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RESEARCH ARTICLE

The Impact of Built-in Ad-Blockers in Web Browsers on Computer Power Consumption

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ABSTRACT

This study investigates the power consumption of various web browsers, specifically focusing on those with built-in ad-blockers compared to standard browsing without ad-blocking features. Using detailed measurements of CPU and GPU power consumption across multiple browsers i.e., Chrome without Ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor—this research highlights the significant impact of ad-blocking on power consumption during web browsing. Experiments were conducted on different types of websites, including video-heavy, news, and entertainment sites, to evaluate how browser optimizations affect overall power usage. Results indicate that browsers with integrated ad-blockers, such as Brave and Librewolf, use significantly reduce power consumption up to 44% compared to traditional browsing setups. The findings also reveal that video content significantly increases CPU and GPU load, with ad-blocking browsers demonstrating superior performance in minimizing energy use. This study emphasizes the importance of browser selection in reducing power consumption, particularly for mobile and battery-dependent devices, and suggests that adopting ad-blocking technologies can lead to substantial energy savings.

Keywords: Built-in Ad-Blockers, Computer Power Consumption, CPU and GPU Usage, Sustainable Web Browsing.

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1. Introduction

The digital era has transformed the way individuals access information, communicate, and entertain themselves, making web browsers one of the most frequently used software applications globally. Browsers serve as the primary interface between users and the internet, facilitating access to a wide range of online services and content. However, the increasing complexity of web pages, coupled with the proliferation of advertisements, has raised concerns regarding the power consumption associated with browsing activities. Ads often involve resource-intensive elements such as high-resolution images, videos, scripts, and trackers that not only slow down page loading times but also increase the computational workload on devices, leading to higher power consumption.

Ad-blockers, designed to eliminate unwanted ads and enhance the browsing experience, have gained significant traction among users seeking faster, cleaner, and less intrusive web interactions. While traditional ad-blockers are available as third-party extensions, an emerging trend is the integration of ad-blocking features directly into web browsers. Browsers like Brave, Opera, and Vivaldi have embedded ad-blockers as core functionalities, offering users a seamless browsing experience without the need for additional extensions. These built-in ad-blockers operate by preemptively blocking advertising content from loading, which not only improves performance but also has potential implications for reducing energy consumption.

Reducing energy consumption is becoming increasingly important in the context of sustainability and environmental impact. The cumulative energy used by billions of devices worldwide contributes significantly to global energy demands, leading to a larger carbon footprint. Even seemingly small reductions in the power consumption of individual devices can have a substantial impact when aggregated across millions of users. Therefore, optimizing the energy efficiency of commonly used software, including web browsers, is a critical area of research that aligns with global efforts toward reducing energy usage and minimizing environmental impact.

Research indicates that advertisements can significantly affect the power consumption of devices due to the additional computational resources required to load and display ad content. For example, video ads demand more processing power from the CPU and GPU, contributing to increased energy usage compared to text-based or static image ads. Ad-blockers mitigate these effects by preventing ads from loading, thereby reducing the amount of data processed and the computational effort required. This reduction in computational load directly correlates with lower energy consumption, offering potential benefits not only for battery-powered devices like laptops and smartphones but also for desktop computers, where energy savings translate into reduced electricity costs.

Browsers with built-in ad-blockers, such as Brave and Opera, offer a distinct advantage over traditional browsers in terms of energy efficiency. Brave, for instance, is designed with privacy and performance optimization in mind, utilizing a native ad-blocking mechanism that minimizes the load on system resources. Opera's built-in ad-blocker, on the other hand, allows users to block ads with a simple toggle, promising a faster browsing experience with lower energy consumption. Unlike external ad-blocking extensions, which operate as separate processes and consume additional memory and CPU cycles, built-in ad-blockers are deeply integrated into the browser architecture, allowing for more efficient operation and further reduction in power consumption.

The effectiveness of these integrated ad-blockers extends beyond mere user convenience; they represent a critical evolution in browser design that aligns with broader technological trends emphasizing efficiency and sustainability. By reducing the resource demands of browsing, these browsers not only enhance user experience but also contribute to a more sustainable digital ecosystem. The reduced energy consumption also translates to longer battery life for mobile devices, enhancing their portability and usability in everyday contexts.

Despite the promising benefits, empirical studies evaluating the specific impact of built-in ad-blockers on power consumption are limited. Most research to date has focused on the performance and security aspects of ad-blockers, with energy efficiency often being an overlooked dimension. This study seeks to fill this gap by conducting a comprehensive analysis of power consumption when using browsers with built-in ad-blockers compared to those without such features. By measuring the power usage of devices while accessing a variety of websites, including those with heavy ad content and those without, this research aims to quantify the energy-saving potential of built-in ad-blockers.

