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Modeling energy usage patterns of a PC and ways of improving it's energy efficiency

This paper describes current status of modeling energy usage patterns for PCs, provides insight in their energy consumption, energy costs and CO_2 emission. It also provides possible solutions for improving energy efficiency and energy savings. The study involved analysis of two different mode settings (High Performance and Power Saver mode) of same computer and gaming test case study. Usage patterns for both modes were modeled based on Intel®'s EEP methodology. Workload was simulated with StressMyPC freeware software. PC energy consumption while executing workload was measured with Trotec® BX11 measuring device during 15 days testing period, 8 hours a day. Computer and monitor were separately observed.

Keywords: *energy efficiency, energy saving, personal computer, usage pattern, workload.*

1. INTRODUCTION

Since begin of industrialisation the CO_2 in our atmosphere increased by 30%, half of it since 1970! The increase of the CO_2 concentration is linked to the expected climate change! [1] Big share of this CO_2 emissions is related to electricity production.

Table 1. Electricity consumption and per capita in 2011 [2].

Country	Electricity consumption [billion kWh]		Electricity consumption per capita [kWh per person]	
	2010	2011	2010	2011
Serbia	33,4	34,1	4 547,41	4 664,49
European Union	2 906	2 901	5 891,7	N/A
World	17 930	17 780	2 649,16	2 566,32

Energy efficiency is one of the most cost effective ways to enchance security of energy supply, and to reduce emissions of greenhouse gases and other pollutants. In many ways, energy efficiency can be seen as Europe's biggest energy source [3].

According to [4] energy efficiency definition is: The ratio of useful energy or other useful physical outputs obtained from a system, conversion process, transmission or storage activity to the input of energy (measured as kWh/kWh, tonnes/ kWh or any other physical measure of useful output like tonne-km transported, etc.).

Energy efficiency means using less energy inputs while maintaining an equivalent level of economic activity or service [3], [5].

Energy saving is a broader concept that also includes consumption reduction through behavior change or decreased economic activity [3], [5].

Energy efficiency in intra-logistics often means to account for direct energy savings such as those achievable through the use of energy efficient drives, lighting or heating. A more holistic view upon energy efficiency in logistics through the use of information technology considers all underlying processes with regard to their potential for direct and indirect energy savings. Information technology offers a high potential in achieving the climate protection goals by encouraging the reduction of energy consumption associated with a decrease of greenhouse gas emissions. Processes in logistics can be optimized by means of information technology (using SmartKanban for example) [6].

According to a study of the US federal environmental agency in about 10% of the electric power consumption is spent by information and comunication technique [3]. And with so many desktop and notebook PCs in use, they have a measurable effect on the world's energy use. [7]

The European Union (EU) has set its specific target of a 20% energy saving in energy consumption by 2020. The EU Commission has recognised information and communication technologies (ICTs) as an enabler that will play a key role in reducing energy consumption and increasing energy efficiency across the whole economy. While the ICT industry accounts for about 2% of global CO_2 emissions, ICTs can have a significant enabling capacity of reducing the remaining 98% of carbon emissions which come from the other sectors of the economy and of society [8].

This paper particularly deals with energy efficiency of ICT equipment (specifically PCs) and ways of

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improving it by simply changing usage patterns and consumers habits.

The first case study dealing with similar issues was published in 1994 [9]. There was conducted research of Energy Star® (ES) computers and printers. The US Environmental Protection Agency estimated that 30-40% of the nation's PCs are left running at night and on weekends. Based on the monitoring, the ES computer system is calculated to produce energy savings of 25.8% (121 kWh) over a year. Of the 25.8% overall energy savings, analysis of the metered data showed that most of the potential savings in that case came from a 37.5% reduction in printer energy use. Computer system user was displeased with slowness of the ES printer start-up cycle (printer reduces power use by turning off the fuser in sleep mode), but found no difficulty or limitation with the ES system's computer and monitor, which were entirely satisfactory.

