U.S. Residential IT Equipment Energy Consumption

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ABSTRACT

TIAX carried out a study to quantify the energy consumption of U.S. residential Information Technology (IT) equipment in 2005 and develop scenario-based projections for 2010 (TIAX 2006). This paper presents the key findings of this study for 2005 only, focusing on ten key equipment types. Prior studies found that PC and monitors accounted for a majority of residential IT energy consumption, but the project team determined that the existing usage data by mode for these devices had very large uncertainties. Consequently, TIAX independently commissioned a survey to assess residential IT usage patterns in 2005 that posed a dozen questions to people in 1,000 demographically-representative households about the usage patterns for up to three computers per household. The responses to the survey questions yielded more accurate estimates of PC and monitor use and, thus, improved the accuracy of the energy consumption estimates for those devices. Overall, U.S. residential IT equipment consumed about 42TWh of electricity in 2005, or about 0.46 quads of primary energy. This translates into approximately 3% of residential electricity consumption and 1% of total U.S. electricity consumption and about 2.4% and 0.4% of residential and total U.S. primary energy consumption, respectively. Desktop PCs and monitors account for about two-thirds of the energy consumed by the key equipment types. Relative to prior estimates of residential IT energy consumption, the current total is much higher, primarily because the new usage data indicate that PCs and monitors spend much more time in active mode.

Introduction

Over the past decade, the widespread commercialization of the Internet, increased integration of IT in peoples' lives, and consistently large gains in equipment capability and functionality coupled with consistent decreases in equipment costs have resulted in a dramatic increase in the use of information technology (IT). Consequently, residential IT equipment has begun to have an impact on residential electricity and energy consumption. An earlier study estimated that residential IT equipment consumed 16.5TWh of electricity in 2001 and that desktop PCs and monitors represented more than 75% of the total (Nordman and Meier 2004).

Although the earlier study indicates that residential IT accounted for a small portion (about 1%) of residential energy consumption in 2001, recent trends suggest that it may have increased substantially since then as the quantity of PCs and other IT equipment in residences has increased, as may have utilization of IT equipment (e.g., due to greater deployment of broadband Internet connections and home networks). Furthermore, the earlier data used to estimate PC and monitor usage had limitations that resulted in a high degree of uncertainty for the energy consumption estimates for those devices.

To support its strategic planning efforts, the U.S. Department of Energy, Building Technologies Program (DOE/BT), contracted TIAX to develop an estimate of U.S. residential IT equipment energy consumption in 2005 and scenario-based projections for 2010. This report describes the methodology and key findings of the evaluation of residential IT energy consumption in 2005.

Equipment Considered for Analysis

Homes contain a wide range of energy-consuming IT equipment. The definition of what equipment falls under the scope of this study is somewhat arbitrary. For instance, IT could, potentially, encompass a broad range of different equipment types, ranging from office equipment to telephony to many consumer electronics (e.g., televisions, personal audio products, etc.). Due to the scope limitations of this study, however, the project team only considered and modeled the energy consumption of a limited subset of equipment types (see Table 1).

Table 1. Potential and Selected Key Equipment Types

Potential Key Equipment (Key equipment types in BOLD)
Broadband Access Devices (cable and DSL modems, satellite)
Cellular/Wireless Phone
Copy Machines
Desktop PCs
Digital Set-Top Boxes with Personal Video Recorder (PVR)
Facsimile Machines
Fiber Optic Terminal (w/ Fiber to the home [FTTH])
Home Routers (wired and wireless)
Home Servers
Inkjet Printers
Laptop PCs
Laser Printers
Monitors
Multi-Function Devices (MFDs)
Personal Digital Assistants (PDAs)
Scanners
Uninterruptible Power Supplies (UPS)
Voice Over IP Adaptor (VoIP)

To focus the analysis on the equipment types that account for most residential IT energy consumption, the team selected ten key equipment types for evaluation (see Table 1). The selections reflect preliminary estimates of current (2005) energy consumption, as well their projected impact in 2010. Subsequently, the team analyzed the energy consumption of each key equipment type in 2005.

