demand of the G7 dGfx's they have been converted, along with the idle mode values, into a TEC value as shown in Figure 27. The conversion assumes that 20% of the time is spent in active mode with a corresponding proportional reduction in time spent in short and long idle (i.e. 21% in short idle and 9% in long idle having been reduced from 35% in short idle and 15% in long idle). The 20% values was taken form a recent study into use hours of office computers conducted for the Californian Energy Commission (CEC)[13]. It is recognised that whilst this 20% value may be an overestimate for desktop computer gamers, where heavy gamers spend around 18 hours per week gaming[14], many G7 dGfx's are used in performance desktop computers designed for heavy computational office based applications and so office based estimates of active mode time are relevant. The results in Figure 27 suggest that total energy use from G7 dGfx's could be very significant at almost 1MWh/year. It should be noted that multiple dGfx's could be installed in a single desktop computer so the maximum TEC

13 California Plug Load Research Center (University of California), October 2014, "Final project report: Monitoring Computer Power Modes Usage in a University Population", Prepared for: California Energy Commission, available from http://www.energy.ca.gov/2014publications/CEC-500-2014-092/CEC-500-2014-092.pdf

14 Eurogamer.net, "Core gamers game 18 hours a week – NPD", available from http://www.eurogamer.net/articles/2011-06-27-core-gamers-game-18-hours-a-week-npd

value could be much higher than indicated in the graph. It is also important to note that sales volumes of G7 dGfx's at the extreme end of performances will be relatively modest in comparison to lower specification dGfx's.

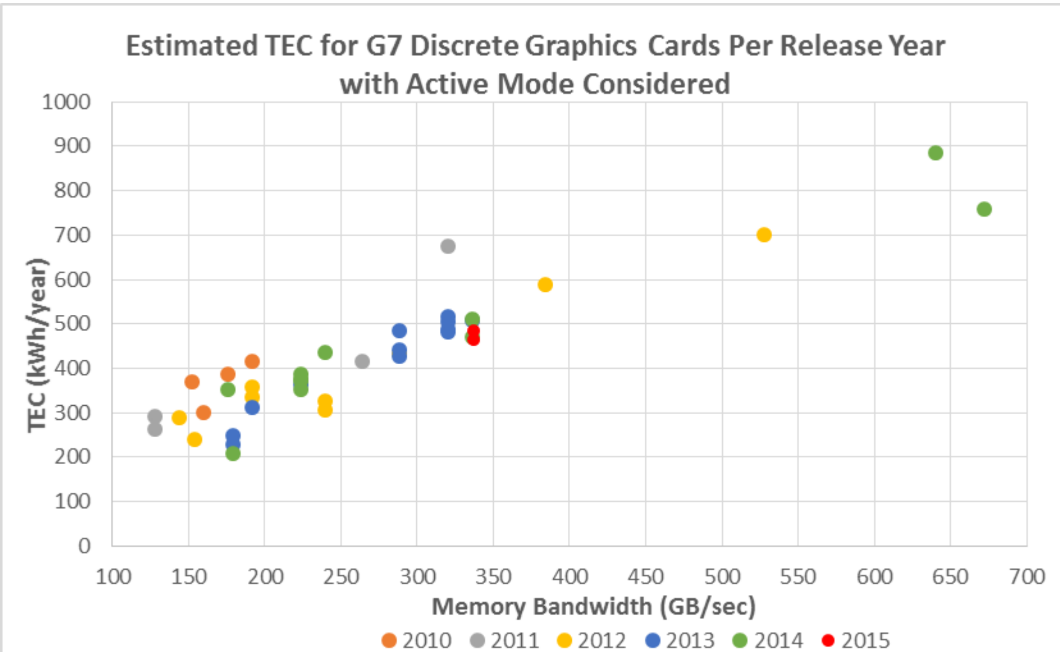

Figure 27 – Average TEC of High End Discrete GPUs per Year of Release Compared with Active Mode Considered

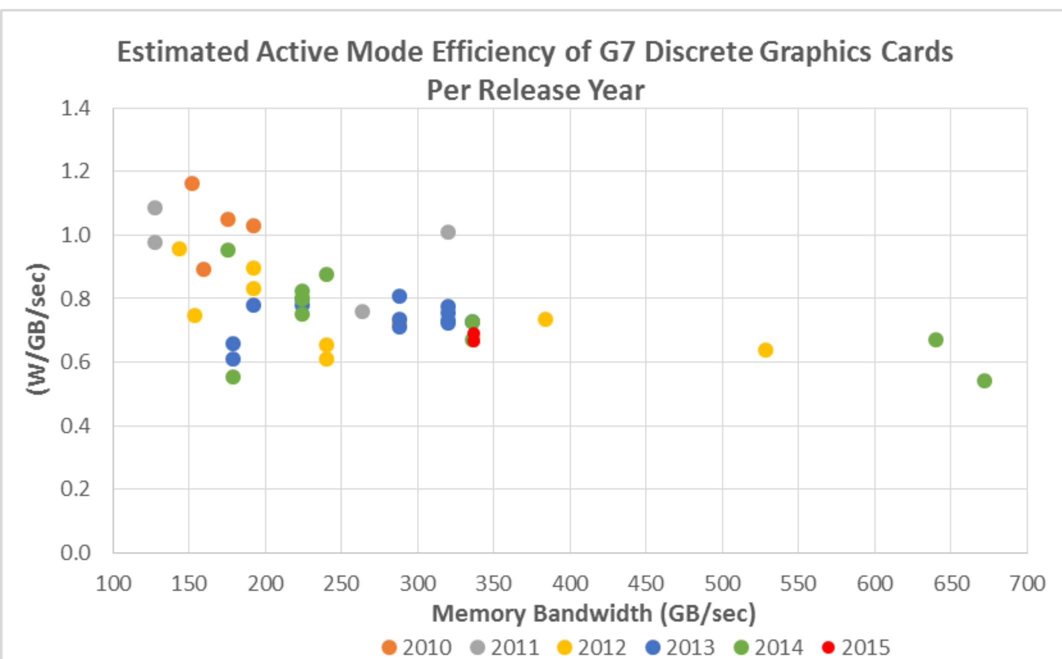

Figure 28 – Estimated Active Mode Efficiency of High End Discrete GPUs per Year of Release

