Sufficient Use of the Cloud for Work: Practitioners' Perception and Potential for Energy Saving

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***Abstract*—Flexible mode of work increases our dependency on cloud services. Although the cloud offers flexibility and collaboration opportunities, it also consumes energy and resources, through the data centers needed for its operation. Suboptimal usage of cloud resources can be minimized through simple tactics towards rational cloud usage in a.o. our daily professional life.**

This paper presents a study analyzing the impacts of applying such tactics while using the cloud during flexible work. The methodology involves a questionnaire survey conducted among practitioners followed by an experiment to measure energy savings from applying one of the tactics. Survey results uncover the participants' perceptions about applying the tactics in practice. Based on the survey outcomes, we experimented with one of the most preferred tactics, namely "Closing a tab when it is not needed anymore". Our experiment did not reveal significant energy savings for this tactic on client-side energy consumption, but data traffic was reduced 15.5 times. Through this study, we uncovered major gaps in the literature to quantify and compare digital sufficient behaviors.

***Index Terms*—Digital sufficiency, flexible work, cloud usage, sufficiency tactics, energy consumption, resource consumption, sustainability**

I. Introduction

The current digital age is marked by a generalized dependency on the Internet to accomplish every task faster and effortlessly. But this comfort comes with a cost. Studies found that the Information and Communication Technology (ICT) sector alone is deemed responsible for about 4% of global greenhouse gas emissions [1]. In the ongoing digital transformation, cloud technology plays a significant role as almost all software-enabled works are dependent on it. For instance, every task of modern professional life from simple email sending to hosting video meetings depends highly on the cloud. Consequently, the energy consumption of cloud usage is rapidly increasing since cloud technology relies on actual hardware that is powered by electricity [2]. To generate this electric energy, limited resources like fossil fuels are burnt which causes carbon footprints with the emission of greenhouse gases. Accordingly, there are initiatives taken to tackle this environmental footprint of ICT, such as the use of renewable energy, the shift of cloud data centers to colder regions [3], and so on. In parallel, end-users should take responsibility for reducing their footprint by minimizing their daily superfluous use of the cloud. This controlled or rational use of digital technology has been termed as "Digital Sufficiency" [4]. To rationalize regular use of cloud technology in particular, a recent study proposed guidelines i.e., tactics to practice in the context of flexible work [5]. The goal of the present study is to assess the impact of applying these tactics through a survey on flexible practitioners, and experiment on the energy or resource consumption of applying tactics. Accordingly, the main research question (RQ) of our study is: *"What is the impact of applying digital sufficiency measures in professional life?"*, from which we derive two sub-research questions:

RQ1: How do practitioners perceive digital sufficiency measures in daily work life?

RQ2: How can digital sufficiency measures affect resource consumption or energy consumption?

This article explores answers to the above research questions. At first, we describe the background (Section II) followed by the overview of study design (Section III) where we discuss the selection of tactics for the survey. Section IV analyzes the survey results and motivates the decision on the tactic selected for the experiment. Sections V and VI present the experiment planning and results, respectively. Section VII discusses the survey findings (RQ1) and the experiment findings while exploring the impacts of applying tactics in literature (RQ2). We close the paper with potential threats to the study validity (Section VIII) and conclusion (Section IX).

II. Background

A. Digital Sufficiency

The Intergovernmental Panel on Climate Change (IPCC) defined "Sufficiency Policy" in their 2023 report as "a set of measures and daily practices that avoid the demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries" [6]. Following the policy, demand for digital technologies should also be rationalized to minimize adverse environmental impacts. Santarius et al. call this process "Digital Sufficiency", i.e., *any strategy that directly aims at decreasing the absolute level of resource and energy use by reducing the levels of production and consumption* [4]. According to them, it can be divided into four dimensions, among which "software sufficiency" and "user sufficiency", that fall in the scope of our research:

Software sufficiency includes strategies to ensure that the data traffic and hardware utilization of applications are kept as low as possible [4].

User sufficiency supports users to apply digital devices frugally and use ICT so to promote sustainable lifestyles [4].

The motivation to emphasize these two dimensions of digital sufficiency is to address that there is a rebound effect of easy-to-use technology of software and so, users should control the unlimited use of technology. Hence, we investigate the impact of applying tactics to reduce energy or resource consumption by minimizing data traffic and use of hardware by the software (software sufficiency) to support users utilizing the cloud technology frugally (user sufficiency).

B. Flexible Work

Flexible work or telework refer to work arrangements that include the flexibility of place and/or time. Since the Covid-19 pandemic, this mode of work has been popularized widely in the world. Even though travel to workplace-related carbon emissions can be minimized by flexible work, other sources of emission emerge. One of these sources is the increasing dependency on the use of the internet and cloud. Telework depends on online modes of communication, such as frequent and long duration of online meetings which increases energy consumption and carbon footprint. At the same time, data centers are causing more carbon footprint to facilitate the speed of flexible work. While existing studies mostly focus on the positive environmental impact of flexible work, the detrimental impact of excessive cloud computation is neglected.

C. Footprint of Cloud Usage

Cloud data centers are structured with large buildings full of computers and hard drives which require lots of energy to operate. Energy is also consumed while sending data to the center from the client side through the infrastructure of internet and fiber optic cables. Although advanced data centers took sustainable initiatives to establish infrastructures with renewable energy, most small-scale data centers cannot afford to do this. Other options of cooling with water or through relocation of data centers to the northern cold countries are also not viable for the long term. According to a study on the environmental impacts of data storage and computation, a single data center can consume the same amount of electricity as 50,000 homes [7].

D. Energy and Resource Consumption

Energy in the form of electricity is required to run any computer system and machinery. In this study, we will often discuss the energy consumption of software systems while applying a certain feature or practice that involves the use of cloud. For the calculation of energy consumption, we measure the energy required to run the software systems in hardware, such as the energy cost of applications in the end user's device. Any superfluous usage of the cloud that requires more energy than usual can be considered to cause a negative impact on the environment. Similarly, we calculate the length of data required to pass through the network to reach cloud for facilitating certain features of an application. In the scope of this research, this traffic of data is termed as "resource consumption".