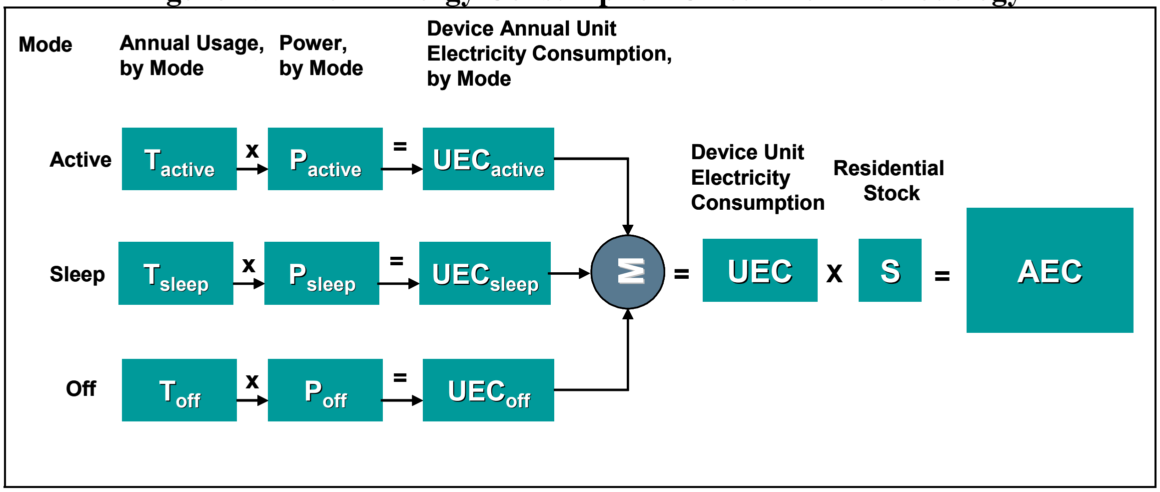
National Energy Consumption Modeling

Energy Consumption Calculation Methodology

Figure 1 depicts the basic methodology used to develop the annual energy consumption (AEC) estimates.

For each equipment type analyzed, the average unit energy consumption (UEC, in kWh) of a single device for an entire year was calculated. The UEC equals the sum of the products of the approximate number of annual hours that each device operates in a residential setting in each power mode and the average power draw in each mode. The product of the residential stock (i.e., installed base) and UEC equals the AEC for that equipment type.

Figure 1. Annual Energy Consumption Calculation Methodology



Source: ADL 2002

The following subsections describe the approaches used to develop values for the different components of AEC calculations.

Residential equipment stock. The residential building equipment stock simply means the number of devices in use in residential buildings. Stock estimates primarily came from published estimates, such as industry market reports, the EIA Residential Energy Consumption Survey (RECS), the TIAX Survey (see subsequent section), and other research reports. Overall, residential stock estimates appear to have the smallest uncertainty of the three components of the AEC calculations. Table 2 displays the stock estimates for the different key equipment types; the full report (TIAX 2006) provides details about the stock estimate calculations.

Table 2. Residential Stock Estimates in 2005 for Key Equipment Types

Equipment Type	Stock Estimate [millions]
Broadband Access Devices	32
Desktop PCs	85
Inkjet Printers	75
Laptop PCs	36
Monitors	85
Multi-Function Devices (MFDs)	13
Digital Set-Top Boxes with Personal Video Recorder (PVR)	10
Uninterruptible Power Supplies (UPS)	8.5
Voice Over IP Adaptor (VoIP)	1.5
Home Routers (wired and wireless)	15

Power draw by mode. The AEC values are based on power draw estimates for different equipment types in each relevant mode of operation. For each mode, the power draw value represents the best estimate for the average power draw of all of the different devices included in a single equipment type. Whenever possible, the active mode power draw values reflect actual power draw measurements as opposed to the device rated power draw. Rated power draws represent the maximum power that the device's power supply can handle and often exceed typical active power draw values by at least a factor of three (see, for example, ADL 2002). Table 3 displays the power draw by mode estimates for the different key equipment types; TIAX (2006) provides details about the estimates, including the sources used to develop each estimate.

Table 3. Power Draw by Mode Estimates in 2005 for Key Equipment Types

Equipment Type	Average Power Draw by Mode		
	Active	**Sleep**	**Off**
Broadband Access Devices	6	n/a	n/a
Desktop PCs	75	4	2
Inkjet Printers	13*	5	2
Laptop PCs	25	2	2
Monitors	45	2	1
Multi-Function Devices (MFDs)	19*	11	7
Digital Set-Top Boxes with Personal Video Recorder (PVR)	27	25**	n/a
Uninterruptible Power Supplies (UPS)	9	6	6
Voice Over IP Adaptor (VoIP)	6	4**	n/a
Home Routers (wired and wireless)	6	n/a	n/a

*Ready to print for inkjet printers and MFDs. **On-ready mode for set-top boxes and VoIP adaptors.