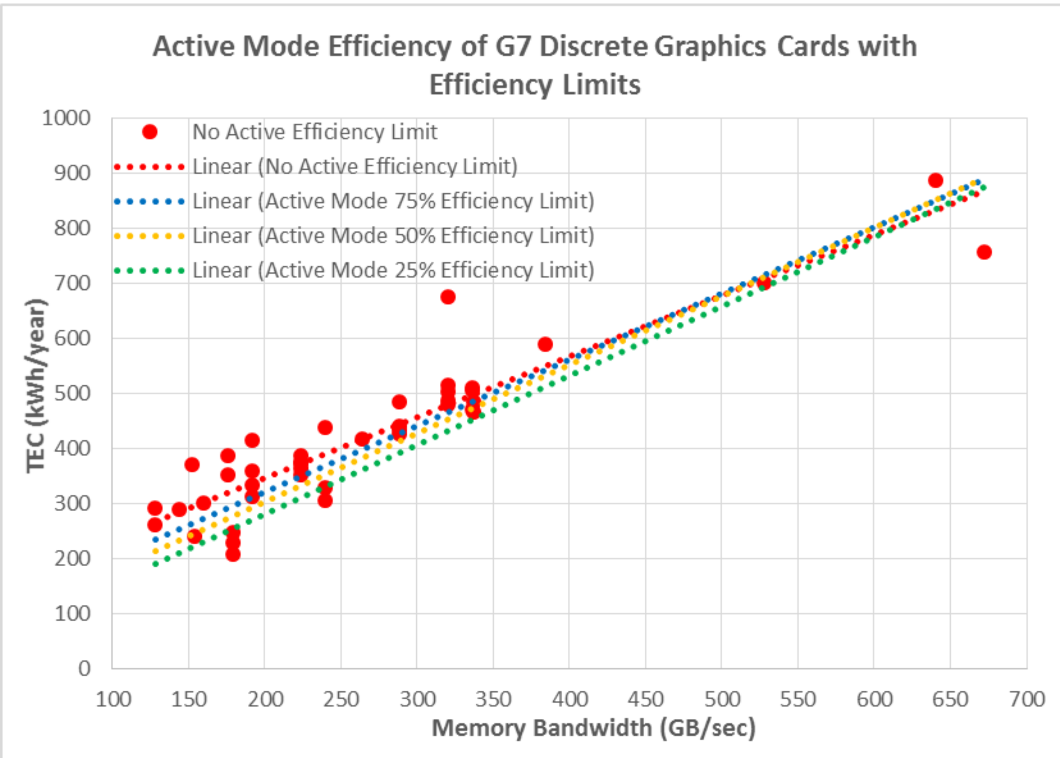

Figure 29 – Impact of Active Mode Efficiency Requirements on TEC of High End Discrete GPUs

Despite the potentially large energy use of some G7 dGfx's it is suggested that it would be unwise for energy efficiency initiatives to set requirements that cap active mode power demand in these products as that would likely curtail performance. However, energy efficiency initiatives could consider investigating how efficiently G7 dGfx's deliver their performances. Figure 28 illustrates the efficiency of the G7 dGfx's in terms of watts per Gigabyte per second (W/GB/s). The graph shows that there is a wide range of active mode efficiencies within the lower specification G7 dGfx's but that efficiency is relatively consistent at around 0.6W/GB/s for the higher specification graphics cards. Figure 29 shows the effects of placing active mode efficiencies on G7 dGfx's based on differing levels of ambition. The results show that as the most efficient G7 dGfx's are at the higher end of performances even setting efficiency requirements at a 25% most efficient level would not result in significant savings for these types of products. However, setting active mode efficiency requirements at higher levels of ambition would result in savings from the lower performance G7 dGfx's. Energy efficiency initiatives could therefore consider setting active mode efficiency requirements on dGfx's based on a metric such as W/GB/s or similar in order to access further savings.

Internal Power Supply Units

Internal power supplies (PSU) efficiency dictates how effectively power drawn from the mains is used by a computer (i.e. the percentage efficiency identifies how much of the drawn power is actually able to be used by the computer). As such, the efficiency of internal PSU's can have a significant impact on the overall levels of energy efficiency in a desktop or integrated desktop computer. Given this fact most energy efficiency initiatives include requirements on the energy efficiency of internal PSU's. Most of the internal PSU requirements used in initiatives around the world are taken directly from, or adopted from, the 80PLUS programme.[15]

	230V EU Internal Non-Redundant							115V Internal Non-Redundant					
Loading	EU Ecodesign	80 PLUS	80 PLUS Bronze	80 PLUS Silver	80 PLUS Gold	80 PLUS Platinum	80 PLUS Titanium	80 PLUS	80 PLUS Bronze	80 PLUS Silver	80 PLUS Gold	80 PLUS Platinum	80 PLUS Titanium
10%	–	–	–	–	–	–	90%	–	–	–	–	–	90%
20%	82%	82%	85%	87%	90%	92%	94%	80%	82%	85%	87%	90%	92%
50%	85%	85%	88%	90%	92%	94%	96%	80%	85%	88%	90%	92%	94%
100%	82%	82%	85%	87%	89%	90%	94%	80%	82%	85%	87%	89%	90%
TOTAL Registered Products	-	46	25	9	13	2	0	1296	2061	384	1118	347	26
Percentage of Registered Products	-	48%	26%	9%	14%	2%	0%	25%	39%	7%	21%	7%	0%

Table 3 – Internal PSU Efficiency Requirements and Numbers of Registered Products under the 80PLUS Programme and the EU Ecodesign Regulation

15 Ecova, Plug Load Solutions - 80 PLUS Certified Power Supplies and Manufacturers, available from http://www.plugloadsolutions.com/80pluspowersupplies.aspx

Table 3 shows the internal PSU efficiency requirements included under the 80PLUS programme and the EU Ecodesign Regulation along with the total numbers of PSU's registered with the scheme under each level of efficiency. It should be noted that whilst there are relatively few internal PSU's tested at 230v registered with the 80PLUS programme there would be a large number of complaint products on the market due to the inclusion of efficiency and 230v testing requirements under the EU Ecodesign Regulation. The ENERGY STAR v6.1 specification includes internal PSU requirements at the 80PLUS Bronze level for 115v testing and at the 80PLUS level for 230v testing.

Year	Distribution	80 PLUS Bronze	80 PLUS Silver	80 PLUS Gold	80 PLUS Platinum	80 PLUS Titanium
2009	Number	312	10	–	–	–
	%	96.9%	3.1%			
2010	Number	407	7	–	–	–
	%	98.3%	1.7%	–	–	–
2011	Number	485	6	8	5	2
	%	95.8%	1.2%	1.6%	1.0%	0.4%
2012	Number	369	10	44	1	–
	%	87.0%	2.4%	10.4%	0.2%	–
2013	Number	659	7	55	–	–
	%	91.4%	1.0%	7.6%	–	–
2014	Number	381	20	65	6	–
	%	80.7%	4.2%	13.8%	1.3%	–
2015	Number	173	11	16	–	–
	%	86.5%	5.5%	8.0%	–	–
Overall	Number	2786	71	188	12	2
	%	91.1%	2.3%	6.1%	0.4%	0.1%

Table 4 – Occurrence of 80PLUS levels of efficiency in desktop Internal PSUs found in the EU ENERGY STAR database per year of product release to market

To assess the current market situation with regards to internal PSU efficiencies the EU ENERGY STAR and US ENERGY STAR databases were questioned. Table 4 shows the numbers (and percentages) of 80PLUS levels achieved by internal PSU's contained within desktop computers registered under the EU ENERGY STAR database per year of product release to the market. The results of the analysis clearly indicate a shift towards more efficient internal PSUs used in EU ENERGY STAR registered desktop computers. The results for 2015 should not be considered complete as many manufacturers have held off registering new products to the older ENERGY STAR v5.0 specification that is still in force within the EU (up to the time of writing this report). It should also be noted that PSU efficiency data was included for 3059 products from a total of 3090 registered desktops with internal PSUs.