Another study on simulated heating, ventilation, and air conditioning (HVAC) interaction showed that if ES computers and printers were used in this building the total annual electricity use would have been reduced by 7,205 kWh or 4 %. This equates to a $576 annual cost savings (assuming $.08/kWh). 28 % of the total savings was due to the reduced cooling load. A 2 kW reduction in the average monthly peak building load was also achieved [10].

Researchers widely acknowledge that actual electrical use of a personal computer differs widely from the nameplate rating of the unit, often suggesting that average demand is approximately 30% of the nameplate values [9], [10]. This was also confirmed during herein presented research.

In addition, herein presented research was based mostly on [7] and [11] usage pattern models.

2. ANALYSED PC SYSTEM

Tested PC consisted of a Intel® Core™ i5-2500K @ 3,3 GHz with 8 GB of random access memory (RAM) , SILENCER® 610 EPS12V power supply unit (610 W, 83% efficiency), GIGABYTE™ GTX 285 (GV-N285-1GH-B) graphics processing unit (GPU), Seagate® Barracuda™ 160GB hard disc (HDD) at 7200 RPM and monitor Samsung SyncMaster 2343BW. Monitor was equipped with internal power supply with AC 120/230V (50/60 Hz) voltage required. Monitor was ENERGY STAR® Qualified and TCO'03 and DDC-2B standards compliant with declared operational power consumption of 44 W and standby/sleep power concumption of 1W.

2.1 Variabillity challenges

Inherent to the manufacture of integrated circuits (ICs) is that two ICs from even the same wafer of silicon can have different power consumption characteristics, which directly affect the energy efficiency of the platform built with these ICs. This variability affects all ICs to some degree, from CPUs, GPUs, RAM, I/O controllers, chipsets, and all others in the system. In addition, power supplies, voltage regulators and fans have inherent variation in their power efficiency, and can also cause variations in power-draw measurements. For example, power supplies can vary by as much as 10 % from supplier to supplier or even within different models from the same supplier [7].

In order to achieve a reasonable degree of repeatability this problem must be solved and it can be done by deciding what is to be the unit under test (UUT), for example pin-compatible CPUs [7].

3. MODES DEFINITION

This analysis included two testing modes with their settings shown in Table 2:

1. High performance
2. Power saver

For Power Saver mode all default settings were used, except maximum processor state which was set to 50%.

Table 2. Testing modes settings.

Settings	High Performance	Power Saver
Turn off hard disc after	20 min	20 min
Sleep after	Never	15 min
Minimum processor state	5 %	5 %
System cooling policy	Active	Passive
Maximum processor state	100%	50% (user limitated)
Turn off display after	15 min	5 min

4. MODELING WORKDAY AND USAGE PATTERNS

4.1 Modeling energy-efficient performance

While there are standard practices that have wide industry acceptance for gauging performance, such as SYSmark, SPEC CPU, and notebook-specific tests such as MobileMark for battery life, there is no standard methodology for evaluating client performance coupled with its associated energy cost [7].

The first step in modeling energy-efficient performance (EEP) is to define workloads that represent everyday PC activities. A test workload must mirror the kinds of activities routinely done during everyday interactions with the PC. Different usage models – digital office, digital home, gaming – require different representative workloads. In order to effectively model this typical behavior, the workloads must be based on real applications [7].

At the time Intel® was working with SYSmark 2007 Preview, which comprises office productivity, e-learning, 3D modeling and video content creation tasks (system level power usage can vary dramatically during each application type). The application mix is based on research into emerging usage models and computing trends. It models realistic human-computer interactions, with "think-time" and human-level typing speeds. During brief periods of inactivity, such as "think-time", answering phone calls or interacting with coworkers, the system drops back to idle. For longer periods of inactivity, such as lunch or overnight, the system is assumed to be configured to drop into standby mode (S3 ACPI state, "suspend to memory") after 30 minutes of idle [7].