Furthermore, this study explores the implications of these findings for everyday users, developers, and policymakers. For users, understanding the energy impact of their browser choices can inform more sustainable digital habits. For developers, insights into energy consumption can drive innovations in browser design, emphasizing efficiency alongside performance and security. For policymakers, the findings can support initiatives aimed at promoting energy-efficient software as part of broader environmental sustainability goals.

In conclusion, the integration of ad-blockers within web browsers represents a significant advancement in the pursuit of energy-efficient browsing. By examining the power consumption characteristics of browsers with built-in ad-blockers, this research contributes valuable knowledge to the fields of sustainable computing and digital efficiency. The findings will not only highlight the potential environmental benefits of these browsers but also encourage further innovation in the design of energy-efficient software solutions, fostering a more sustainable digital future.

2. Literature Review

Ad-blockers significantly contribute to reducing energy consumption across various digital platforms by preventing the loading of resource-intensive advertisements. Pearce highlights the role of open-source ad-blockers in conserving energy, particularly by reducing the processing load on devices. This study demonstrates that by blocking ads, devices require less computational power, directly lowering energy consumption during web browsing [1].

Torjesen *et al*. Introduced the "CarbonTag" method, quantifying the energy usage associated with online ads and underscoring the environmental benefits of ad-blockers. Their findings reveal that ad-blocking technologies can significantly reduce the energy footprint of web browsing, highlighting their importance not just for user experience but also for environmental sustainability [2].

Supporting these results, a study from the University of Twente measured the effect of ad-blockers on energy consumption during mobile web browsing. The study confirmed substantial reductions in power usage when ads were blocked, emphasizing the potential of ad-blockers to enhance energy efficiency on a large scale, especially in mobile contexts where battery life is crucial [3].

Further, Heitmann *et al*. explored the energy perspectives of mobile web browsers equipped with ad-blocking features, showing that these tools contribute to significant energy savings by reducing the amount of data processing required [4]. This aligns with Roth *et al*. [5], who analyzed various internet browsers and found that those using ad-blockers exhibited lower energy consumption due to fewer background processes related to ad loading.

These studies collectively underscore the importance of ad-blockers in reducing energy consumption, highlighting their role as essential tools for enhancing the efficiency and sustainability of digital interactions.

Technological advancements in ad-blocking have been pivotal in enhancing the efficiency and effectiveness of these tools, directly impacting energy consumption during web browsing [5]. Storey *et al*. discuss the evolution of ad-blocking technologies, emphasizing the development of new analytical frameworks and techniques that improve blocking accuracy while reducing resource demands. These advancements help ad-blockers operate more efficiently, conserving energy by minimizing the processing power required to detect and block ads [6].

One significant innovation is "PERCIVAL," introduced by Abi Din *et al*., a perceptual ad-blocking tool that utilizes deep learning to enhance blocking capabilities without compromising performance. By intelligently filtering content, "PERCIVAL" allows for more precise ad detection and blocking, which in turn reduces the computational workload on devices, contributing to energy savings. This approach not only improves user experience but also directly addresses the need for more energy-efficient ad-blocking technologies [7].

Similarly, Tigas *et al*. explore in-browser perceptual ad-blocking, highlighting the balance between effectiveness and performance. Their work demonstrates that these advanced ad-blockers can significantly reduce the energy consumed by web browsers by preventing the loading of ads that would otherwise increase data processing requirements [8].

Lashkari *et al*. [9] further contribute to this field with the development of CIC-AB, a browser-specific ad-blocker designed for scalability and adaptability. Their research shows that modern ad-blockers, through their improved design and functionality, can significantly reduce the energy consumption associated with web browsing, reinforcing the importance of continuous technological innovation in this space.

These technological advancements illustrate how evolving ad-blocking solutions are becoming increasingly effective in reducing the energy demand of digital devices, highlighting the critical role of ongoing innovation in this field.

Ad-blockers are not only recognized for their role in enhancing web performance and protecting user privacy but also for their indirect impact on energy consumption [9]. Borgolte and Feamster analyze the trade-offs associated with privacy-focused browser extensions, including ad-blockers, highlighting how these tools improve user privacy while maintaining efficient web performance. The reduction in energy usage is an added benefit, as ad-blockers streamline the browsing experience by blocking ads that would otherwise consume additional processing power and data bandwidth [10].

Williams *et al*. and Gervais *et al*. delve into the dual impact of ad-blockers on performance and privacy, emphasizing that by preventing data-intensive advertisements from loading, ad-blockers contribute to reduced energy consumption. Their findings suggest that ad-blockers are effective in limiting the collection of personal information by third-party trackers, reducing the computational burden on devices, which directly correlates with lower energy use [11], [12].