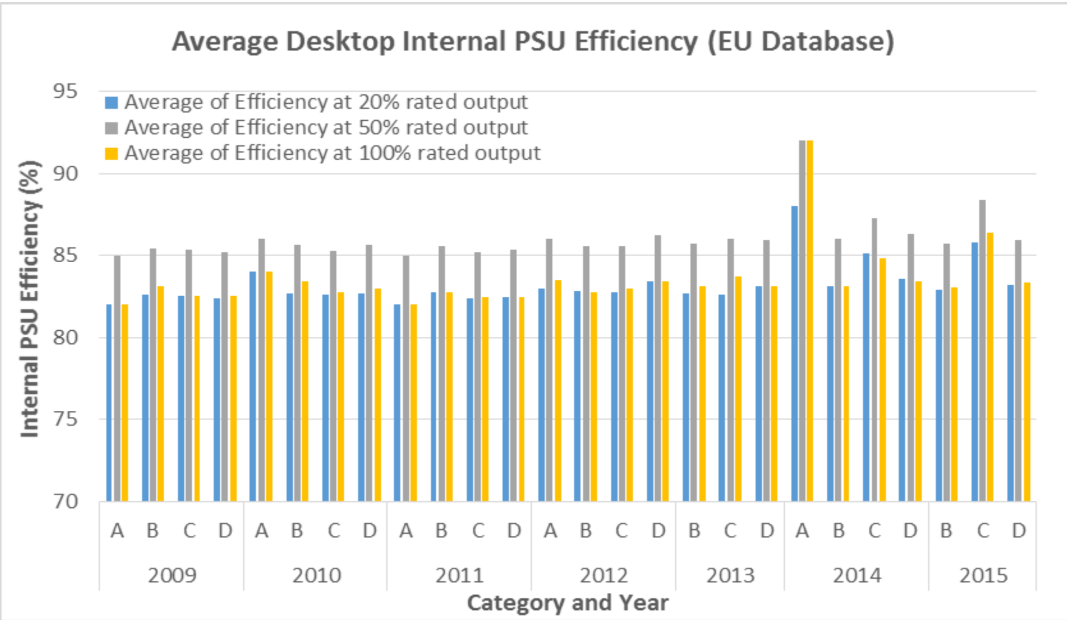

Figure 30 – Average Internal PSU Efficiency at different loading points for Desktop Computers in the EU ENERGY STAR database

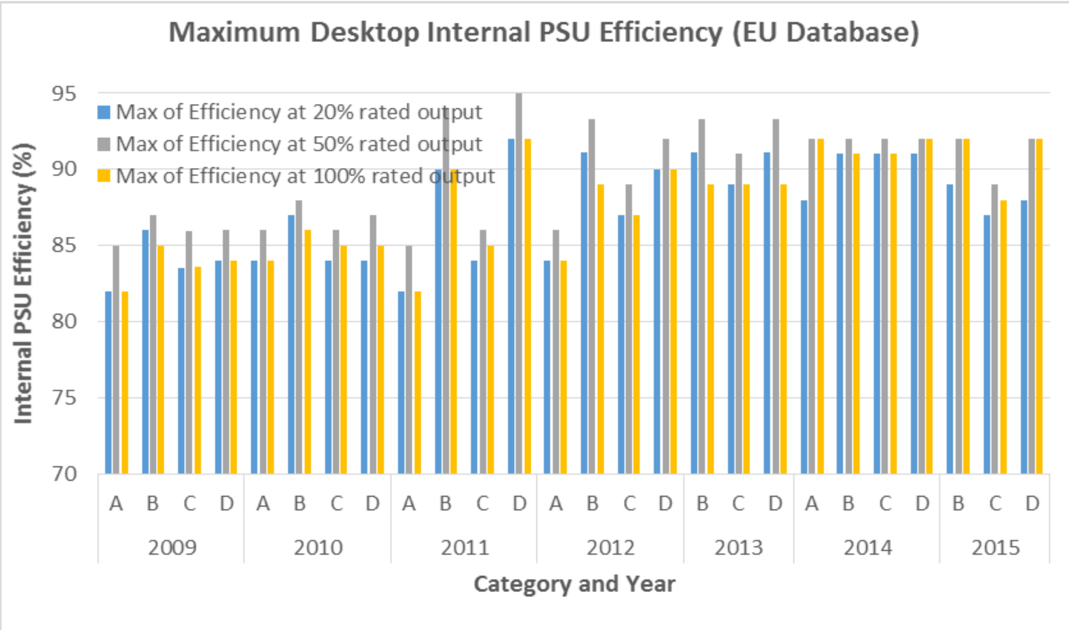

Figure 31– Maximum Internal PSU Efficiency at different loading points for Desktop Computers in the EU ENERGY STAR database

The spread of the average PSU efficiencies found in EU ENERGY STAR registered desktop computers can be seen in graphical form within Figure 30. The results show that average PSU efficiency has not increased significantly within EU ENERGY STAR registered products since 2009. Figure 31 conversely shows that the maximum average efficiency found in PSU's within EU ENERGY STAR registered desktop computers has increased significantly since 2009 (with a slight decrease in 2015 likely due to smaller number of registrations). These results suggest that there is some barrier to the uptake of more efficient PSUs despite higher efficiency PSUs being available on the market.

The occurrence of 80PLUS internal PSUs in desktops registered to the US ENERGY STAR database is shown in Table 5. The PSU efficiency data for the desktop computers registered in the US ENERGY STAR database was very incomplete. There were only 272 full sets of PSU efficiency data from 1008 registered desktops. Given the lack of data it is difficult to draw any conclusions from the results.

Year	Distribution	80 PLUS Bronze	80 PLUS Silver	80 PLUS Gold	80 PLUS Platinum	80 PLUS Titanium
2013	Number	90	-	49	6	-
	%	62.1%		33.8%	4.1%	-
2014	Number	83	3	26	7	-
	%	69.7%	2.5%	21.8%	5.9%	-
2015	Number	5	-	3	-	-
	%	62.5%	-	37.5%	-	-
Overall	Number	178	3	78	13	-
	%	65.4%	3.2%	85.7%	100.0%	-

Table 5 – Occurrence of 80PLUS levels of efficiency in desktop Internal PSUs found in the US ENERGY STAR database per year of product release to market

The average and maximum reported PSU efficiencies for desktop computers registered under the US ENERGY STAR programme are shown in graphical format in Figure 32 and
Figure 33 respectively. As previously mentioned, given the incomplete dataset it is difficult to draw conclusions from the results.