Usage patterns. A device's usage pattern refers to the average number of hours per week that a device spends in a given mode. Most equipment types have several different modes that are typically condensed into three distinct modes (see Table 4). In many cases, power management (PM) strategies and their degree of implementation have a major impact on the amount of time spent in the active and sleep modes.

Table 4. Office Equipment Usage Modes

Mode Type	Description	Example
Active	Device carrying out intended operation	• Monitor displays image • Copier printing
Sleep	Device not ready to carry out intended operation, but on	• Monitor powered down but on • Copier powered down but on
Off	Device not turned on but plugged in	• Monitor off, plugged in • Copier off, plugged in

Table 5 displays the usage patterns estimated for the different key equipment types; TIAX (2006) provides details about the estimated usage patterns. Overall, device usage patterns have the greatest uncertainty of any component of the AEC calculations.

In contrast to commercial building IT equipment, very few measurements exist for residential IT usage. Most prior studies of residential IT energy consumption have used informed estimates for usage by mode (e.g., Nordman and Meier 2004, Kawamoto et al. 2001). One survey, the EIA Residential Energy Consumption Survey (RECS), asked respondents to estimate weekly PC usage and reported results in very broad time bands (e.g., 2-15 hours, 16-40 hours, 41+ hours; EIA 2001). Although these data were the best available prior to this study, they provide only a general feel for PC active mode usage and do not directly address time spent in sleep and off modes. Because desktop PCs and monitors appear to dominate residential IT energy consumption (per Nordman and Meier 2004, Kawamoto et al. 2001), TIAX[1] commissioned a phone survey to develop more refined and up-to-date estimates for PC and monitor usage by mode (henceforth referred to as the "TIAX Survey"). The following subsection discusses the survey and its findings in more depth.

Table 5. Usage Patterns Estimates in 2005 for Key Equipment Types

Equipment Type	Average Annual Hours by Mode		
	Active	Sleep	Off
Broadband Access Devices	8,760	0	0
Desktop PCs	2950	350	5460
Inkjet Printers	50*	1610	7100
Laptop PCs	2370	930	5460
Monitors	1860	880	6020
Multi-Function Devices (MFDs)	50*	1610	7100
Digital Set-Top Boxes with Personal Video Recorder (PVR)	2890	5870**	0
Uninterruptible Power Supplies (UPS)	2500	1070	5180
Voice Over IP Adaptor (VoIP)	360	8400**	0
Home Routers (wired and wireless)	8760	0	0

*Ready to print for inkjet printers and MFDs. **On-ready mode for set-top boxes and VoIP adaptors.

TIAX Residential IT Usage Survey

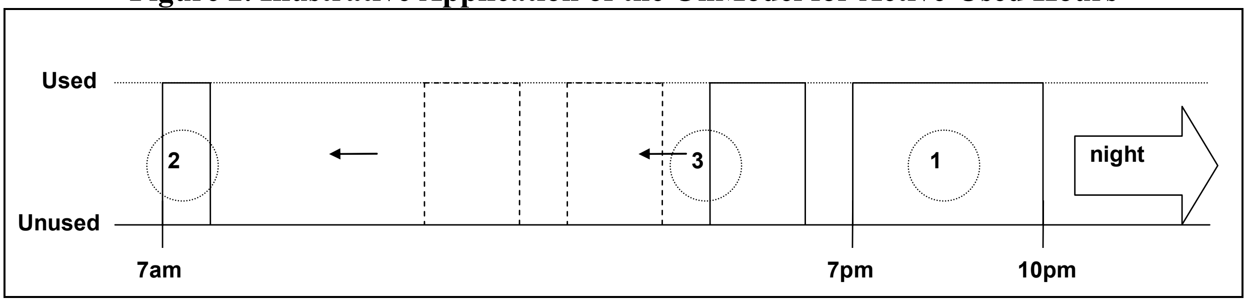
The TIAX survey[2] posed twelve questions to 1,000 demographically-representative households about the usage patterns of up to three PCs and monitors used most often in each household. The final usage estimates equal the average of the usage values calculated for each device. The team developed two models to translate the TIAX survey responses into daily weekday and weekend usage patterns for each residential PC and monitor. For both models, the assumptions made (discussed below) reflect the team's best estimates of how people typically use PCs at home; they are not derived from actual data for the time of day when PCs are used. On the other hand, the two models do approximate upper- and lower-bound cases for residential PC usage. The first model, known as the OffModel, assumes that the user turns off her PC outside the timeframe that the PC has the potential to be routinely used. The second, known as the OnModel, makes the opposite assumption, i.e., that the PC remains on. The current (i.e., 2005) usage estimates presented for PCs and monitors use the "OffModel"; applying the "OnModel" approach increased desktop PC and monitor AEC by approximately 30% and 25%, respectively.