Li *et al*. developed a scale to measure the intrusiveness of advertisements, validating the need for ad-blockers to enhance user experience and reduce the negative impact of ads. This reduction in ad exposure also translates to energy savings, as fewer resources are consumed in rendering and processing ads, particularly on mobile devices where energy efficiency is crucial [13].

Miroglio *et al*. further explore the effect of ad-blocking on user engagement, demonstrating that sites free from intrusive ads see higher engagement levels and improved performance. By blocking resource-heavy ads, these ad-blockers help conserve device energy, which is especially important in maintaining battery life and reducing the overall energy footprint of digital interactions [14].

These studies underscore the broader benefits of ad-blockers, showing that their impact on performance and privacy also significantly contributes to energy conservation, enhancing the sustainability of web browsing.

Ad-blockers extend their influence beyond individual user benefits by significantly impacting the digital advertising ecosystem and contributing to environmental sustainability [14]. Krawczyk and Borowiec examine how ad-blocking technologies affect the development of the digital advertising ecosystem, highlighting the shift toward more sustainable advertising practices. By disrupting traditional revenue models, ad-blockers push advertisers to adopt less intrusive and more energy-efficient ad formats, indirectly contributing to energy conservation across digital platforms [15].

The environmental benefits of ad-blockers are further underscored by Pesari *et al*., who assess the energy consumption and greenhouse gas emissions associated with online advertising and tracking. Their findings demonstrate that ad-blockers can substantially reduce the environmental footprint of web browsing by blocking energy-intensive ads and trackers. This reduction in digital energy use supports broader sustainability goals, aligning ad-blocking technology with efforts to minimize the environmental impact of internet use [16].

In enterprise settings, Samsuddin *et al*. evaluate the implementation of ad-blocking techniques within network environments, showing that these tools can effectively reduce energy consumption on a larger scale. Their study emphasizes the adaptability of ad-blockers, not only as consumer tools but also as valuable components in energy-efficient network management, particularly for organizations looking to reduce operational energy costs [17].

Bruguera Micó delves into the ongoing battle between ad-blockers and anti-blocking technologies, highlighting the continuous evolution of countermeasures employed by advertisers. While this dynamic reflects the tensions between user control and advertising revenue, it also points to the need for innovative ad-blockers that can maintain their effectiveness without increasing energy consumption through more complex detection algorithms [18].

Barbacovi explores the ethical and legal implications of ad-blocking, emphasizing the challenges faced by developers in balancing user preferences with the economic needs of content providers. This discussion underscores the broader impact of ad-blockers on the digital ecosystem, where their role in reducing energy consumption and supporting sustainable practices must be balanced against the financial realities of online media.

These studies illustrate that ad-blockers are not only tools for enhancing user experience and privacy but also play a critical role in supporting environmental sustainability by reducing the energy demands of the digital advertising ecosystem.

While ad-blockers have proven effective in enhancing user experience, privacy, and energy efficiency, they also face significant challenges that shape their ongoing development [19]. Pourghassemi examines the performance and privacy trade-offs associated with ad-blocking technologies, highlighting that complex filtering processes can introduce computational overhead. This additional processing may counteract some energy-saving benefits, emphasizing the need for scalable solutions that optimize performance without increasing energy consumption.

The environmental impact of digital advertising remains a crucial focus for the future of ad-blocking technologies [20]. Pesari *et al*. provide a comprehensive assessment of the energy and greenhouse gas emissions associated with advertising and tracking on news websites. Their study underscores the importance of developing more efficient ad-blocking technologies that minimize the environmental footprint of web browsing. As digital consumption continues to grow, enhancing the energy efficiency of ad-blockers will be vital in supporting global sustainability efforts [21].

Barbacovi explores the ethical, legal, and technical challenges surrounding the use of ad-blockers, particularly the ongoing conflict between user rights and the economic needs of content providers. The debate over ad-blocking reflects broader questions about user autonomy, privacy, and the sustainability of digital advertising models. To maintain their relevance, ad-blockers must evolve to balance these competing interests, ensuring they continue to provide energy savings and privacy protection without undermining the financial foundations of online content [22].

Chrome, the most widely used browser, lacks native ad-blocking and relies on third-party extensions, which increase CPU and memory usage, especially on ad-heavy sites, impacting performance negatively [23]. Brave, with built-in ad-blocking that block both video ads and trackers by default, significantly reduces CPU activity, enhancing browsing speed and reducing power consumption by up to 44% compared to non-blocking browsers [24]. Opera's built-in ad-blocker works well on pop-ups and intrusive ads, but it must be manually enabled. Research shows it improves page load times and lowers energy use but may face compatibility issues with some content [25].