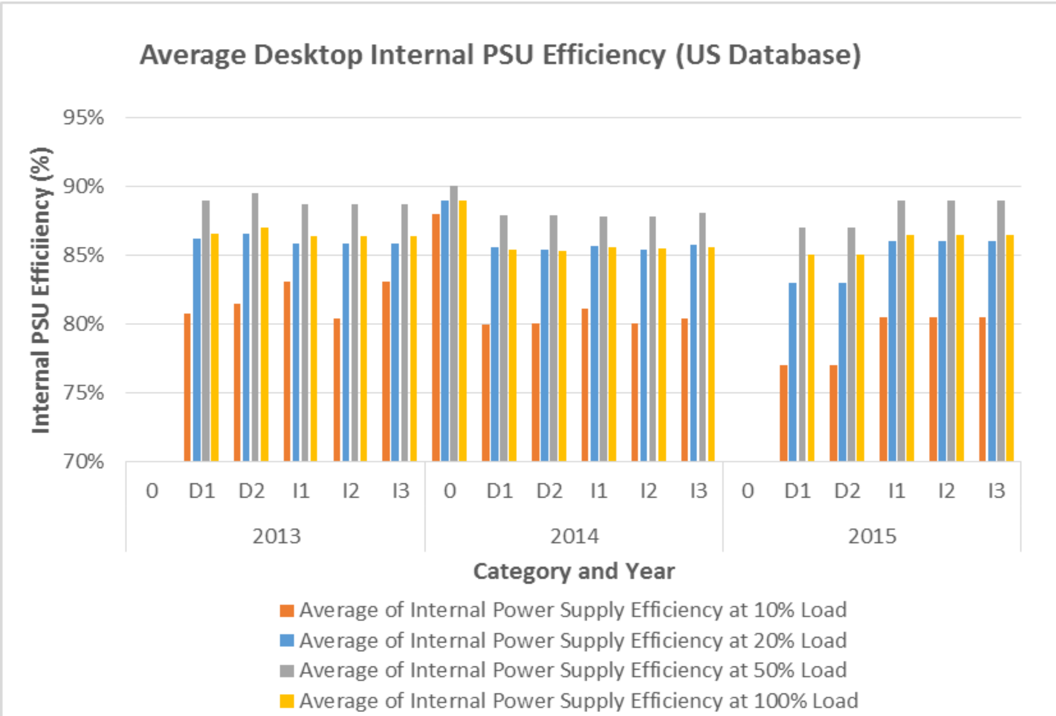

Figure 32 – Average Internal PSU Efficiency and loading for Desktop Computers in the US ENERGY STAR database

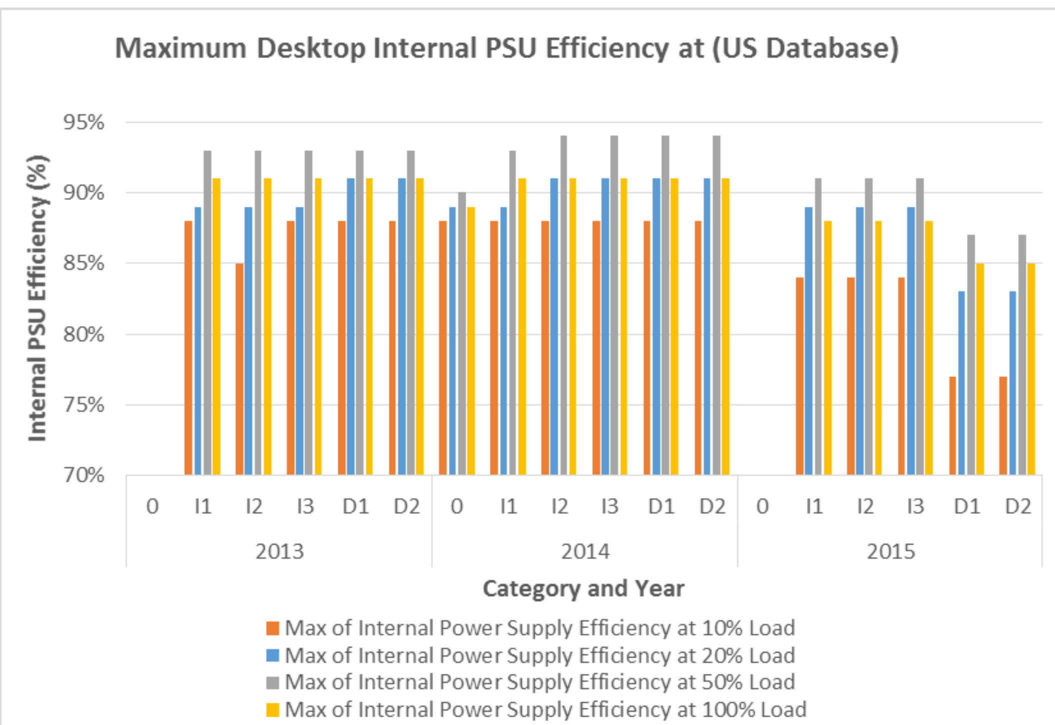

Figure 33 – Maximum Internal PSU Efficiency and loading for Desktop Computers in the US ENERGY STAR database

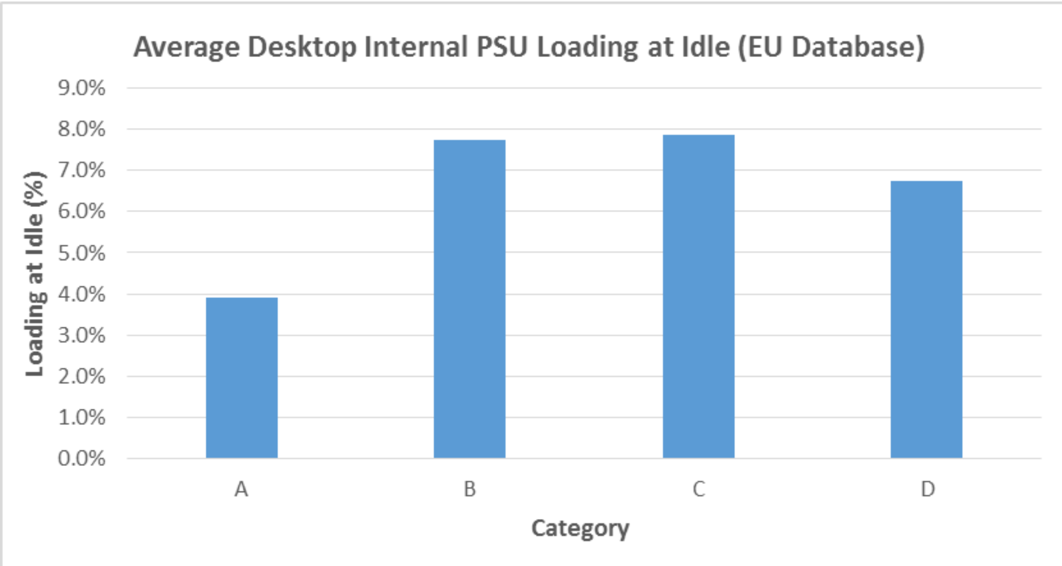

Figure 34 – Average Internal PSU Loading at Idle for Desktop Computers in the EU ENERGY STAR database

It is important to note the efficiency levels at 10% loading which is reported voluntarily within the ENERGY STAR programme (unless an 80PLUS Titanium level PSU is used as these have 10% loading requirements). Loading refers to the % of power drawn over the total rated output of the PSU (i.e. the percentage of drawn power over the total that can be drawn). It is clear that the efficiency of PSU's is significantly lower at 10% loading than at 20%, 50% or 100% loading. PSU efficiency normally decreases rapidly below 20% loading and continues to decrease beyond 10% loading. This is an important consideration since the 80PLUS programme does not place efficiency requirements on PSU's at 10 % loading (apart from Titanium level PSU's) but as can be seen in Figure 34 and Figure 35 PSU loading whilst a desktop is in idle is often well below the 10% loading level. Given that desktop computers are assumed to be spending around half their time (according to the EU Ecodesign Regulation and ENERGY STAR v6.1 use profiles) in idle modes then it appears that PSU efficiency is not being adequately addressed in most energy efficiency initiatives. Future revisions to existing initiatives should therefore consider investigating the inclusion of PSU efficiency requirements at 10% loading and even below.