The survey explicitly asked how many hours each PC (and, thus, its monitor) is actively used on both weekdays and weekend days and both models directly incorporate this data. Using the data from the TIAX Survey, each model also calculates the hours each PC and its monitor spend active-unused, sleeping, and off per week based on a used-hours allocation algorithm, model-specific assumptions, and a weighting mechanism that reflects the average likelihood that the PC and its monitor will be turned off during the day when not in use and overnight. Specifically, both models assume that a PC is most likely to be continuously used from 7pm to 10pm during a typical weekday and 3pm to 5pm for weekend days (the following discussion focuses on weekday hours).

[1] This survey was funded in its entirety by TIAX LLC, i.e., no government funds were used to carry out the survey.
[2] An appendix in the full report (TIAX 2006) contains the TIAX Survey.

OnModel. The usage pattern for the OnModel first allocates active-used time in the 7pm-10pm window (labeled "1" in Figure 2). If additional active-used hours remain, the model subsequently allocates a half hour of usage at 7am (labeled "2" in Figure 2), i.e., it assumes that the PC is turned on first thing in the morning. It then allocates remaining active-used hours by adding a ½-hour active-unused break before 7pm (assuming that users often take a break from their PCs instead of continuously using them[3]), followed by up to a 2-hour active-used period (labeled "3" in Figure 2). If active-used hours still remain, the algorithm repeats this ½-hour active-unused 2-hour active-used pattern as many times as necessary, working back to 7am until all the active-used hours have been allocated (see Figure 2). If additional hours remain, the algorithm converts the ½-hour active-unused periods to active-used to account for the remaining active-used hours (beginning with the ½ hour closest to the 7pm-10pm period, i.e., 6:30-7pm). Finally, if yet more time remains, the time during the 10-11pm period converts to active-used.

Figure 2. Illustrative Application of the OnModel for Active-Used Hours



Once turned on in the morning, the model uses the response to the question about how often users leave the PC on during the day if it is not used for more than half an hour to determine its daytime status. If they never do, the model assumes that the PC is turned off until the additional active-used hours later during the day (case ON_A). If they always leave their PC on during the day, the model assumes that the PC remains in active-unused for an hour. Subsequently, any time between that point in time and the time of the later active-used hours begin is allocated to active-unused and sleeping[4] based on the devices PM-enabled status (the ON_B case). The response to the question about how often users leave the PC on during the day if it is not used for more than half an hour is used to calculate the weighting between the ON_A and ON_B cases and calculate the average usage by mode (see Table 6).

For example if the response is that the person "often" leaves their PC on during the day if not used for more than half an hour, the ON_B case would receive a 75% weighting and the ON_A case a 25% weighting. The OnModel also consists of two weighted sub-models based on whether or not the PC is turned off at night. If the PC remains on at night, the hours will either be active-unused or sleep, depending on the PCs PM-enabled status (ON-$Night_A$). If the PC is turned off, it is off[5] (ON-$Night_B$). The weighting assigned to the two night models, ON-$Night_A$ and ON-$Night_B$, is determined by the response to the question about how often users typically turn off their PC at night and used to calculate the average usage by mode.

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[3] Implicit in this assumption is that the PC does not have sufficient time during the 0.5-hour breaks to enter sleep mode, an assumption generally consistent with the sleep-mode settings for new desktop PCs.

[4] In essence, the model assumes that a PC spends 1 hour in active-unused before sleeping.

[5] When PC usage is less than 3 hours per day, e.g., the active-use hours do not fill the 7pm to 10pm window, the algorithms assume that the PC is turned off immediately after the last used hour if the PC is turned off at night.