E. Sufficiency Tactics

Madon et al. [5] explore the necessary and superfluous usage of the cloud in flexible work. This study is based on three focus groups involving employees from a small and a large-scale company. Participants of the groups discussed their daily usage of the cloud by differentiating between actual needs and usages. By analyzing data from the sessions, the researchers finalized a catalog of 48 digital sufficiency tactics that can be followed to minimize the unnecessary use of the cloud in regular work life. An example of tactic is "Archiving or deleting old or useless data" [5]. However, this research does not provide experimental evidence of benefits while applying the tactics. The study also could not ensure if general people would be interested in practicing the sufficiency tactics in everyday life. Hence, it offers the scope for the current study to investigate people's acceptance regarding the tactics and actual advantages of applying those.

III. Study Design

Figure 1 provides the overview of the design of our study. Taking as input an existing catalog of tactics for digital sufficiency [5], we designed and executed a questionnaire survey among real-life practitioners to understand their related perception. Based on the survey results, we ranked and selected a short list of tactics. We then assessed the impact of applying one of these tactics by performing an empirical experiment.

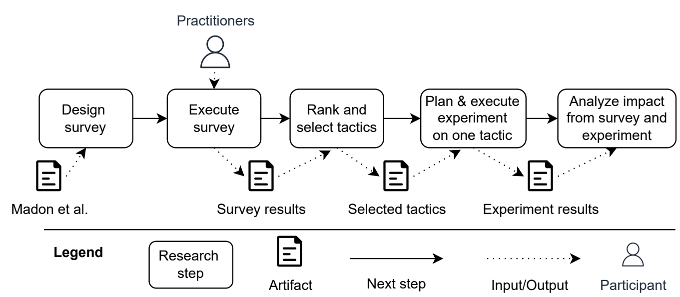


Fig. 1: Overview of study design

As the tactic chosen for the experiment derives from the survey results, we first explain the survey design and execution (in the rest of this section), and the survey results (in Section IV). The experiment planning and execution follows (in Section V).

A. Survey Design

The survey was designed to analyze the acceptance of some of the proposed tactics by practitioners (RQ1).

1) Selection of Tactics: We selected 16 tactics from the original set of 48 tactics reported by Madon et al. [5] to make it feasible to conduct a survey. These tactics were selected based on two reasons:

(1) Tactics should be generic so that they can be practiced by most people who use the cloud in their daily professional lives. This can ensure more participation in the survey. For instance, "Apply auto-scaling technique to automatically adapt server capacity" is one of the tactics that is not applicable to those who are not familiar with auto-scaling.

(2) Tactics can be both measurable and non-measurable in terms of energy consumption. We prioritized the measurable tactics so that experiments can be performed to measure the benefit of their adoption.

Following the above reasoning, we selected 16 tactics to include in the survey. Among them, 5 tactics (reported in Table I) are considered as measurable or feasible for experiment. Rest of the 11 non-measurable tactics in the survey are about different ways of communication. We exclude these tactics from the scope of this article to discuss thoroughly about the measurable tactics.

TABLE I: Tactics Feasible for Experiment

Tactic 1.	Use the local, off-cloud version of an application if the work doesn't need to be shared
Tactic 2.	Performing a task offline and only synchronizing with the online version from time to time
Tactic 3.	Turn the camera off or lower the default video quality in online meetings
Tactic 4.	Enclosing large files as links rather than attachments in email
Tactic 5.	Closing an application, window, or tab when it is not needed anymore

2) Structure of Survey Questionnaire: The first section of the survey questionnaire included general demographics questions on the participants' current or last profession, job sector, position, experience, and flexibility of work. The second section of the questionnaire was about participants' acceptance of digital sufficiency tactics. Participants were asked to select different answers on each of the Tactics 1-5 in Table I.

B. Survey Execution

We implemented the questionnaire survey by using Google Forms. The target group for this survey was the corporate and flexible professionals who use cloud technology in daily work life both on-site and remotely. We disseminated the survey through contacts with different companies in the Netherlands and Germany. In addition, we published it as a post on the career-focused social media platform LinkedIn. We continued the survey for a month and received responses from 61 participants around the world. Based on the survey responses, we rank the tactics reported in Table I and select one of the tactics to perform the experiment, as explained at the end of Section IV.

IV. Survey Results

A. Demographics

Although the survey was anonymous, we collected professional demographic information and kept the survey open until we could count on participants from diverse categories. Survey responses reflect a wide variety of professional sectors which includes both the field of Information Technology, and Consultancy, Marketing, Academia, Banking, and other financial services. Job positions from different sectors include Software Engineer, Architect, Application Developer, Data Engineer, HR Specialist, Consultant, Researcher, and so on. In addition to the variations in job sectors and positions, we managed to engage people having a wide range of job experience. Figure 2 shows that almost 69% of the respondents (42 out of 61) indicated that they perform hybrid work (both remote and on-site).

Fig. 2: Participants' flexibility of work

B. Preference on Applying Tactics

In the second part of the survey, we investigate how likely would the respondents be to apply the five digital sufficiency tactics in their daily professional life. The responses are illustrated in Figure 3.

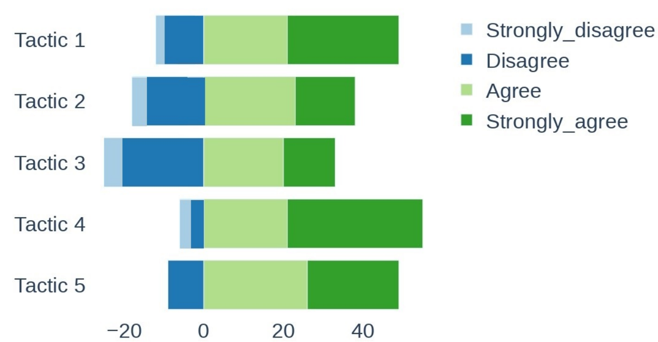


Fig. 3: "I would consider applying each of these tactics in my daily work life" (61 responses)

From the figure, it is obvious that most people strongly agree with Tactic 4 which is about enclosing large files as links rather than attachments. In total, 55 of 61 participants agreed they would consider applying this tactic in their daily work life. In addition, Tactics 1 and 5 have the same number of responses in terms of agreement (49 in total). Although Tactic 1 has a higher count of strongly agreed, it also shows more disagreement than Tactic 5. Tactics 2 and 3 are less agreed upon or even disagreed in terms of practicing in regular life.