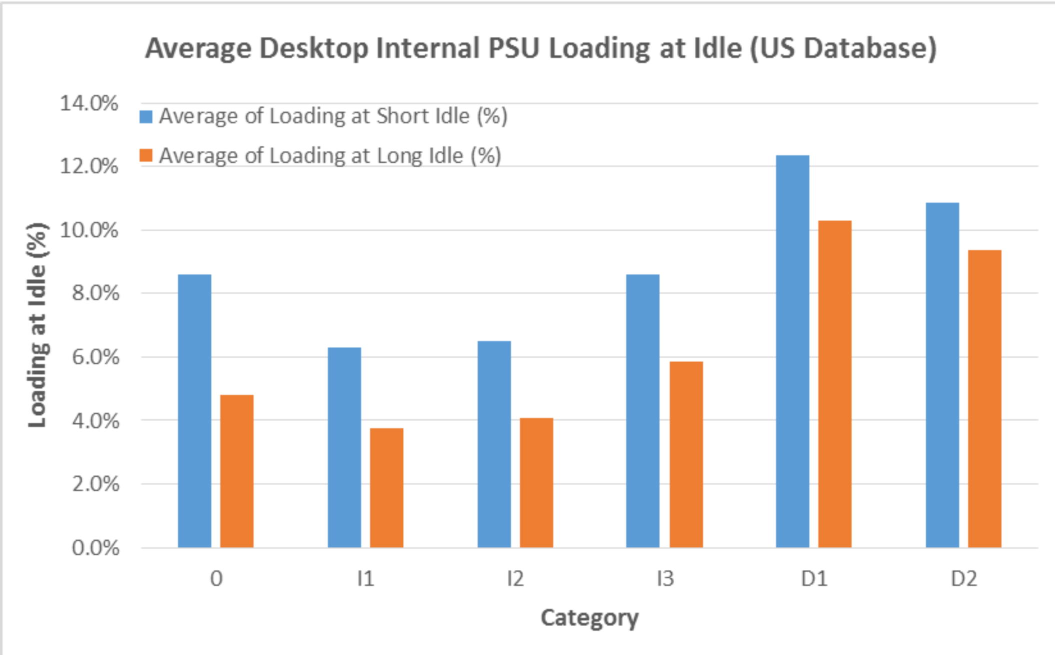

Figure 35 – Average Internal PSU Loading at Short and Long Idle for Desktop Computers in the US ENERGY STAR database

External Power Supply Units

Whist internal PSU's are traditionally used in desktop computers, external PSU's are used to supply mains power to notebook computers and many other types of electronics products (including some desktop and integrated desktop computers). External PSU's will not be investigated in detail within this report as they are already subject to ambitious regulatory measures in most major markets around the world.

Integrated Displays

Integrated displays in notebook and integrated desktop computers can use a significant amount of energy with this energy usage generally increasing with increased display size and with increased display resolution. The EU Ecodesign Regulation does not address energy use of integrated displays as the Regulation was based on the older ENERGY STAR v5.0/5.2 specification which required that all integrated displays were turned off during power demand testing so that only the computing components of computers were power tested. However, it was recognised that the energy use of integrated displays is an important consideration and so the energy efficiency of these parts of notebook and integrated desktop computers are covered under the ENERGY STAR v6.1 specification.

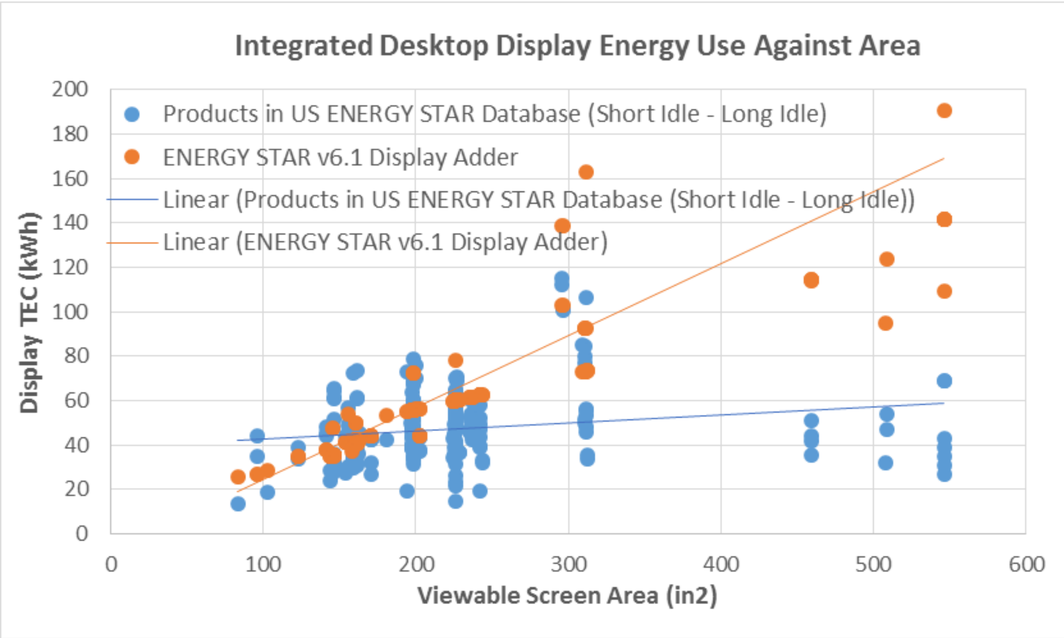

Figure 36 – Estimated ENERGY STAR v6.1 TEC of Displays and Allowances in Integrated Desktop Computers Listed in the US ENERGY STAR database (May 2015) against Viewable Screen Area

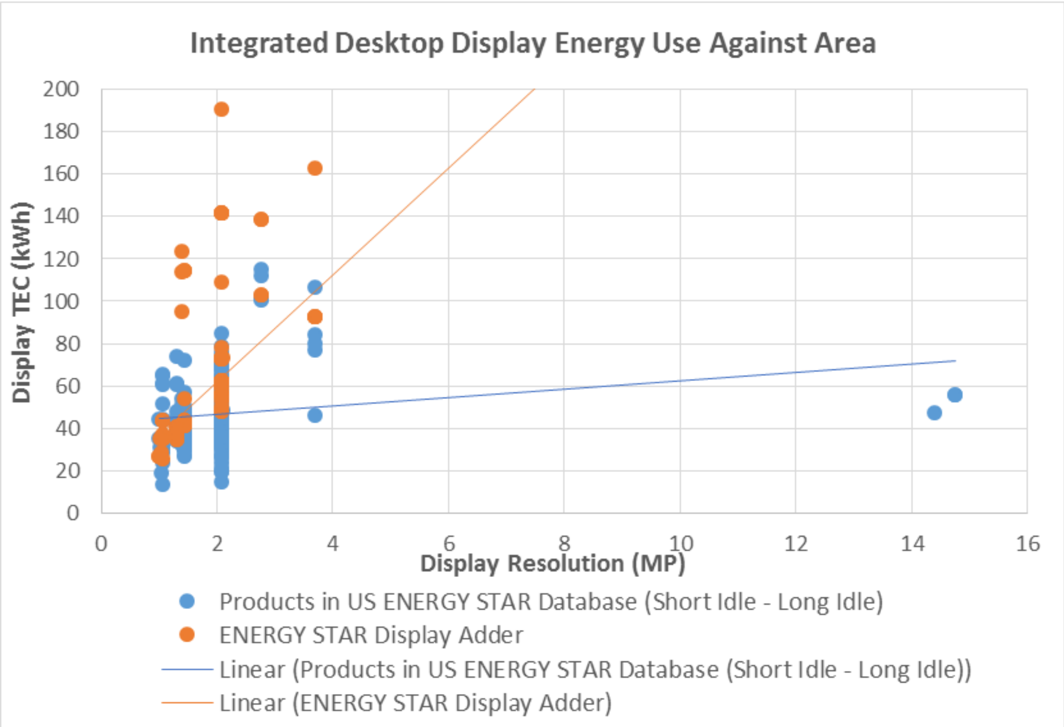

Figure 37 – Estimated ENERGY STAR v6.1 TEC of Displays and Allowances in Integrated Desktop Computers Listed in the US ENERGY STAR database (May 2015) against Resolution