Firefox includes enhanced tracking protection that blocks trackers, scripts, and some video ads, reducing energy consumption but potentially slowing page loads due to extensive privacy settings [26]. Vivaldi's ad-blocker is customizable and can target specific types of ads, including banners and pop-ups, but performance varies depending on user settings and the customization level [27]. Librewolf enhances ad-blocking on all types of trackers and scripts by default but may slow performance due to its strict privacy measures [28]. Tor, known for its anonymity, does not specifically target ads but provides high privacy through multi-layered routing, resulting in higher CPU usage and slower speeds [29]. FreeTube, designed as an ad-free YouTube client, specifically targets video ads, significantly reducing CPU usage compared to YouTube's standard site, enhancing battery life and user experience by up to 30% [30].

3. Experiment

The experimental section of this research focuses on evaluating the power consumption of various web browsers during typical browsing activities, emphasizing the role of ad-blocking features. The primary objective is to assess how different browsers, with and without native ad blockers, affect overall power efficiency. Given the increasing concern over digital device energy consumption, understanding the impact of ad-blocking capabilities on power usage is crucial for optimizing both user experience and energy conservation.

The experiments utilize an HP EliteBook 840 G5 equipped with an Intel(R) Core(TM) i5-7300U CPU, which features an integrated GPU. Although the GPU values are included in the overall CPU measurements, separate calculations of GPU power consumption are performed to provide a comprehensive analysis of power usage dynamics. The system's specifications, including 16 GB of RAM and the Windows 11 Home operating system, were chosen to reflect a typical user environment.

Power consumption data was collected using HWiNFO, a sophisticated software tool that allows for detailed monitoring of CPU and GPU power usage in real time. HWiNFO provides accurate and comprehensive insights into system performance, making it an ideal choice for assessing power consumption during the experiments.

The study involves testing several popular browsers—Chrome, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor—across a variety of website types, including news, video streaming, and entertainment. By measuring the power consumption of both the CPU and GPU during these browsing sessions, the research aims to identify key differences in energy efficiency among browsers and assess the impact of ad-blocking features.

The results of these experiments will be presented through detailed comparisons, highlighting the implications for browser selection and the potential benefits of ad-blocking features in reducing power consumption.

3.1. Experimental Setup

3.1.1. Hardware Description

The experiments were conducted using an HP EliteBook 840 G5 laptop equipped with an Intel(R) Core(TM) i5-7300U CPU, which operates at 2.60 GHz with two cores and four logical processors. This processor includes an integrated GPU (Intel HD Graphics 620), which is commonly used in many modern laptops. The integrated GPU allows the system to manage graphical tasks without a separate, dedicated graphics card, making the power consumption data relevant to a typical user environment. The laptop also features 16 GB of RAM, which ensures stable performance during multi-tab browsing and data collection.

The choice of this hardware setup reflects a typical usage scenario for many users who rely on integrated graphics for web browsing, media consumption, and everyday computing tasks. By using this hardware configuration, the study aims to provide results that are applicable to a wide audience, especially those using similar devices. The integrated GPU's power consumption is included in the overall CPU power measurements, but separate GPU-specific calculations are made to provide a more granular understanding of energy usage.

3.1.2. Software Tools

The primary software tool used for monitoring power consumption was HWiNFO, a comprehensive system information and diagnostics tool widely recognized for its ability to accurately track real-time power consumption of both CPU and GPU components. HWiNFO provides detailed data on various system parameters, including voltage, temperature, and power consumption metrics, which are critical for analyzing the performance of web browsers under different conditions.

HWiNFO was configured to log power consumption data during the browsing sessions, capturing the integrated GPU's impact alongside the CPU. The software's ability to provide high-frequency data sampling allows for precise measurement of power consumption spikes and trends, ensuring that the collected data accurately reflects the browser's performance. The choice of HWiNFO is grounded in its reliability and precision, making it an ideal tool for the purpose of this study.

3.1.3. Browsers Tested

The experiments included seven popular web browsers: Chrome without Ad blocker, Brave, Opera, a hardened version of Firefox, Vivaldi, Librewolf, and Tor. These browsers were chosen for their varying levels of native ad-blocking capabilities, allowing for a comprehensive comparison of power consumption influenced by ad-blocking features:

- *Chrome without Ad blocker:* A widely used browser known for performance and stability, tested without any ad-blocking extensions to establish a baseline for comparison.
- *Brave:* A privacy-centric browser with a built-in ad blocker that blocks ads, trackers, and invasive cookies by default, aimed at enhancing performance and security.
- *Opera:* A browser with integrated ad-blocking designed to improve page load speed and reduce resource usage.
- *Hardened Firefox:* A modified version of Firefox with advanced privacy settings and enhanced ad-blocking capabilities configured for this study. This version blocks a broader range of ads and trackers than standard Firefox, aiming to reduce power consumption by minimizing unnecessary resource loads.
- *Vivaldi:* A highly customizable browser with built-in ad-blocking and tracking protection, allowing for user-defined content filtering and privacy controls.
- *Librewolf:* A privacy-focused fork of Firefox with built-in ad-blocking that blocks most ads and trackers by default, enhancing privacy while reducing resource demand.
- *Tor:* Primarily focused on anonymous browsing, Tor includes basic ad-blocking to improve privacy and security, though its primary function is to protect user anonymity rather than optimize performance.