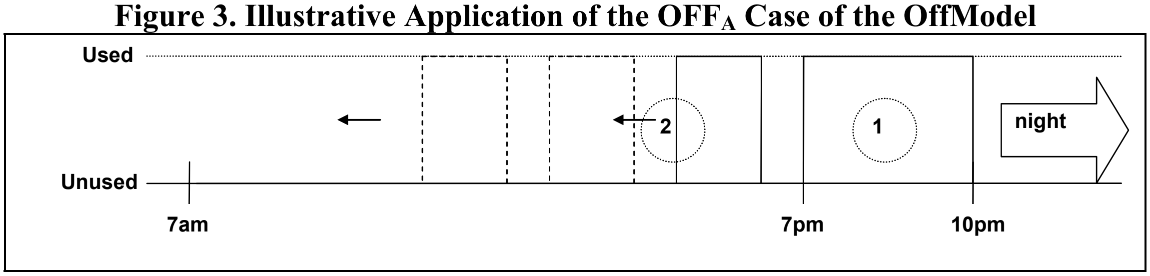
Table 6. OnModel Weighting Based on Survey Response

Survey Response	OnModel Weighting
Always	100%
Almost always	90%
Often	75%
About half the time	50%
Occasionally	25%
Rarely	10%
Never	0%

For weekend usage, the algorithm first allocates time from 3pm to 5pm and then propagates the ½-hour active-unused / 2-hours used allocation sequence before 3pm. If additional active-used hours still remain, it then begins to convert the ½-hour active-unused periods to active-used (as with the weekday model) and, subsequently, assigns hours *continuously* (i.e., without ½-hour active-unused periods) after 5pm to active-used until all of the active-used hours have been allocated. In the OnModel, the day is assumed to begin at 9am (versus 7am on weekdays). The nighttime calculation procedure does not change.

OffModel. The OffModel uses both the OnModel and another model, depending on the night status of the device. If the device is always off at night, the OffModel assumes that the device is **not** turned on at 7am (or 9am on weekends). Instead, it first allocates active-used hours in the 7pm-10pm (or 3pm-5pm) window (labeled "1" in Figure 3) and any additional active-used hours via the ½-hour active-unused / 2-hours active-used allocation sequence described above (labeled "2"), followed by conversion of 0.5-hour active-unused periods to active-used and, if necessary, addition of the 10-11pm period (case OFF_A). All remaining daytime hours are off hours.