The ENERGY STAR v6.1 database was used to assess the current performances of integrated displays within notebook and integrated desktops with the results shown in Figure 36 and Figure 37. It is important to note that the actual power demand (and hence energy use) of integrated display is not measured directly as part of the ENERGY STAR v6.1 test procedure and so power demand was estimated by subtracting the long idle power demand (which is measured with integrated displays turned off) from the short idle power demand (where the integrated display is turned on during testing). Taking this approach has the effect of overestimating the power demand used by integrated displays as other components (e.g. Hard drives and dGfx's) are also power managed during long idle. As such, the power demand (and consequently energy use) for the integrated displays shown in the results below are over estimated meaning that the actual difference from the ENERGY STAR specification lines (which are not impacted by this overestimation) would be larger than shown if the integrated displays were power tested directly. Even with this overestimation of integrated display power demand, it is clear from Figure 36 and Figure 37 that the ENERGY STAR v6.1 integrated display allowances are too generous by a significant margin. As with the dGFx's this is an important issue because the integrated display allowances under ENERGY STAR v6.1 are not ring fenced meaning that any excess allowance can be used to compensate for inefficiencies elsewhere in the computer. The findings suggest that future specifications dealing with integrated displays of notebook and integrated desktop computers should be significantly more ambitious than those laid down in the ENERGY STAR v6.1 specification.

Storage

All desktop and notebook computers have some means of storing data. This is usually accomplished through the inclusion of a hard disk drive (HDD) or solid state drive (SSD). Some computers may have multiple storage devices to increase storage capacity. Allowances for additional internal storage devices, such as HDDs and SSDs, beyond a first storage device are a common element within the EU Ecodesign Regulation and ENERGY STAR specifications for computers. These additional allowances are given as it is presumed that additional storage devices will also have significant power demands when the computer is in an idle or sleep mode. The EU Ecodesign Regulation allows for an additional 25kWh/year for additional internal storage devices in desktop computers and 3 kWh/year in notebook computers. The ENERGY STAR v6.1 specification allows for 26kWh/year in desktop computers and 2.6kWh/year in notebook computers.

However, it is unclear if these additional allowances are required as secondary storage devices can be power managed into a low power state where they draw minimal power demand. The Mac and Linux operating systems both have utilities included to power manage secondary storage devices. Whilst the Windows 8.1 operating system does not natively support this functionality, there are third party applications that can perform this functionality on windows computers. Traditional HDDs and SSDs can have low power demands as low as 0.25W (equivalent to around 1kWh/year for desktops and notebooks under the ENERGY STAR v5.2/EU Ecodesign Regulation test procedure and 1.6kWh/year for desktops and notebooks under the ENERGY STAR v6.1 test procedure). Newer types of PCIe SSDs coming to market have been shown to use as little as 2mW (0.002W) during low power states[16]. This would equate to less than 1kWh/year under the ENERGY STAR v6.1 test procedure.

Given the fact that secondary storage devices can be power managed, and the fact that low power demand in most types of drives can be very low, it suggested that future initiatives do not grant additional allowances to secondary storage devices for desktop or notebook computers (neither for similar form factors such as workstation computers). The exception to this no additional allowance stance should be when computers have RAID configured storage devices as multiple disk drives are seen as a single drive when using this technology, meaning that additional drives cannot be power managed.

Memory

All computers include a certain amount of random access memory (RAM) to enable the computer to function. Most desktops, and to a lesser extent notebooks, are highly configurable in terms of the amount of RAM that can be installed. The EU Ecodesign Regulation took the same stance as the ENERGY STAR v5.2 specification and assigned a base amount of RAM per product type and category. Any additional RAM over the base amount is awarded 1 kWh/year for desktop computers and 0.4kWh/year for notebook computers. The ENERGY STAR v6.1 specification takes a different approach and provides an allowance of 0.8kWh/year for each GB of RAM installed in either a desktop or notebook computer.

Checking the ENERGY STAR development files provides no real evidence concerning how these levels were developed. Analysis conducted as part of this SEAD computer working group project suggests that

16 http://www.anandtech.com/show/8979/samsung-sm951-512-gb-review

the additional allowances given in the EU Ecodesign Regulation and the ENERGY STAR v6.1 specification may be too generous. This is an important consideration as the relatively new DDR4 memory architecture will allow for much higher RAM capacity DIMMs. Table 6 illustrates the RAM allowances under ENERGY STAR v6.1 for different amounts of installed RAM within desktop and notebook computers. Will DDR4 RAM modules expected to be offered in 64GB and 128GB capacities it is clear that RAM allowances could easily be higher than allowances for the rest of the computer system combined (e.g. the highest specification notebook computer (D2 category) under ENERGY STAR v6.1 has a base allowance of just 18kWh/year with a maximum additional allowance of 60kWh/year for a G7 discrete GPU).

	Desktop and Notebook
Installed RAM (GB)	TEC (kWh/year)
4	3.2
8	6.4
16	12.8
32	25.6
64	51.2
128	102.4

Table 6 – ENERGY STAR v6.1 Allowances for varying amounts of installed RAM

DDR4 RAM also includes an enhanced power management functionality called "deep power down" which allows a RAM module to go into a sleep mode that requires no refresh of the memory. In addition DDR4 will allow the refreshing of individual chips on a DIMM rather than needing to refresh all of the DIMM. The large capacity of DDR4 DIMMs in conjunction with the enhanced power management functionality increase the need for energy efficiency initiatives to take a closer look at RAM allowances to ensure that excessive amounts of allowance are not being given.

As part of this SEAD project the power demands of example RAM modules were sourced from various manufacturer websites and then converted to TEC values. It is currently unclear how power states of RAM modules match with the power modes of desktop and notebook computers. That is, it is not clear whether RAM modules are able to enter sleep modes during computer's idle modes. It is suggested that additional work needs to be carried out in this area. Given the uncertainty of matching up the RAM states with the computer power modes, the TEC values were developed under three different scenarios:

a. RAM idle, sleep and off power demands matched with the time the computer spent in each of these power modes
b. RAM long idle power demand used when the computer was in short idle with RAM power demand in sleep mode and off mode matched to the computer use time in sleep and off mode
c. RAM sleep mode power demand assigned to the short and long idle usage hours in computers with RAM off mode power assigned to the time the computer spends in off mode.