C. Effect on Work Productivity

This section of the survey relates work productivity with regular practice of digital sufficiency tactics. The motivation for this question was to encourage participants to think about the effects of applying tactics on their work productivity. If a certain tactic's effect on work productivity is positive, it is likely to minimize both energy and time spent while using the cloud. Figure 4 illustrates the responses on work productivity the tactics might bring to the practitioners' professional lives.

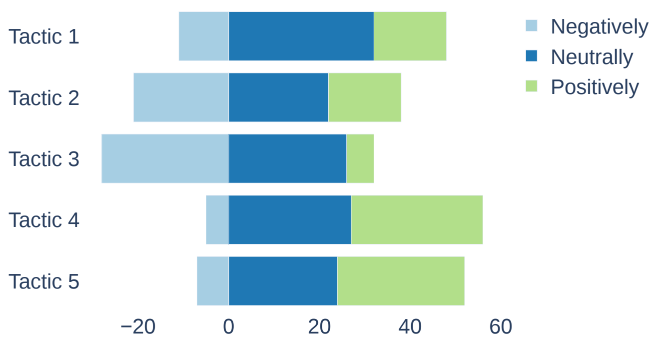


Fig. 4: "How would each of these tactics affect your daily work productivity?" (61 responses)

According to the figure above, Tactic 4 and 5 show the most likely positive effect on work productivity. On the contrary, many participants answered that Tactic 2 and 3 might have more negative effects on their daily work productivity, while most people chose a neutral effect on Tactic 1.

D. Beneficial to Environment

In the survey, practitioners also selected tactics they thought would be beneficial to reduce energy or resource consumption if those were practiced regularly. Although these are only perceptions from the practitioners, we intend to link it with experimental results. Figure 5 displays the selection of tactics derived from the survey.

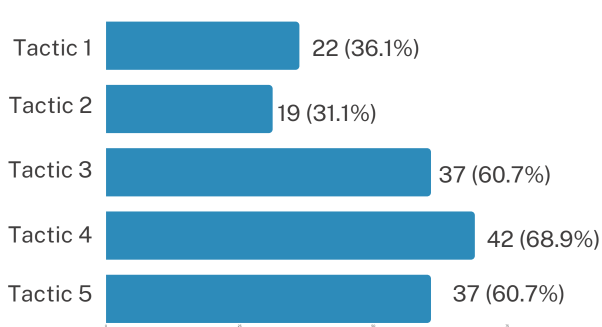


Fig. 5: "Select 0-3 tactics that you think would be most beneficial to reduce energy or resource consumption in daily work-life." (number of times the tactic was selected)

Results show that almost 69% of participants think Tactic 4 can be effective in reducing energy or resource consumption i.e. beneficial to the environment. In addition, 37 out of 61 respondents selected Tactic 3 and 5 as beneficial. The rest of the tactics received a lower count of selection from the respondents.

E. Decision on Tactics for Experiment

According to the survey responses, Tactic 4 on "Enclosing large files as links rather than attachments" ranked highest among all tactics as applicable, likely to have a positive effect on work productivity, and more beneficial to the environment. Moreover, Tactic 5 on "Closing application, window or tab when it is not needed anymore" ranked as the second. Hence, these tactics are likely to have more impact than other tactics as most people are inclined to apply them in their regular professional lives. However, we found online studies available on the benefits of applying Tactic 4. Therefore, we decided to measure energy and resource consumption of applying Tactic 5.

V. Experiment Planning and Execution

To experiment on Tactic 5, we compare the energy and resource consumption of keeping a higher number of tabs (10 tabs) and fewer tabs (1 tab) open in different browsers.

A. Scope of Experiment

Classically, energy consumption of a computer service is divided in three scopes:

1) Energy Consumption of Client: Energy consumed by the end-user's device (e.g., CPU, screen). It can be measured with hardware or software tools.

2) Energy Consumption of Network: Energy consumed by routers, network switches, and all networking equipment between the client and server. It can be calculated by analyzing the lengths of application data in data traffic.

3) Energy Consumption of Server: Energy consumed by the servers in the data centers delivering the service. This consumption is the most complex to estimate, as it takes place on the service providers' side.

In our case, for Tactic 5, server-side energy consumption could have been quantified by hosting the web servers in the lab and monitoring their consumption. Alternatively, we could have made an estimation based on publicly available averages. However, both strategies have large uncertainties and might not provide a trustworthy value tailored to our use case. For this reason, we chose to exclude this phase from the experiments, and emphasize on the above-mentioned first two phases.

B. Plan of Experiment

1) Experimental Hypotheses: To answer the second sub-research question (RQ2) on Tactic 5, we have formulated the following pair of hypotheses:

H_0 : energy or resource consumption does not vary with the number of open tabs in a browser

H_1 : energy or resource consumption of a large number of open tabs in a browser is higher than that of fewer number of tabs

$$H_0 : E_1 = E_2 \qquad H_1 : E_1 < E_2$$

Given that E_1 is the energy or resource consumption of fewer number of tabs and E_2 is the same consumption of higher number of tabs, H_0 is the null hypothesis and H_1 is the alternative hypothesis.

2) Subjects Selection: To experiment on Tactic 5, two browsers with ten websites are selected as subjects. According to statistics, the top three browsers in terms of market share are Google Chrome, Safari, and Microsoft Edge [8]. Since Microsoft Windows is still the most commonly used operating system [9], we choose to conduct the experiment on Windows and thus, select browsers Google Chrome and Microsoft Edge as subjects. In addition, we select ten websites (reported in Table II) from the most popular websites based on the Similarweb list updated on June 2023 [10].