Figure 3. Illustrative Application of the OFF_A Case of the OffModel

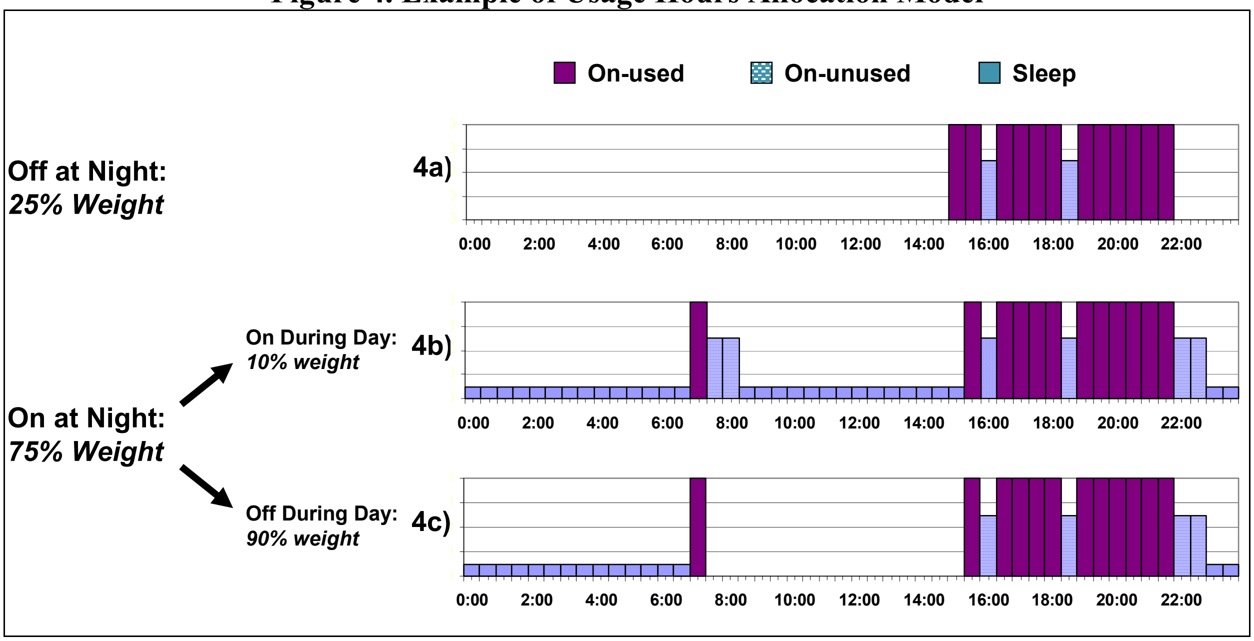


If the device always remains on at night, the OffModel uses the OnModel to calculate the usage pattern (case OFF_B). The weighting assigned to cases OFF_A and OFF_B is determined by the response to the question about how often users typically turn off their PC at night and used to calculate the average usage by mode. In all cases, monitors were assumed to have the same basic usage patterns as their PCs, albeit using the monitor PM-enabled and night status information instead of that for the PC.

For example, the model would allocate hours as follows for a person responding that she typically used her PC six hours a day and always (100% weight to OffModel) turned off her PC at night. First, the OffModel would allocate three hours to the 7-10pm period. Next, it would allocate an additional 2 hours to the 4:30pm-6:30pm period, assigning ½ hour to active-unused between 6:30pm and 7pm. Finally, it would assign the remaining hour to the 3pm-4pm period, with an additional ½ hour active-unused between 4pm and 4:30pm. In total, the model allocates six hours active-used, one hour active-unused, and seventeen hours off per day.

If, however, she responded that she turned off her PC at night occasionally (25%) and rarely (10%) left her PC on after not using the PC for more than half an hour during the day, and her PC was found to have PM enabled, the calculation becomes more complex. In that case, the model calculates daily usage in two ways and weights them appropriately to derive the usage estimate. For the 25% of the days when the PC was turned off at night, the usage calculation uses the process described in the prior paragraph and receives a 25% weighting (see Figure 4a). For the 75% of the days when the PC remained on at night, the model allocates hours based on two usage scenarios based on her "rarely" response that indicates that she left her PC on after not using the PC for more than half an hour during the day about 10% of the time: one for the estimated 10% of days that the PC remains on during the day (Figure 4b) and a second for the estimated 90% of days that the PC is turned off during the day (see Figure 4c).

Figure 4. Example of Usage Hours Allocation Model



Subsequently, the model weights the outputs from those two scenarios appropriately (10% and 90%) and sums them to obtain the average daily usage for the 75% of the days when the PC remains on at night. Finally, the model weights the model usage output for the 75% of the days when the PC remains on at night and that for the 25% of the days when the PC is turned off at night and sums them to obtain the average daily usage estimate for that PC.

Power management. Power management (PM)-enabled rates can have a significant impact on the UEC of a given device, notably when a device remains on overnight. Consequently, the TIAX survey also posed questions to ascertain the PM-enabled rates for each PC and monitor in the survey. Based on responses to the question: "If the computer monitor of the computer is left on, after one hour or more of no use, does it continue to display the same image, display a screensaver, or go blank?", residential monitors are estimated to have a PM-enabled rate of about 60%. This rate is consistent with the estimate of Nordman and Meier (2004) and similar to values from surveys of monitors in commercial buildings (about 70%; Roberson et al. 2004).

The project team also attempted to develop a meaningful question that users could readily answer to determine the PM-enabled status of PCs and solicited feedback from several people outside of TIAX. Ultimately, PM-enabled rates were derived from respondents' answers to the question: "If members of your household leave the computer on and do not use the computer for one or more hours, how long does it take for the computer to respond to moving the mouse or typing on the keyboard?." If respondents selected the response "In about ten or more seconds," PM was assumed to be enabled for that PC. Analysis of the responses to this question suggests a residential desktop PC power management (PM) enabling rate of about 20%, which is higher than the commercial sector rate of roughly 6% (Roberson et al. 2004). As one researcher points out, however, responses to the question may correlate more with monitor PM-enabled status, i.e., people realize if the monitor displays an image or not, and may prevent accurate characterization of the PCs' PM-enabled status (Webber 2006). Consequently, the approach taken may provide a general sense of desktop PC PM-enabled status but has appreciably uncertainty.