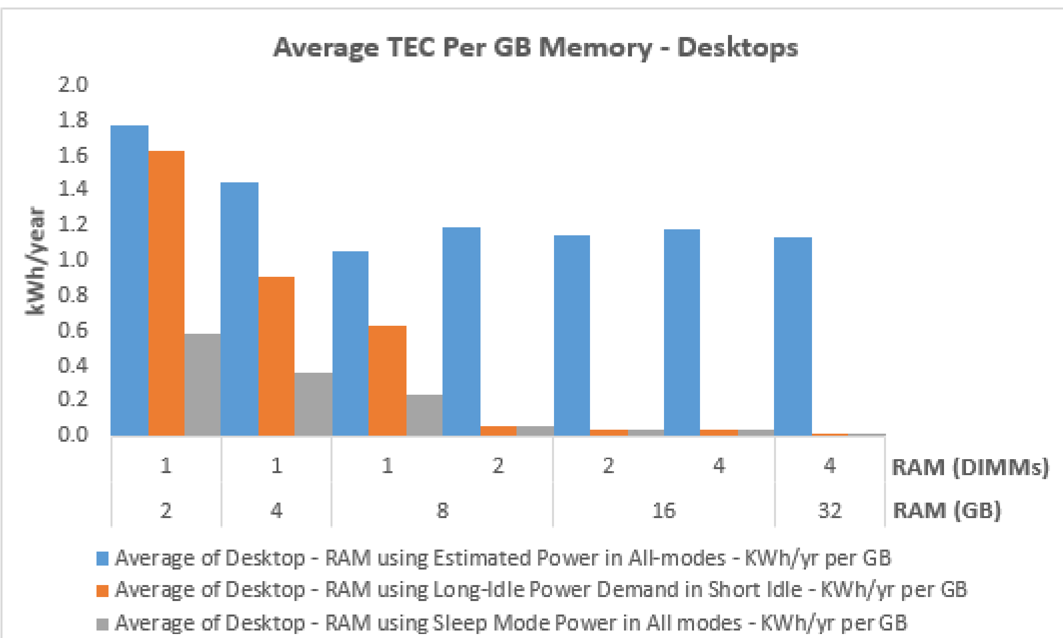

Figure 38 – Average Desktop based TEC per GB of RAM for Sample RAM Modules

Figure 38 shows the varying amount of TEC per RAM module and per GB of RAM when used in desktop computers. It is clear that the way in which RAM is power managed has a significant impact on its total energy use. The extremely low values under 0.2kWh per GB of RAM are based on power demand values sourced for DDR4 RAM.

Figure 39 shows the same calculations as illustrated in Figure 38 but using the ENERGY STAR v6.1 notebook use profiles. Again it is clear that the potential energy use by RAM, especially DDR4 RAM, could be significantly below the allowances provided for in current energy efficiency initiatives.

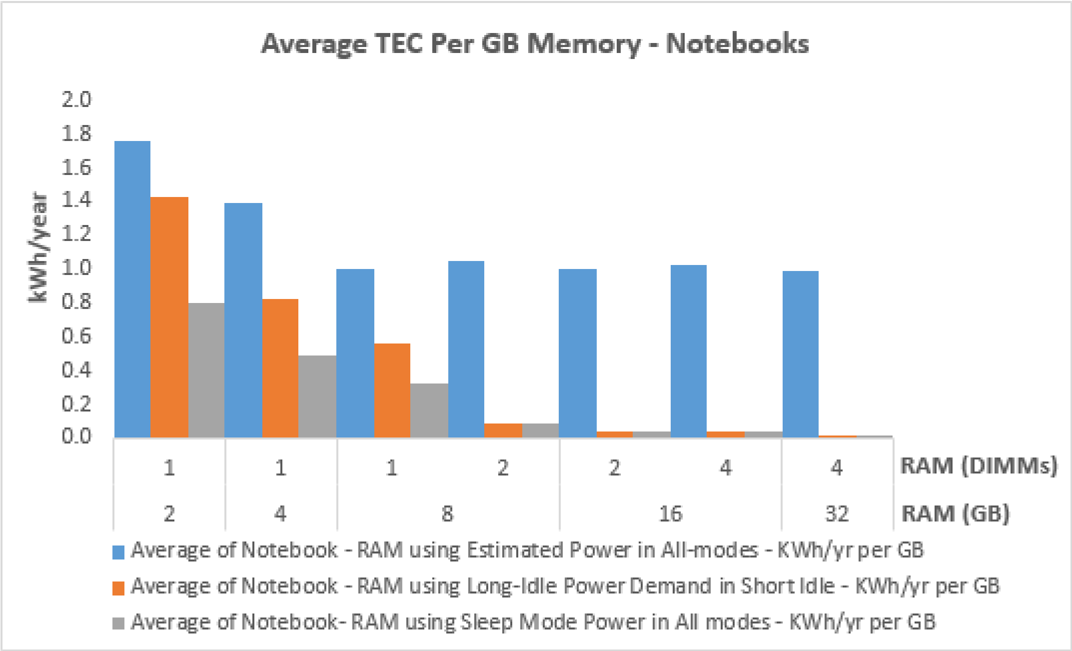

Figure 39 – Average Notebook based TEC per GB of RAM for Sample RAM Modules

Figure 40 and Figure 41 show the total energy use in kWh/year for example memory modules included in desktop and notebook computers. It is clear from the results that when the RAM idle, sleep and off power demands are matched with the time the computer is expected (i.e. under the ENERGY STAR v6.1 use profiles) to spend in each of these power modes the total RAM is strongly correlated with total energy use. However, when some degree of power management is used in the RAM modules then the number of RAM modules installed is more strongly correlated to total energy than total GB's of RAM. As such, it is suggested that when developing or refreshing RAM allowances in energy efficiency initiatives close attention should also be given to whether allowances should be based on total installed numbers of DIMMs rather than total GB of RAM. Indeed basing allowances of numbers of RAM DIMM's rather than GB of RAM would also reduce the chances of excess RAM allowances being allocated to products since numbers of available DIMM's in a product are significantly more limited that total GB of RAM.