3.1.4. Ad-Blocking Capabilities and Limitations

The ad-blocking features of each browser significantly influence their power consumption profiles. Here's a detailed overview of each browser's capabilities and limitations regarding ad-blocking:

- *Chrome without Ad blocker:* No native ad-blocking, relying entirely on third-party extensions, which were not utilized in this baseline setup.
- *Brave:* Blocks most ads and trackers by default, significantly reducing load on both CPU and GPU, which can lead to noticeable energy savings.
- *Opera:* Built-in ad-blocking is less aggressive than Brave's but effective enough to block a substantial amount of intrusive content, providing moderate energy reduction benefits.
- *Hardened Firefox:* The modified Firefox was specifically configured to block a broader range of ads and trackers beyond its default settings. This customization enhances its performance, reducing the computational workload and, consequently, power consumption.
- *Vivaldi:* Offers adjustable ad-blocking settings, allowing users to strike a balance between performance and content filtering. This flexibility, while beneficial, also introduces variability in its energy efficiency.
- *Librewolf:* Designed for privacy, Librewolf's strong ad-blocking settings help reduce power consumption by blocking ads and trackers comprehensively, which aligns closely with privacy-centric performance.
- *Tor:* Includes basic ad-blocking capabilities, primarily aimed at reducing exposure to tracking rather than optimizing for performance. Its focus on privacy can sometimes impact power efficiency due to security overhead.

3.2. Selection Criteria

The websites selected for this study were chosen based on their popularity, content type, and the diversity of browsing experiences they offer. This selection was aimed at replicating real-world usage scenarios that are representative of typical user behavior. The inclusion of a variety of websites ensures that the study captures a broad range of web content types, including high-resource-demanding media sites and simpler news platforms.

The selected websites include:

- *YouTube:* A leading video streaming platform, representing high graphical and resource usage typical of video content.
- *9gag:* A popular entertainment site known for hosting videos and GIFs, which can significantly impact GPU usage.
- *Kisscartoon:* An entertainment site focused on streaming animated content, often heavy on ads and trackers.
- *ARYZAP:* A media streaming site featuring video content, including live TV channels and shows.
- *Dailymotion:* Another prominent video streaming platform, offering a mix of user-generated and professional video content.

- *Dawn, The News, Ausaf:* Major news websites representing content-heavy but less graphically intensive browsing, commonly visited by users for news and information.
- *Cricbuzz, ESPNcricinfo:* Sports news and live score websites that combine text with multimedia elements like images and embedded videos.

3.2.1. *Website Categorization*

To analyze power consumption effectively, the selected websites were grouped into two categories:

- *News Websites (Dawn, The News, Ausaf, Cricbuzz, ESPNcricinfo):* This category represents text-dominant sites with minimal video content but includes ads, images, and interactive elements that contribute to power consumption. These sites are chosen for their relevance in everyday browsing, providing insights into how news consumption affects browser performance.
- *Video Streaming Websites (YouTube, Dailymotion, ARYZAP, 9gag, Kisscartoon):* This category includes platforms that are graphically intensive, requiring significant processing power from both CPU and GPU. These websites were selected to examine how browsers handle high resource-demand scenarios, particularly in terms of video content, ads, and embedded trackers.

Grouping the websites into these categories allows for targeted comparisons, highlighting how different types of content affect power consumption across various browsers. This categorization also enables a deeper analysis of how browser and ad-blocking capabilities influence energy efficiency in different browsing contexts.

3.3. *Data Collection Methodology*

Power consumption data was collected using HWiNFO software, which monitored both CPU and GPU usage during controlled browsing sessions. Each browser was tested across the selected websites with identical conditions to ensure consistency, including the same system settings, browser configurations, and minimal background activity. Each test involved visiting the websites for a fixed duration, with repeated trials conducted to account for variability and enhance data reliability. The power consumption was logged in real-time, capturing fluctuations in energy use as browsers loaded different types of content, such as videos, ads, and trackers. The experiments aimed to mirror typical browsing behaviors while controlling external factors, providing a reliable basis for comparing the power efficiency of each browser and its ad-blocking capabilities.

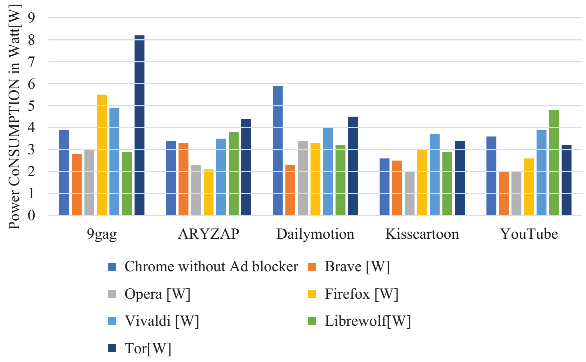

Fig. 1. CPU power consumption on video websites.