Results, Discussion, and Conclusions

This study finds that residential IT equipment in the U.S. consumed around 42TWh in 2005 (see Figure 5), or 3% of residential electricity consumption and 1% of U.S. electricity consumption (EIA 2005[6]). For comparison sake, residential IT is projected to account for about 1.4%[7] of electricity consumed in Germany in 2005 (Cremer et al. 2003). Translated into primary energy, residential IT accounts for 0.46 quads, which equals approximately 0.4% of U.S. primary energy consumption in 2005[8] (EIA 2005). The key equipment types represent about 90% of this total and other devices[9], including copy machines, facsimile machines, laser printers, and scanners, account for the remainder. In 2005, desktop PCs and monitors account for about 65% of residential IT energy consumption.

Comparison to Other Studies

The current estimate of residential IT energy consumption is more than twice as high as the Y2001 estimate of reference (Nordman and Meier 2004). In addition, the current estimate for the sum of desktop PC, laptop PC, and monitor AEC is about 35% greater than that used in the Annual Energy Outlook (AEO, from EIA 2005; see Figure 6). Overall, increased residential IT usage estimates for both PCs and monitors drive the higher levels of total AEC. Specifically, data from the TIAX Survey suggests that PCs and monitors spend at least *100% and 60%* more hours per week in active modem, respectively, than estimated by Nordman and Meier (2002)

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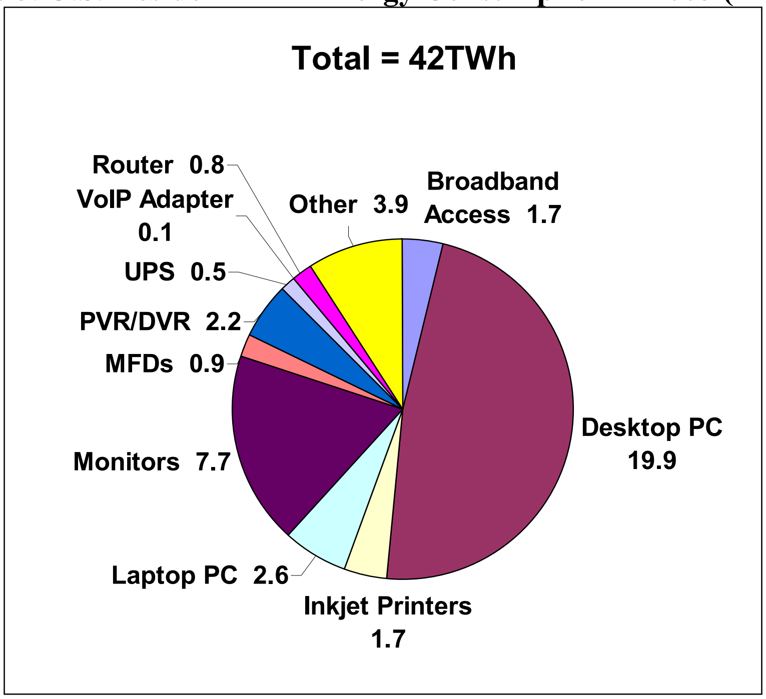
[6] Electricity consumption data for the entire U.S. and the residential sector from EIA (2005).
[7] This total includes additional devices not included in this study, including: Mobile phone chargers, personal digital assistants (PDAs), scanners, matrix printers, copiers, "active boxes," ISDN boxes, and assumes that 50% of set-top boxes and satellite receivers are digital devices in 2005.
[8] Assuming that each kWh of electricity requires the consumption of 10,913 Btus on average to generate, transmit, and distribute (BTS 2004).
[9] The values for these "other" devices come from Nordman and Meier (2004), with scanners accounting for around 75% of the total. As Nordman and Meier (2004) note, the value for scanners appears to be quite high. The AEC of at least three of the four "other" devices is probably decreasing as MFDs supplant scanners, facsimile machines, and copy machines.

(based on EIA 2001[10]). This occurs because a non-trivial minority of desktop PCs remains on overnight at least some portion of the time. On the other hand, the current study finds that 2005 residential IT energy consumption is less than half of projections of commercial IT energy consumption[11] from ADL (2002).