TABLE II: Selected 10 web pages for tabs in browser,
* marked websites are chosen for the cases with 1 tab

Website	Link in open tabs
Google*	http://www.google.com
Open AI	http://openai.com
Amazon	http://amazon.com
LinkedIn	http://linkedin.com
Wikipedia	http://wikipedia.org
WhatsApp	http://whatsapp.com
Twitter	http://twitter.com
Facebook	http://www.facebook.com
Instagram	http://instagram.com
YouTube*	http://www.youtube.com

3) Experimental Variables: Before designing the experiment for Tactic 5, the independent and dependent variables are specified following Wohlin et al. [11]. The dependent variables "energy consumption" and "resource consumption" are derived from the second sub-research question (RQ2). For the client-side experiment, the dependent variable is "energy consumption" and the measurement unit for consumed energy is Joules (J). Besides the regular websites, we consider the video streaming website YouTube to explore energy and resource consumption while streaming takes place in the foreground or background. Hence, there are two independent variables- (1) number of open tabs, and (2) type of streaming. For the independent variable "number of open tabs", there are two treatments - (1) one open tab, and (2) ten open tabs. This variable is also the main factor of this experiment. For the other independent variable "type of streaming", there are three treatments - (1) video streaming in the foreground, (2) video streaming in the background, and (3) without streaming.

Similarly, for the network-side experiment, the dependent variable is "resource consumption" which is measured by the total length of "application data" captured while monitoring the transport layer security (TLS) protocol in the network traffic. Therefore, the measurement unit for this variable is Bytes. The main factor, independent variables, and treatments are the same as mentioned above for the client side of the experiment.

4) Experiment Design: For both client-side and network-side, we perform experiments on two browsers with different treatments which are about the number of tabs and type of streaming. Test cases with these treatments are reported in Table III. There are six test cases for each browser, three of which have only one tab open. In other cases, ten tabs are loaded with regular and streaming type of sites. Regular sites are mentioned in Table II and the streaming tab played a certain video on YouTube for 60 seconds either in the foreground or background. Each test case is repeated ten times to mitigate noise and bias in the experiment. Hence, the total run time calculation for client-side is:

(2 subjects) × (2 treatments) × (3 treatments) × (10 repetitions) × (60 seconds of runtime + 2 seconds of idle time) = 7440 seconds ≈ 2 hours 4 minutes

Similarly, the total run time calculation for network-side is:

(2 subjects) × (2 treatments) × (3 treatments) × (10 repetitions) × (60 seconds of runtime + 10 seconds of idle time) = 8400 seconds ≈ 2 hours 40 minutes

TABLE III: Test cases for experiment

Browser	Tabs	#regular - #stream	Stream. type
Chrome	1	1 - 0	N/A
Chrome	1	0 - 1	Background
Chrome	1	0 - 1	Foreground
Chrome	10	10 - 0	N/A
Chrome	10	9 - 1	Background
Chrome	10	9 - 1	Foreground
Edge	1	1 - 0	N/A
Edge	1	0 - 1	Background
Edge	1	0 - 1	Foreground
Edge	10	10 - 0	N/A
Edge	10	9 - 1	Background
Edge	10	9 - 1	Foreground

C. Execution Preparation

The following steps are performed as preparation before running the tests to ensure some settings in the personal computer (PC) do not affect the measurement:

- turned off all other applications running on the PC
- turned off unnecessary processes running in the background
- removed the power plug to stop charging the battery
- fixed screen brightness to the minimum
- connected the PC to the network using WiFi

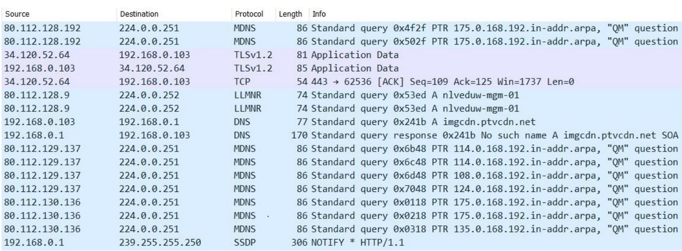
D. Setup

During the experiment, we used specific devices and software tools. In flexible work, people strongly depend on their professional or personal desktop or laptop. Hence, our experiment is based on a computer without focusing on any other device. The laptop used for the experiment is an ACER Aspire A515-54G[1].

[1]CPU: Intel i5-8265U with 12 GB memory, OS: Windows 10 v.22H2 (x64-based), GPU: NVIDIA GeForce MX250 with Intel UHD graphics 620

As mentioned earlier, there will be two phases of experiment execution both using the same PC: (1) measuring the energy consumption of the client-side, and (2) measuring the resource consumption of the network-side. There are different power monitors and energy profilers to measure energy consumption. However, setting up a power monitor is critical and often requires custom changes to computer devices [12]. Therefore, we choose the energy profiler software tool Intel Power Gadget (version 3.6), which is compatible with our specified device [13]. This energy profiler uses RAPL (Running Average Power Limit) internally for energy measurement of Intel devices [12].

For the second part of the experiment, we used Wireshark (version 4.0.6) to capture the length of application data passed within the network while monitoring the TLS 1.2 (Transport Layer Security) protocol. Wireshark is the world's leading network protocol analyzer which allows users to scrutinize their network at a microscopic level [14]. Figure 6 presents the interface of Wireshark capturing packets of data traffic. In the "Info" section, "Application Data" is visible which has a data length of 81 Bytes provided in the "Length" section.