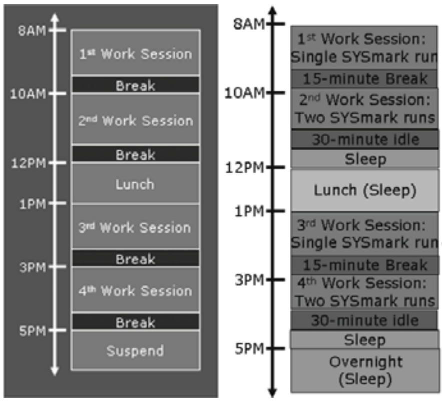

Figure 1. 9-hour workday modeled with EEP 1.0 [11] and EEP 2.0 [7] methodology

Modeling 9-hour workday with EEP 1.0 methodology the eight hours of working time was broken into four two-hour blocks. Any time left in a 2-hour block after completing the task is considered a "break", during which the system is at idle or, after 15 minutes of idle, in standby mode. The system is also assumed to be on standby during lunch hour and through the night and non-workdays [11].

The 90-minute run time (SYSmark 2004 SE) allowed only four work sessions per day and one run per session [11]. The 50-minute run time of SYSmark 2007 permits two runs per work session—or just a single run—so that the overall number of tasks performed and amount of idle time can be tuned to more accurately reflect actual human workdays [7].

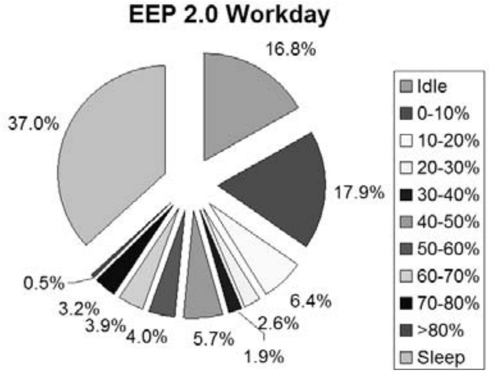

Figure 2. System power-draw levels during 9-hour workday. The percentages shown here are the power level amounts above the idle power level as compared to the idle power level [7].

The first EEP model (EEP 1.0) had four SYSmark 2004 SE runs in as many work periods [11]. New model (EEP 2.0) achieved a better balance of work time, idle and sleep, while retaining about the same amount of work per day as EEP 1.0.

The main observation here was that over 34% of the time during the nine-hour working day (just over three hours) the system was at or near an idle power-draw level in this proposed methodology [7].

4.2 Modeling 8-hour workday based on EEP methodology

With regard to EEP methodology 8-hour workday model can be formed. 8-hour workday model consist of four work sessions with 30 minutes shorter lunch-time break. During overnight periods PC was shut down. Based on EEP 1.0 and EEP 2.0 models it can be concluded that considered computer system sits idle (or near idle) or is put on standby/sleep for 71,7%, which is 5h 45min (345 minutes) for 8-hour workday.

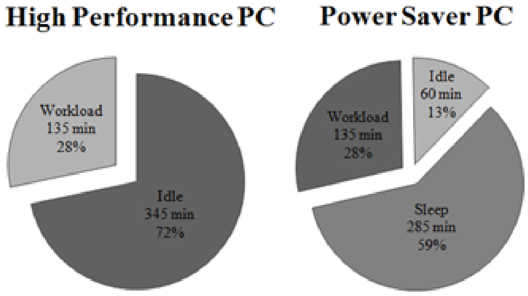

Figure 3. Modeled 8-hour workday for High Performance PC and Power Saver PC.

According to Figure 1 and EEP 2.0 there are 4 breaks (one break is connected with lunch break). With regard to mode settings it can be said that High Performance PC was whole 345 minutes sitting idle (never goes to sleep) and Power Saver PC was 60 minutes sitting idle and 285 minutes put on standby/sleep.

5. TESTING PERIOD AND SOFTWARE

Testing was conducted in a period of 15 days per mode, 8 hours a day using StressMyPC freeware software, version 1.12 available at http://www.softwareok.com/?seite=Microsoft/StressMyPC. Testing was carried-out with Paint-Stress and Aggressiv CPU-Stress settings turned on. HDD-Stress was not conducted because of HDD drive speed which was low and thus limitating data flow between other system components resulting in their limited usage (components were not 100% utilized) and in that way not providing clear picture of how system works.