Figure 5. U.S. Residential IT Energy Consumption in 2005 (in TWh)



The authors believe that the current study provides a more accurate estimate of residential IT energy consumption than RECS for several reasons. First, the Survey posed more targeted questions about residential PC and monitor usage than RECS. Specifically, the TIAX Survey asked about the number of hours that people typically use PCs on both week and weekend days, how frequently PCs and monitors are left on overnight, how frequently PCs and monitors are left on during the day after a period of non-use, and also included questions designed to ascertain PM-enabled status of both PCs and monitors. In contrast, RECS obtained an estimate for total weekly hours that *all* of the PCs in a home were turned on and did not explicitly address time spent in sleep modes. Second, the TIAX Survey elicited information about the individual usage of up to three computers and their monitors for each household. As mentioned, RECS requested aggregate information about all PCs in a given residence. Third, the TIAX Survey allowed a much wider range of responses than RECS, i.e., respondents provided numerical estimates of both typical weekday and weekend residential PC usage. RECS, on the other hand, allowed less precise "broad bucket" response ranges for all PCs of: less than 2 hours, 2 to 15 hours, 16 to 40 hours, 41 to 167 hours, and 168 hours per week (EIA 2001). Finally the TIAX Survey was carried out in March of 2005, so it provides more recent data than RECS.

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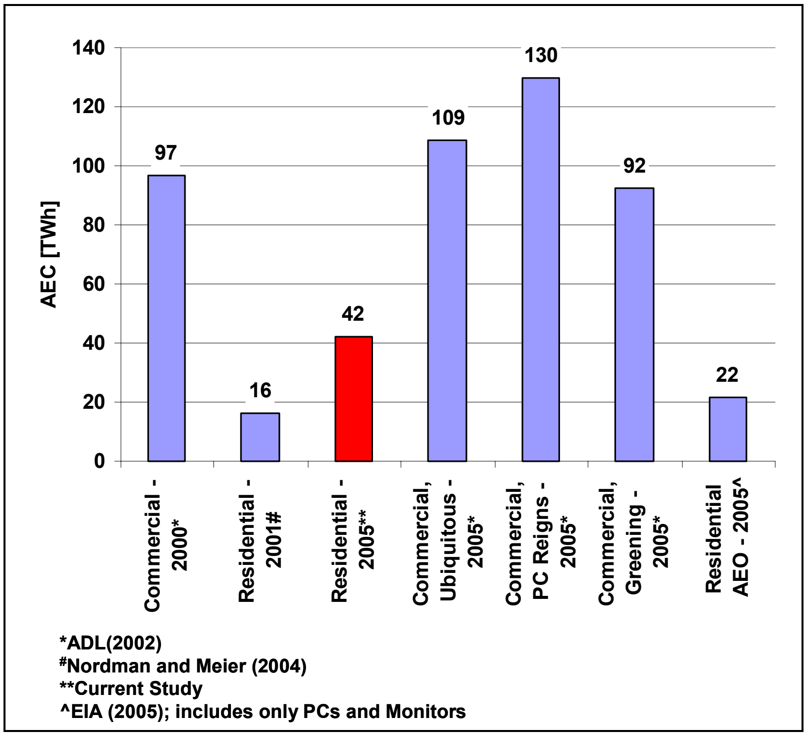
[10] For comparison sake, the active mode hours per year estimates for desktop PCs and monitors are more than four and five times greater than those for Germany in 2005 (from Cremer et al. 2003).

[11] The values shown for ADL (2002) equal the projections for the key equipment types divided by 0.9 to include energy attributed to other (i.e., non-key) devices.

Figure 6. Comparison of Current U.S. Residential IT Energy Consumption Estimate with Other Studies



Recommendations

This study yields one primary recommendation. Programmatically, data developed over the course of this study underscore the strong link between power management (PM)-enabling rates and residential IT energy consumption. The TIAX Survey suggests that residential PCs may have higher PM-enabling rates than commercial PCs (approximately 20% as compared to approximately 6%), while monitor PM-enabled rates appear to be around 60%. Nonetheless, increasing the PM-enabled rates of the population of both has a large energy saving potential that may well increase in the future as always-on operation of residential IT equipment becomes even more common. Consequently, programmatic actions that can increase the PM-enabled rate of PCs and monitors have a large energy saving potential.

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