Source	Destination	Protocol	Length	Info
80.112.128.192	224.0.0.251	MDNS	86	Standard query 0x4f2f PTR 175.0.168.192.in-addr.arpa, "QM" question
80.112.128.192	224.0.0.251	MDNS	86	Standard query 0x502f PTR 175.0.168.192.in-addr.arpa, "QM" question
34.120.52.64	192.168.0.103	TLSv1.2	81	Application Data
192.168.0.103	34.120.52.64	TLSv1.2	85	Application Data
34.120.52.64	192.168.0.103	TCP	54	443 → 62536 [ACK] Seq=109 Ack=125 Win=1737 Len=0
80.112.128.9	224.0.0.252	LLMNR	74	Standard query 0x53ed A nlveduw-mgm-01
80.112.128.9	224.0.0.252	LLMNR	74	Standard query 0x53ed A nlveduw-mgm-01
192.168.0.103	192.168.0.1	DNS	77	Standard query 0x241b A imgcdn.ptvcdn.net
192.168.0.1	192.168.0.103	DNS	170	Standard query response 0x241b No such name A imgcdn.ptvcdn.net SOA
80.112.129.137	224.0.0.251	MDNS	86	Standard query 0x6b48 PTR 114.0.168.192.in-addr.arpa, "QM" question
80.112.129.137	224.0.0.251	MDNS	86	Standard query 0x6c48 PTR 114.0.168.192.in-addr.arpa, "QM" question
80.112.129.137	224.0.0.251	MDNS	86	Standard query 0x6d48 PTR 108.0.168.192.in-addr.arpa, "QM" question
80.112.129.137	224.0.0.251	MDNS	86	Standard query 0x7048 PTR 124.0.168.192.in-addr.arpa, "QM" question
80.112.130.136	224.0.0.251	MDNS	86	Standard query 0x0118 PTR 175.0.168.192.in-addr.arpa, "QM" question
80.112.130.136	224.0.0.251	MDNS	86	Standard query 0x0218 PTR 175.0.168.192.in-addr.arpa, "QM" question
80.112.130.136	224.0.0.251	MDNS	86	Standard query 0x0318 PTR 135.0.168.192.in-addr.arpa, "QM" question
192.168.0.1	239.255.255.250	SSDP	306	NOTIFY * HTTP/1.1

Fig. 6: Data traffic and packet capture in Wireshark interface

E. *Measurements*

Before beginning the measurements, we loaded the browser with the tabs of specified sites. However, for the cases with a single tab, we loaded it only with the URL of the search engine Google (google.com) or with a video on YouTube in the case of streaming. Then all the test cases reported in Table III were performed in order, at first with the browser Google Chrome, and then with Microsoft Edge[2]. Measurement of energy consumption with the tool Power Gadget was conducted at first. After completing this phase, we measured the data traffic as resource consumption with Wireshark by running the same test cases for equal duration. Measurements of energy and resource consumption were done separately because we terminated all the other applications running on the PC to separate the browser's energy consumption. Therefore, Wireshark was not being used while Power Gadget was taking logs of energy consumption by the Processor. The measurement process of both phases is explained step-by-step in the following:

1) Client-side: After the browser was loaded with specified tab/tabs, a script was executed to start Power Gadget automatically. The script was programmed to start and stop the recording of the power data by Power Gadget. Each recording continued for a minute, and then there was an idle time of two seconds. During this time, Power Gadget saved the log of each recording in an Excel sheet. For each test case, this process was repeated ten times. After running all test cases on both browsers, each log file was analyzed and the value of cumulative processor energy in Joules was extracted. According to the log-file data documentation provided by Intel Power Gadget [13], cumulative processor energy stands for the total energy of the processor and can be defined as follows:

Processor Energy = IA Energy (Energy of the CPU/processor cores) + GT Energy (Energy of the processor graphics) + Others

2) Network-side: During the second phase of this experiment, Wireshark was set up to capture data traffic for a minute after loading the tabs of each test case. From the log files, we extracted the length of "Application Data" in the unit of Bytes. After executing all test cases, we summed up the collected application data length found in each file to calculate the total consumed data in one run of the experiment. Only application data length was collected since it is the data that is generated as a part of the browser application running on a device.

VI. EXPERIMENT RESULTS

A. *Energy Consumption*

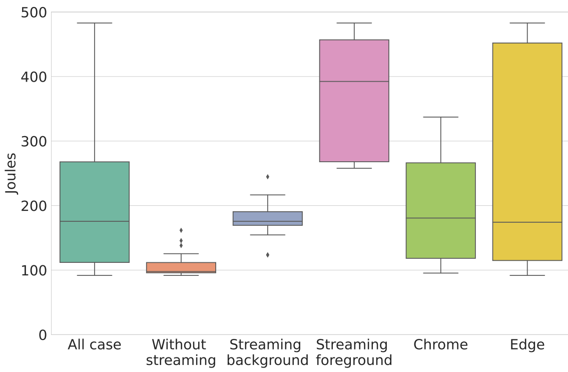
At first, we analyze the descriptive statistics of applying two treatments (one tab and ten tabs) with the data collected from Power Gadget. Statistical values of mean, standard deviation, minimum, and maximum are presented in the following tables and figures for combined and particular test cases.

Table 7c depicts the overview of the energy consumed in Joules during the experiment on fewer tabs. From the table, it can be observed that the average energy consumption of one tab in all cases of both browsers is 219 Joules. The highest mean is found in the case of streaming in the foreground (fg). In addition, Chrome browser consumes less energy than Edge on average. Similarly, Table 7d depicts the overview of the energy consumed in Joules during the experiment on more tabs. From the table, it can be observed that the mean energy consumption of ten tabs in all cases is 171 Joules. The highest energy was consumed while streaming in the foreground. In addition, Edge and Chrome have almost the same mean value of energy consumption. Besides, the high value of standard deviation indicates that there exists a great variability in the results. Therefore, we observe a counter-intuitive result at this stage since mean energy consumption, $E_1 > E_2$ and so, we need to analyze the network part to conclude about the overall consumption.