4. Results

The Results section presents a detailed analysis of the power consumption of various web browsers on different types of websites, categorized into video and news websites. The focus is on evaluating CPU and GPU power consumption across several popular browsers, including Chrome without ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor. Each comparison aims to highlight the differences in energy efficiency among these browsers, particularly in relation to their built-in ad-blocking capabilities and performance optimizations. The results are organized into four key comparisons, examining CPU and GPU consumption separately for video and news websites, followed by a summary of key findings that provide insights into the most efficient browser choices for different types of content.

4.1. *CPU Power Consumption on Video Websites*

This section examines the CPU power consumption of various browsers when accessing video websites, including YouTube, Dailymotion, Kisscartoon, ARYZAP, and 9gag. The analysis highlights how different browsers manage energy demands during video streaming, emphasizing the impact of ad-blocking features and performance optimizations on reducing CPU load (Table I).

The grouped bar graph in Fig. 1 illustrates the CPU power consumption of each browser on the tested websites, providing a visual comparison of browser performance. Results were collected while playing the same video on all websites.

TABLE I: CPU Power Consumption on Video Websites

Websites	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
9gag	3.9	2.8	3	5.5	4.9	2.9	8.2
ARYZAP	3.4	3.3	2.3	2.1	3.5	3.8	4.4
Dailymotion	5.9	2.3	3.4	3.3	4	3.2	4.5
Kisscartoon	2.6	2.5	2	3	3.7	2.9	3.4
YouTube	3.6	2	2	2.6	3.9	4.8	3.2

TABLE II: Power Consumption on News Websites

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
Ausaf	3.8	2.3	2.3	1.7	2.3	1.7	1.9
Cricbuzz	6.8	3.4	2.3	2.4	4	3.2	6.2
Dawn	4.2	3.3	3.5	1.8	2.9	2.1	3.2
ESPNcricinfo	4.6	2.9	4	2.3	5.2	4.4	5.1
The News	4.2	1.3	2.4	1.4	3.1	2.2	2.9

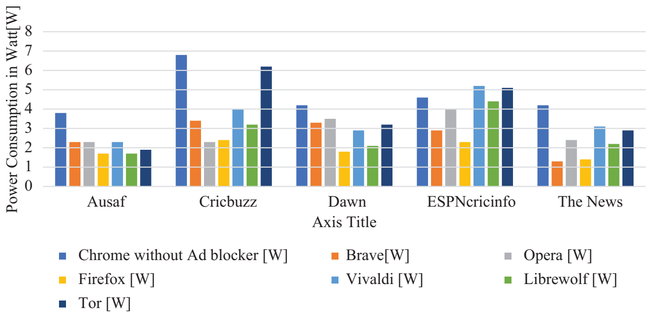

Fig. 2. CPU power consumption on news websites.

Fig. 1 visually represents the CPU power consumption of each browser across the selected video websites. The grouped bar graph format allows for an easy comparison of performance, highlighting which browsers consume more or less power when handling video content.

The comparison reveals that Brave consistently shows the lowest CPU power consumption, positioning it as the most efficient browser in terms of energy usage. Conversely, Chrome without Ad blocker and Tor exhibit the highest power consumption, particularly on resource-heavy websites like 9gag and Dailymotion, suggesting a less optimized performance. Opera and Firefox perform moderately, balancing efficiency and resource demand. These findings underscore the significant impact of browser optimizations, ad-blocking capabilities, and overall performance on CPU energy consumption.

The results clearly show that CPU power consumption is highest when using browsers without ad-blocking features, such as Chrome without Ad blocker and Tor, particularly on resource-heavy sites like 9gag and Dailymotion. Conversely, browsers like Brave and Librewolf, which include built-in ad-blockers, exhibit significantly lower CPU usage. Brave consistently performs as the most efficient browser, reducing CPU power consumption by up to 44% compared to Chrome. This demonstrates the effectiveness of ad-blocking and performance optimizations in reducing the energy demands of video content, making such browsers ideal for users looking to minimize their power consumption during streaming.