StressMyPC is not intended for modeling workload as SYSmark 2007 Preview, and it can not generate different tasks. But it can generate flat workload and in combination with modeled usage patters provide reasonable results.

6. MEASURING DEVICE

In order to calculate the energy cost, the PC must be monitored for actual energy consumption during the run. Electricity consumtion was measured with TROTEC® BX11 measuring device.

Table 3. Technical data for measuring device.

Voltage	230 V, AC, 50/60 Hz
Maximum input	3680 W / 16A
Measuring range	2 - 3680 W
Transient over-voltage category	CAT II (2500)
Maximum recording capacity	999,0 kWh
Maximum recording time	999,9 hours
Minimum energy display	0,1 kWh
Minimum cost display	0,1 €
Batteries	3 x AAA R03/1,5 V
Operating temperature	+5 °C to +40 °C
Operating conditions	80% relative humidity below 31 °C from 31 °C to 40 °C to 50% decreasing linearly
Protection	IP20
Degree of contamination	II (Dry, non-conductive contamination only. Occasional temporary conductivity through dewing mus be reckoned with.)

7. MEASURING AND RESULTS

7.1 Measured monitor power consumption

Work in comfort zone comprise area from 70-80% brightness settings. By setting brightness into this range significant power savings could be achieved. Assuming that monitor is used 8 hours a day (without turning off or putting on sleep) it could be saved 48-64 Wh a day this way.

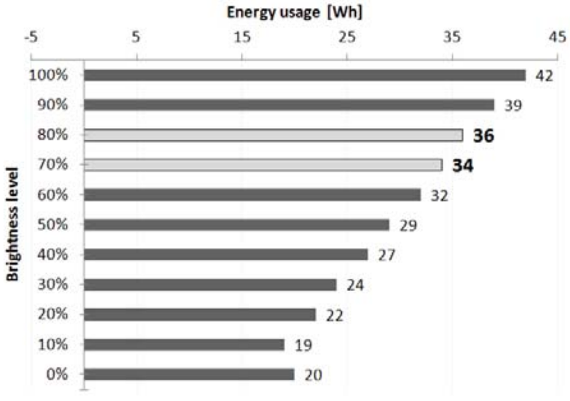

Figure 4. Monitor power consumption with regard to brightness settings diagram

Declared consumption of 1 Wh for standby/sleep mode could not be measured because of measuring device characteristics (2-3680 W measuring range).

There was no detected difference in power consumption with regard to other monitor settings such as color tone, contrast, etc. Therefore, main indicator for power consumption of monitors is brightness settings.

With regard to modeled workday and modes settings monitor is put on sleep (or turned off) for 285 minutes when set to High Performance mode and 325 minutes when set to Power Saver mode.

Table 4. Monitor workload and consumption distribution during 8-hour workday.

Mode	Brightness 100%	Brightness 70%	Sleep
High Performance	195 min 136,5 Wh	-	285 min 4,75 Wh
Power Saver	-	155 min 87,8 Wh	325 min 5,42 Wh

7.2 Measured PC power consumption

When PC was set to High Performance mode it consumed 230 W, while in Power Saver mode it consumed 199 W. When PC was sitting on idle it consumed 92 W and when put on standby/sleep - 2 W.

According to modeled workday and modes settings workload distribution during workday is presented in Table 5.

Table 5. PC workload and consumption distribution during 8-hour workday.

Mode	Workload	Idle	Sleep
High Performance	135 min 517,5 Wh	345 min 529 Wh	-
Power Saver	135 min 447,75 Wh	60 min 92 Wh	285 min 9,5 Wh

7.3 Results

With regard to measured energy consumption of monitor and PC there can be provided insight in their power consumption during workday.

Obtained results according to modes definition, modeled 8-hour workday usage pattern and measured power consumption of monitor and PC are shown in Table 6.

Table 6. PC and monitor energy consumption during 8-hour workday.