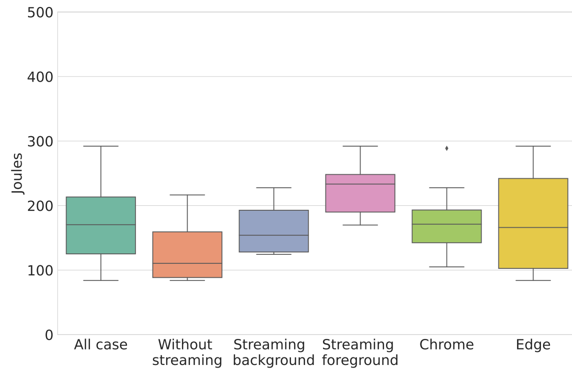
To get a clearer understanding of the data, two box plots are created with combined data of both browsers in Figure 7a and Figure 7b. The figures illustrate two box plots of the energy consumption of one and ten tabs for different cases. According to the plots, ten tabs consume more energy than a single tab when there is no streaming involved. However, it is the opposite when there is a streaming tab in the foreground or background. Additionally, it is observed from the plots that

[2]Chrome v. 123.0.6312.106 (64-bit) with 5 browser extensions, Edge v. 123.0.2420.65 (64-bit) with 3 browser extensions

(a) Figure 7a: Energy consumption for one tab



(b) Figure 7b: Energy consumption for ten tabs



(c) Table 7c

		Streaming			Browser	
	All case	wo	bg	fg	Chrome	Edge
count	60	20	20	20	30	30
mean	219.2	107.6	179.8	370.1	194.2	244.2
std	124.9	19.6	28.6	92.7	76.1	157.1
min	91.7	91.7	123.5	257.7	95.3	91.7
25%	111.8	95.8	169.4	267.9	118.2	114.8
50%	175.6	97.7	175.6	392.3	180.6	174.2
75%	267.7	111.7	190.5	456.8	266.2	451.9
max	482.9	161.6	244.6	482.9	337.1	482.9

(d) Table 7d

		Streaming			Browser	
	All case	wo	bg	fg	Chrome	Edge
count	60	20	20	20	30	30
mean	171.1	126.2	160.9	226.1	171.1	171.1
std	56.4	42.1	35.1	38.4	40.2	69.7
min	83.9	83.9	124.3	169.8	104.9	83.9
25%	125.1	88.4	128.0	189.9	142.4	102.5
50%	170.3	110.5	154.0	233.3	171.1	166.0
75%	213.3	159.2	192.7	248.2	193.1	242.0
max	292.1	216.4	227.6	292.1	288.7	292.1

Fig. 7: Energy consumption (in Joules) caused by the browser with 1 tab (left) and 10 tabs (right) opened. Boxplots and descriptive statistics. Abbreviations: wo: “without”, bg: “background”, fg: “foreground” streaming.

the distributions for almost all test cases overlap with each other.

B. *Resource Consumption*

At first, we analyze the descriptive statistics of applying two treatments (one tab and ten tabs) with the data collected by Wireshark. Statistical values of mean, standard deviation, minimum, and maximum are presented in the following figures for combined and particular test cases.

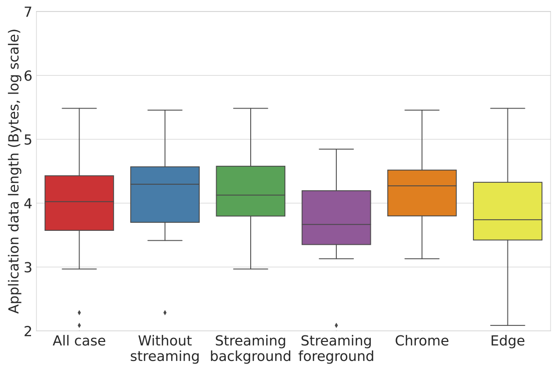
Table 8c depicts the overview of the application data length in Bytes consumed as a resource during the experiment on fewer tabs. From the table, it can be observed that the minimum and maximum values have a high difference. This is because some captured packets do not contain application data within the tested duration of 60 seconds whereas other packets may contain more than average. However, the average resource consumption of one tab in all cases of both browsers is more than 37308 Bytes. The highest mean is found in the case of streaming in the background. In addition, the Chrome browser causes more data traffic (41542 Bytes) than Edge (33073 Bytes) on average. Similarly, Table 8d depicts the overview of the resource consumed in Bytes during the experiment on more tabs. From the table, it can be observed that the mean application data length of ten tabs in all cases is 5.8×10^5 Bytes. The highest application data was passed while streaming in the background. In addition, Edge causes 10 times more application data traffic than Chrome in the case of ten tabs. Therefore, it can be inferred from the descriptive statistics that the difference between data consumption of fewer and more tabs is significant and it is much higher for running ten tabs instead of one tab.

To get a clearer understanding of the data, two box plots are created with combined data of both browsers in Figure 8a and Figure 8b. The figures illustrate two box plots of data consumption of one and ten tabs for different cases. According to the plots, ten tabs consume much more data than one tab in all cases. This hints that there is a difference in resource consumption while keeping more tabs or streaming tabs open in the browser. However, box plots indicate that there are outlier values that cause large variability among the data and the distributions overlap in almost all test cases.

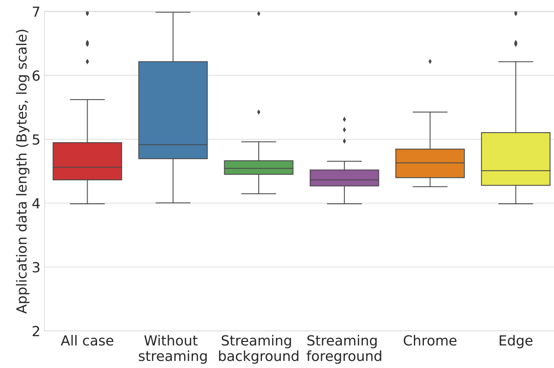
C. *Statistical Tests*

1) Normality Testing: In this section, we perform analysis to ensure the normal distribution of data to be able to conduct an ANOVA test. To do this, we plotted two histograms to visualize the distribution of energy consumption in one tab and ten tabs in both browsers combining all test cases. However, the plot for energy consumption in one tab does not follow a bell shape. Therefore, we perform the Shapiro-Wilks test to determine the normality of both datasets. From the test, we found statistic = 0.834 and p-value = 0.000001 for the case of one tab, and statistic = 0.966, p-value = 0.098 for ten tabs. Since the p-value of one case is not above the significance threshold of 0.05, we decide that the data is not normally distributed.