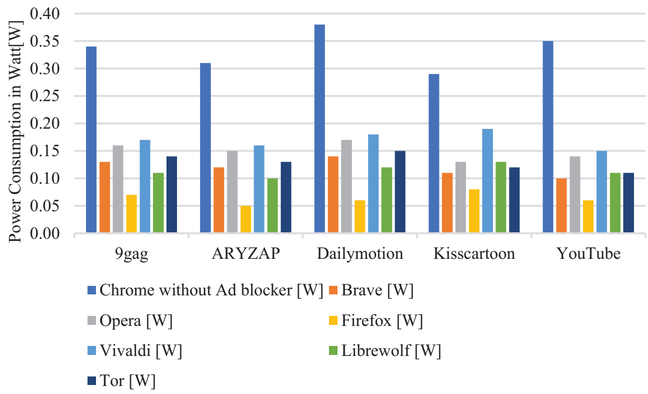

Fig. 3. GPU power consumption on video websites.

4.2. *CPU Power Consumption on News Websites*

Table II presents the average CPU power consumption of various browsers on news websites, including Ausaf, Cricbuzz, Dawn, ESPNcricinfo, and The News. These sites are generally less resource-intensive compared to video websites, providing insights into browser performance on typical web content.

Fig. 2 visualizes the CPU power consumption of each browser across various news websites. It allows for an easy comparison of browser performance on less demanding content.

4.3. *GPU Power Consumption on Video Websites*

Table III shows the average GPU power consumption of various browsers when accessing video websites. The data reflects how each browser manages graphical processing demands, especially on sites with intensive video content.

Fig. 3 illustrates the GPU power consumption of each browser on video websites, visually comparing their performance in handling graphical content. This grouped bar graph format allows easy identification of which browsers are more GPU efficient.

TABLE III: GPU Power Consumption on Video Websites

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
9gag	0.34	0.13	0.16	0.07	0.17	0.11	0.14
ARYZAP	0.31	0.12	0.15	0.05	0.16	0.1	0.13
Dailymotion	0.38	0.14	0.17	0.06	0.18	0.12	0.15
Kisscartoon	0.29	0.11	0.13	0.08	0.19	0.13	0.12
YouTube	0.35	0.1	0.14	0.06	0.15	0.11	0.11

TABLE IV: GPU Power Consumption on News Websites

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
Ausaf	0.33	0.12	0.12	0.04	0.13	0.09	0.1
Cricbuzz	0.37	0.14	0.14	0.07	0.14	0.1	0.13
Dawn	0.36	0.13	0.15	0.06	0.15	0.11	0.14
ESPNcricinfo	0.34	0.12	0.16	0.05	0.16	0.12	0.12
The News	0.32	0.11	0.14	0.04	0.14	0.1	0.13

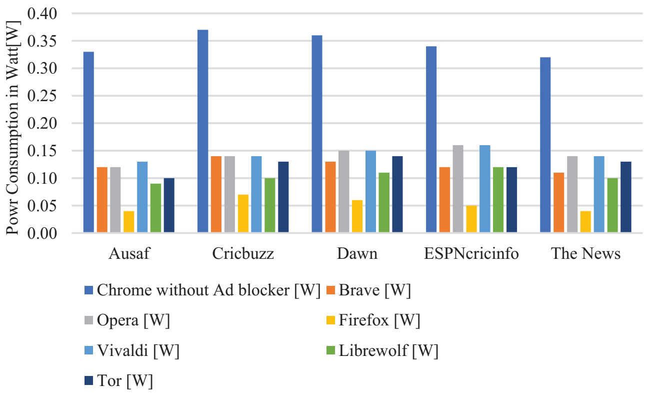

Fig. 4. GPU power consumption on news websites.

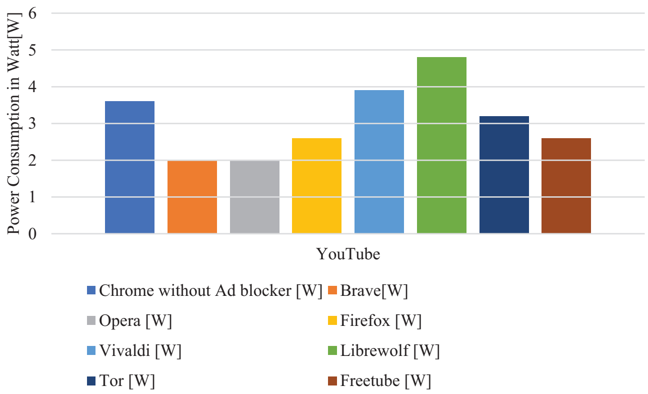

Fig. 5. Comparison of CPU power consumption on YouTube: Ad-Blocking browsers vs. FreeTube.

The GPU power consumption data indicates that browsers with built-in ad-blockers, such as Brave and Librewolf, use significantly less GPU power compared to browsers like Chrome without Ad blocker and Tor. For instance, Brave's GPU consumption is consistently the lowest across all tested video websites, showing up to a 63% reduction in power usage compared to Chrome. These findings highlight the advantages of using privacy-focused browsers with performance optimizations, especially for users who frequently engage with video content, as they not only enhance the browsing experience but also contribute to significant energy savings.