Mode	Consumption [Wh/day]		
	PC	Monitor	PC + Monitor
High Performance	1 046,5	141,25	1 187,75
Power Saver	549,25	93,22	642,47

7.4 Gaming test case study

Durind the research gaming test was also conducted. User was asked to play game Civilization V. PC was set to High Performance mode. After that system was set to Power Saver mode with limitated CPU power to 50% without user's knowledge. It is important to underline that user did not notice any difference between these two modes. PC power-draw was 25 W lower in Power Saver mode.

8. POSSIBLE SAVINGS CALCULATIONS

Most of the households in Republic of Serbia consume 351-1600 kWh ("Blue zone") of electricity per month. One kWh of electricity in that zone costs 7,76 RSD (0,066 €). According to National Bank of RS mean value for 1 € was 117,4 RSD on the day 28th of August 2012 [12].

According to [13], [14] there was 2 497 187 households in Republic of Serbia in 2009. and 47% of them possessed a PC. Number of PCs per household in most cases (89,3%) was one (2 PCs had 8,2%, 3PCs - 1,1% and 4 or more PCs - 1,4% of Serbian households). According to previous total number of PCs in RS was 1 173 678 units (≈1,2 million). In EU 27 percentage of households that possessed a PC in 2009 was 71% [13], while total number of households was around 300 million (estimate according to [15]). This leads to a total of 213 million computers. According to [16] there were over one billion PCs in use worldwide by the end of 2008. And with PC adoption in emerging markets growing fast, it is estimated that there will be more than two billion PCs in use by 2015. For this study it will be assumed that there is one billion PCs worldwide.

Carbon dioxide emissions from electricity production depend on the fuel source for electicity generation. Fosil fuels have bigger carbon footprint compared to renewable energy sources, such as wind, solar or hydro. In Republic of Serbia the biggest share of electricity is provided from coal burning (lignite). According to [17] producing 1 kWh of electricity from lignite results in 940 g CO_2 emission.

Table 7. Energy consumption, energy costs and possible savings for one PC unit.

	Energy consumption	Energy costs	CO_2 Emission
High Performance	1 187,75 Wh	≈0,08 €	1 116 g
Power Saver	642,47 Wh	≈0,04 €	604 g
Possible savings / day	545,28 Wh	≈0,04 €	512 g
Possible savings / year	≈120 kWh	≈8 €	≈113 kg

It is assumed there is 220 workdays a year (52 weekends, 25 days of vacation and 16 days - hollidays).

With regard to herein conducted study yearly energy costs for High Performance PC were about 18 € and for Power Saver PC around 9 €. Results are comparable with [7]. According to [7] yearly energy costs for well-managed desktop Intel® Core 2 Duo PC were about 10 $.

Table 8. Possible annual savings.

	RS	EU	World
Number of PC units	$1{,}2 \cdot 10^6$	$213 \cdot 10^6$	$1 \cdot 10^9$
Possible energy savings [kWh]	$144 \cdot 10^6$	$25{,}56 \cdot 10^9$	$120 \cdot 10^9$
Possible costs savings [€]	$9{,}6 \cdot 10^6$	$1{,}7 \cdot 10^9$	$8 \cdot 10^9$
Possible CO_2 reduction [t]	$135{,}6 \cdot 10^3$	$24{,}1 \cdot 10^6$	$113 \cdot 10^6$

Although Table 8 is not completely valid (not all PCs operate 8 hours per workday) it can provide an insight in possible savings.

9. CONCLUSION

Bearing previous analysis in mind it can be concluded that great savings can be achieved by simply improving awareness that little change in consumption pattern (which does not affect on performances of ICT systems) can lead to significant saving on national/global level. Using Power Saver mode with herein described settings savings of 46% can be achieved in electricity consumption, electricity costs and CO_2 emission compared to High Performance mode. By giving energy consumers insight in how much they could save by slightly changing their usage patterns it is more likely they would change it. Since power saving settings do not affect performances of PC their utilisation is strongly recommended and every user should set his own power saving scheme according to his needs. This technology exists to enable better energy efficiency, and should be used to minimize energy use when the computer is not being used. It can be pointed out that this study (and similar) should encourage manufacturers of hardware components for ICT technology (as well as software manufacturers) to continue producing and upgrading energy efficient devices and software.

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