(a) Figure 8a: Resource consumption for one tab (logarithmic scale)



(b) Figure 8b: Resource consumption for ten tabs (logarithmic scale)



(c) Table 8c

		Streaming			Browser	
	All	wo	bg	fg	Chrome	Edge
count	60	20	20	20	30	30
mean	37.3	41.2	59.4	11.3	41.5	33.1
std	69.7	68.2	94.4	16.8	68.9	71.4
min	0.0	0.0	0.0	0.0	0.0	0.0
25%	3.8	5.0	6.3	2.2	6.3	2.6
50%	10.6	19.8	13.6	4.6	18.7	5.5
75%	26.8	37.0	41.0	15.7	33.1	21.2
max	304.8	285.9	304.8	70.1	285.9	304.8

(d) Table 8d

		Streaming			Browser	
	All	wo	bg	fg	Chrome	Edge
count	60	20	20	20	30	30
mean	580.8	1188.6	512.0	41.9	113.6	1048.1
std	1825.8	2321.3	2064.1	49.3	296.3	2498.4
min	9.8	10.1	14.0	9.8	18.1	9.8
25%	23.1	50.3	28.3	18.6	25.1	19.0
50%	36.5	82.2	35.0	23.1	42.7	32.3
75%	88.5	1640.2	46.2	33.4	70.2	128.9
max	9731.8	9731.8	9278.5	204.9	1654.1	9731.8

Fig. 8: Network resource consumption (in kilobytes) caused by the browser with 1 tab (left) and 10 tabs (right) opened. Boxplots and descriptive statistics. Abbreviations: wo: "without", bg: "background", fg: "foreground" streaming.

Similarly, we plot histograms and perform the Shapiro-Wilks test to determine the normal distribution of application data consumption in one tab and ten tabs in both browsers combining all test cases. From the histograms, it is observed that none of the plots form a bell shape, which indicates that the data is not normally distributed. From the test, we found statistics = 0.549 and p-value = 2.755×10^{-12} for the case of one tab, and statistics = 0.342, p-value = 6.295×10^{-15} for ten tabs. Therefore, since the p-values of both cases are below the significance threshold of 0.05, we decide that the data is not normally distributed.

2) Hypotheses Testing: Since the data is not normally distributed and we focus on more than two treatments, a non-parametric test Kruskal-Wallis is executed. According to the test result, the p-value is 0.184 for the experiment of energy consumption. As the p-value is above the threshold of 0.05, it means that we cannot reject the null hypothesis. Therefore, from the experiment results on the client side, we cannot conclude that having ten tabs open consumes more energy than having only one.

Similarly, we conduct the Kruskal-Wallis test on the data of resource consumption since it is also not normally distributed. According to the test result, p-value is 5.559×10^{-8} for the experiment of resource consumption. As the p-value is below the threshold of 0.05, it means that we can reject the null hypothesis. More data traffic in the application phase is likely to cause more energy consumption on the network side. Hence, from the analysis of resource-consumption data, we can accept the alternative hypothesis which states that resource consumption of a large number of open tabs in a browser is higher than that of a smaller number of tabs.

VII. Discussion

A. Findings from Survey

From the survey results, it is interesting to note that the answers from our participants to the first (Figure 3) and the second (Figure 4) survey questions are very similar. They follow the same pattern of 'strongly disagree' / 'disagree' versus 'agree' / 'strongly agree' (respectively 'negatively' versus 'neutrally' / 'positively'). This suggests that willingness to adopt the tactics and perception of how they will affect work productivity are correlated. In other words, *practitioners would consider applying tactics when they do not affect their work productivity*.

Regarding participants' perception of the environmental impact of each tactic (Figure 5), the pattern of answers looks again similar. The only noteworthy difference is Tactic 3 (switching off the camera) which was the least preferred but assumed by most respondents to be beneficial to reduce energy or resource consumption. This suggests that *despite knowing that switching off their camera during meetings could make a difference, practitioners are not ready to give up on the benefits it brings to them.*

B. Findings from Experiment

The first phase of the experiment is on the energy consumption of applying the tactic. According to the results, fewer tabs consume more energy than a higher number of tabs considering all cases, which is a counter-intuitive result. However, mean energy consumption can be 17.8% higher for more tabs than that for fewer tabs while video streaming cases are not considered. The reason behind this result can be the measurement process which relies on the "cumulative processor energy" as the energy consumption of the browser application. To measure the client side's energy consumption of applying the tactic, browser's energy consumption needs to be separated from the total consumed energy by the processor. Although we tried to minimize the process and applications running in the background, some hidden processes can still consume energy which can cause unexpected results.

The second phase of the experiment is on the resource consumption of applying Tactic 5 where we analyze the network traffic. In this case, the resource consumption of a larger number of tabs provides much higher values than that of fewer tabs which is the expected outcome. Results of this phase of the experiment show that the resource consumption can be 15.5 times higher for a large number of tabs. In addition, the total size of application data length came out much higher for more tabs than fewer tabs even in the cases of video streaming. In this measurement process, we were able to separate "application data" length in the network traffic as the browser is the application that was interacting with the network actively during the experiment. Hence, it can be a reason for the expected results of this phase of the experiment.

Thus, we can summarize that even though energy consumption measurement on the client side could not prove that the tactic can reduce energy, the network side of the measurement proves that it causes less data traffic and resource consumption. This reduction in consumption should eventually contribute to decreasing energy consumption in the data centers or server-side as well.

C. Comparison between Tactics

The five studied tactics have different potential to lower energy or resource consumption. In this part we gather data from different sources and try to put them in comparable values.

a) Tactic 1&2: Experimental data on Tactics 1 and 2 can be found in a study from Vishwanath et al. [15]. They compared the energy consumption of interactive cloud-based office applications (word processing, presentation and spreadsheet) with their local counterparts. Three scenarios are compared:

(1) Creating, editing and saving in the cloud (→ baseline),
(2) Creating and editing locally, saving in the cloud (→ Tactic 2),
(3) Creating, editing and saving locally (→ Tactic 1)

They performed an extensive set of experiments on a netbook, including different network interfaces, applications, and application providers. We report in Table IV only the results for the Google word processing application.