4.4. GPU Power Consumption on News Websites

Table IV displays the average GPU power consumption of various browsers when accessing news websites, including Ausaf, Cricbuzz, Dawn, ESPNcricinfo, and The News. These websites generally have lower graphical demands compared to video content, allowing us to see how efficiently each browser handles basic web graphics.

Fig. 4 shows the GPU power consumption of each browser on news websites, highlighting differences in their efficiency when handling less intensive graphical content.

The data shows that GPU power consumption on news websites is generally low across all browsers, with Brave and Firefox showing the lowest power usage. Brave, for example, consumed only 0.12 W on Ausaf, demonstrating up to a 63% reduction compared to Chrome without Ad blocker. This consistent efficiency among browsers with built-in ad-blockers emphasizes their role in optimizing graphical performance, even on standard content. These results suggest that using browsers with integrated ad-blockers not only improves browsing speed but also significantly reduces energy usage, making them ideal for users seeking energy-efficient web browsing.

4.5. Comparison of CPU Power Consumption on YouTube: Ad-Blocking Browsers vs. FreeTube

Table V compares the CPU power consumption of various browsers, including Chrome without Ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, Tor, and FreeTube, specifically on YouTube. The data highlights the energy demands of each browser when streaming content, emphasizing the benefits of ad-free and optimized environments.

Fig. 5 visually represents the CPU power consumption of each browser while streaming on YouTube. The grouped bar format allows for a clear comparison of how each browser manages energy usage, highlighting the impact of ad-blocking and performance optimizations.

The results demonstrate that FreeTube, with an average CPU power consumption of 2.6 W, significantly outperforms browsers like Chrome without Ad blocker, which consumes 3.6 W on YouTube. This represents a 28% reduction in CPU usage, emphasizing the impact of an ad-free environment on energy efficiency. Similarly, Brave

TABLE V: Comparison of CPU Power Consumption on YouTube: Ad-Blocking Browsers vs. FreeTube

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]	Freetube [W]
YouTube	3.6	2	2	2.6	3.9	4.8	3.2	2.6

and Opera also showcase lower power consumption, each using only 2 W, reflecting their integrated ad-blocking and performance enhancements.

The Results section reveals that built-in ad-blockers and performance optimizations significantly impact CPU and GPU power consumption across browsers. Brave and FreeTube consistently demonstrated the lowest power consumption. Brave reduced CPU usage by up to 44% and GPU usage by 68% compared to Chrome without Ad blocker, while FreeTube, an ad-free alternative, showed a 28% reduction in CPU consumption on YouTube compared to Chrome with ads. This highlights the effectiveness of ad-free environments and optimized browsing in reducing energy use.

Conversely, Chrome without Ad blocker and Tor had the highest power consumption across all tested websites. Chrome's lack of ad-blocking led to a 5.9 W CPU consumption on Dailymotion, showing the strain of unoptimized environments. Tor, despite its privacy features, consumed consistently high power due to its complex security protocols, illustrating a trade-off between privacy and performance efficiency. Video websites demanded up to 40% more processing power than news websites, especially in browsers lacking ad-blocking capabilities, emphasizing the added energy cost of handling high-resource content.

Browsers with built-in ad-blockers, such as Brave and Librewolf, maintained superior performance even on less demanding news sites, with Brave reducing GPU power consumption by up to 63% compared to Chrome. These findings suggest that selecting ad-blocking browsers not only minimizes power consumption but also enhances overall device performance and sustainability. The study underscores the importance of choosing optimized browsers like Brave and FreeTube to achieve significant energy savings, extended battery life, and a more sustainable browsing experience.

5. Conclusion and Future Work

This study provides a comprehensive analysis of the power consumption of web browsers with and without built-in ad-blockers, highlighting the significant impact of ad-blocking technology on energy efficiency. The results demonstrate that browsers equipped with integrated ad-blockers, such as Brave and Librewolf, consistently consume less CPU and GPU power compared to traditional browsers like Chrome without ad-blockers, achieving up to a 44% reduction in CPU power consumption, particularly on resource-intensive video websites. The findings underscore that content type plays a critical role in power consumption, with video-heavy websites imposing greater energy demands than news and entertainment sites. The elimination of ads and trackers not only enhances browsing performance but also contributes to substantial energy savings, making ad-blocking browsers ideal for users concerned with device battery life and sustainability. Future work could explore the impact of ad-blocking technology on mobile browsers and its effect on battery life in real-world scenarios, including a broader range of devices such as smartphones, tablets, and low-power laptops. Additionally, evaluating the performance of emerging privacy-focused browsers and alternative ad-blocking solutions could offer deeper insights into how software optimizations influence power consumption while investigating user behavior patterns related to ad-blocker use could further contribute to the development of sustainable browsing practices.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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