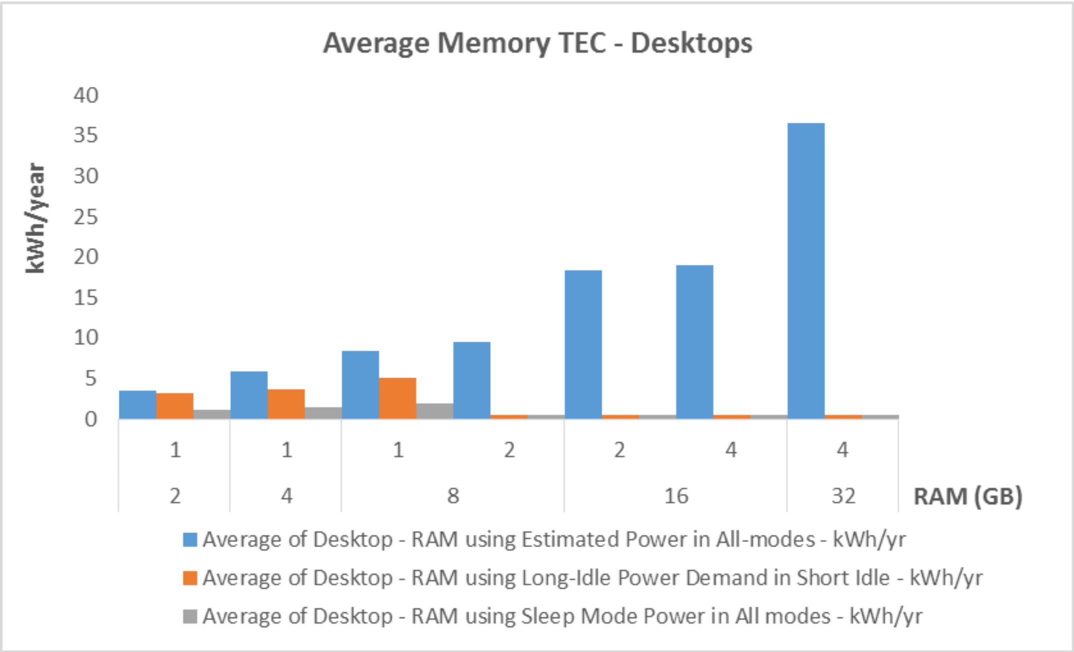

Figure 40 – Average Desktop based TEC for Sample RAM Modules

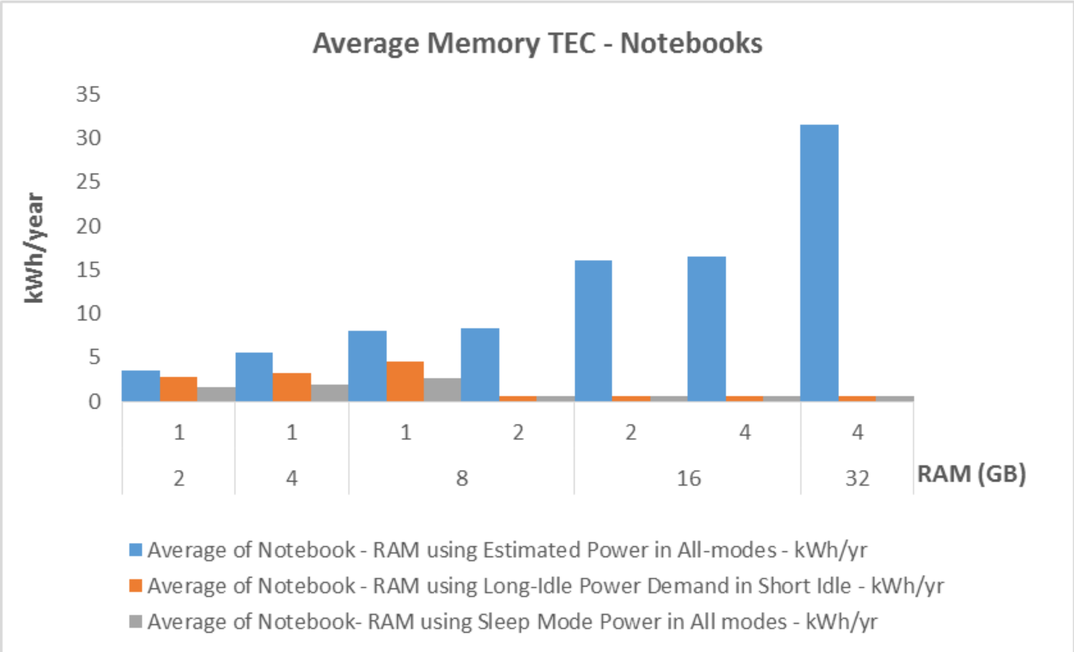

Figure 41 – Average Notebook based TEC for Sample RAM Modules

Additional Technical Features for Energy Efficiency

As well as reviewing base, graphics, display, storage and memory allowances, as well as the inclusion of active mode efficiency requirements, there are a number of other issue areas that future energy efficiency initiatives could investigate further in order to drive energy efficiency in computers. Some of these other issues are explored below:

- ### Panel self-refresh

  Within a typical computer images are sent to a display at a constant rate of at least 60 Hz (i.e. video processing components send an image to a connected display at least 60 times per second which is known as the "refresh rate" or "vertical frequency") even when there is no change in the image. Panel self-refresh (PSR) technology relies on the inclusion of a small piece of RAM in a display to store the last screen update therefore allowing computer components that support video playback (e.g. GPUs, CPU, RAM) to be power managed when a display is not being refreshed. With this installed memory the panel in the display can be continually repeated until the user or computer instructs the display to change the image. PSR is supported within existing display standards (e.g. Embedded DisplayPort (eDP)).

  Panel self-refresh was primarily designed to support increased energy efficiency in notebook computers in order to extend battery life. However, the inclusion of this technology in normal external displays could help to facilitate enhanced power management of dGFx's and other components in desktop computers. Energy efficiency initiatives could look to include requirements for the support of PSR within both display and computer specifications.

- ### Software Enhancements

  Both desktop and notebook computers generally include a plethora of options for reducing power demand through software alterations. These can be basic options such as ensuring that the power management settings are set to power down a computer to sleep after a predetermined length of inactivity but can also include more comprehensive changes to the BIOS of the computer. A result report published by Aggios to inform the Californian Energy Commission (CEC) rule making process on computers showed that the idle power demand of example desktops could be reduced by almost 50% through comprehensive power management software fixes alone[17]. Energy efficiency initiatives could move beyond simply setting basic power management requirements on products to looking at all power management functionalities included within modern day computers in order to enhance savings levels.

- Segregation of Mobile and Non-Mobile Products

  Mobile (e.g. notebook computers) and stationary (e.g. desktop computers) are most frequently treated as separate product types in most energy efficiency initiatives with stationary devices being afforded much higher allowances. This approach is taken because mobile computers are traditionally designed to be significantly more energy efficient that stationary computers in order to extend useful battery life (i.e. the amount of time the products can be operated on battery power before recharging via a mains outlet is required). Given that stationary computers often had significantly higher computational performances and on average cost considerably less than mobile products this distinction between mobile and stationary computers was continued in energy efficiency initiatives. However, the cost and performance differences between mobile and stationary computers are now much smaller than in the past so energy efficiency initiative could carefully consider whether all stationary computers, regardless of computational performances, should continue to be given much higher energy or power allowances than similarly performing mobile products.

17 Aggios, 2015, "Desktop Computer Optimization Analysis and Demonstration Project - Final Report V1.0, May 31st 2015", available from http://docketpublic.energy.ca.gov/PublicDocuments/14-AAER-02/TN204795_20150531T234825_Vojin_Zivojnovic_Comments_Desktop_Computer_Optimization_Analysi.pdf

5. Conclusion

This SEAD report has shown that the energy efficiency performance of current desktop, integrated desktop and notebook computers on the market is superior to the EU Ecodesign Regulation requirements and the ENERGY STAR v6.1 specifications. The report has stated that this is in no way a criticism of the two initiatives but merely indicates that the time is probably right for both initiatives to be refreshed so that they better reflect the energy efficiency of computers currently on the market.

The report has shown that the current energy efficiency levels of some discrete graphics cards (dGfx's), integrated displays, RAM memory, storage and internal power supplies (PSU's) are well in advance of allowances given for these components in either the EU Ecodesign Regulation or the ENERGY STAR v6.1 specification. As such, the requirements placed on these components within both initiatives need to be reviewed and updated.

The report has also shown that additional energy savings could be achieved through energy efficiency initiatives addressing the active mode of dGfx's, paying closer attention to the motherboards used in products and encouraging the uptake of innovative technologies such as panel self-refresh (PSR). In addition it was suggested that on refresh initiatives, such as the EU Ecodesign Regulation and ENERGY STAR, investigate the potential savings from enhanced power management settings and inclusion of new low power modes with quick wake up times.

Lastly, on refresh both initiatives could take the bold step of breaking from the traditional of setting separate specifications for stationary and mobile computers and instead set specification based on computational performance regardless of form factor.