TABLE IV: Impacts of applying the tactics, client-side, server-side and network-side.

	Energy saved		Saved	Ref.
	Client-side	Server-side	data traffic	
T.1	0.3-1W*	0.25W**	all	[15]
T.2	0.3-1W*	∅	2-3 orders of magnitude***	[15]
T.3	4W†	∅	∅	[16]
T.4	∼0	?	∼0	rough estimate
T.5	no statistical evidence	∅	1 order of magnitude	this study

∅ indicates "out of scope" *word processing in google drive, difference between power consumption of netbook in offline and online edition (Table VI [15])
**assumption used in the article (Section IV.D.6 [15])
***slopes in Figure 4 [15]
† mean values in Table 7 [16], converted to Watts

b) Tactic 3: Obringer et al. made a study on the neglected environmental footprint of rising internet use [17]. According to them, having 15 1-hour meetings every week results in a monthly carbon footprint of 9.4 kg CO_2e. Simply turning off the video would lower it to 377 g CO_2e. Wattenbach et al. also compare the energy consumption of joining an online meeting with and without the camera [16]. They monitor the energy consumption of Google Meet and Zoom, running on a smartphone. We report in Table IV the results for Zoom.

c) Tactic 4: Emails are often discussed when talking about the environmental impact of ICT. A simple Google search reveals plenty of blog posts and newspaper articles on the topic. However, we are not aware of any peer-reviewed study measuring this impact with precision. Most resources on the web refer to a book by Berners-Lee [18], putting the carbon footprint of a "standard email" at 4 g CO2e and the one of an email with "long and tiresome attachments" at 50 g CO2e. Another online study reports that email attachments can cause 55,000 file duplicates per user per year while link attachments create only 5,000 file duplicates [19]. Getting accurate and comparable figures for Tactic 4 would require more work. A reasonable approximation would be that client-side consumption is equivalent to sending an attachment and a link (same time spent with the device powered on). The amount of data traffic is the same because the sender will upload the attachment to a cloud, from which the recipients will download it. Only server-side consumption is likely to be different since file duplicates are avoided. This is the estimate we report in Table IV.

Following Table IV, it is clear that we lack experimental data to compare the effects of tactics on energy or resource consumption, and answer RQ2. From the data we have, it looks like Tactic 3 (switching off the camera) has the most impact, followed by Tactics 1 and 2 (local VS cloud-interactive).

Tactics 4 (email attachment) and 5 (closing tabs) come last.

Interestingly, this order is quite different from the perception of our survey participants, as reported in Figure 5: they ranked Tactic 4 highest, followed by Tactics 5 and 3. Consequently, *practitioners seem to have a wrong idea on the efficiency of the various actions they can take*. According to Elgaaied-Gambier et al. [20], this wrong perception is probably due to a mix of factor: intangibility of digital footprint and general lack of knowledge, perceived sacrifice of each tactic, skepticism toward change, etc.

D. Related Work

Rowanne Fleck et al. conducted an HCI (Human Computer Interaction) based research about balancing boundaries while using multiple devices to maintain work-life balance [21]. The methodology of this paper involves a questionnaire survey of over two hundred employed participants to investigate work-life balance boundary behaviors and the use of technology. Another research similar to our study conducted by Elgaaied-Gambier et al. analyzes consumers' enthusiasm to adopt eco-friendly online behavior [20]. According to the study findings, consumers lack awareness about the adverse environmental effects of internet use and are reluctant to change online behavior while preferring authorities to take steps instead. João de Macedo et al. experimented on the energy consumption of two popular browsers Chrome and Firefox using the RAPL framework similar to our study [22]. Their findings indicate that energy consumption depends on the type of interaction on the web pages. Interestingly this research found that the highest peaks of energy consumption occur when a new tab is opened in the Chrome browser.

E. Suggestions towards Sufficiency

This section suggests strategies to end users and service providers to apply the two top ranked tactics according to survey findings. To apply Tactic 4 to software applications that provide mailing services, the design of the user interface can be modified. Service providers can suggest users the option of link attachment whenever users opt to attach files for sending mail and impose more limit on the size of total attachment. Similarly, for Tactic 5, there can be modifications in the browsers to notify users to close tabs when the number of total open tabs exceeds a limit. Besides, for streaming sites, there can be an alert or auto-closing option as it may cause more resource and energy consumption than regular sites. While service providers can claim to be carbon neutral, there are still carbon footprints caused by the end-users. Modern end-users should come out of the age-old custom of sending mail with direct file attachments and get used to sending files using link attachments. Besides saving storage space in the cloud, this option provides scope to update the sent item and delete it in case of mistakenly sent. Thus, Tactic 4 can provide privacy and security which should encourage users to apply it in daily mailing activity. Users should also consider the energy and resources that are consumed in the background of a browser and server-side while providing the services to save the battery power of their own devices.

VIII. Threats to Validity

During the questionnaire survey, subjects or participants might react differently while responding to the survey. Hence, the survey responses might be affected by their negative or positive mood. Besides, the number of participants (61) was not high, and we cannot ensure that they were representative of the flexible practitioners worldwide. Concerning usage scenarios during the experiment, there can be some threats associated with human factors while interacting with the browser as we did not pre-record the actions. Since we do not focus on any specified action, the web pages were only scrolled casually without performing any activity to initiate the next page. In addition, some of the selected websites have been designed to be lightweight, such as Google, OpenAI, and Wikipedia, which might cause less energy or resource consumption than any other typical website. The device selection for the experiment was limited by the availability of a PC and compatibility with the software for energy consumption measurement. In our experiment, only one laptop was used, which is currently on the market but it cannot be considered as representative of the entire population of computers. Besides, this experiment excludes other operating systems, such as Linux or Mac OS, and smart devices which are also common resources for modern, flexible modes of office work. As only one energy consumption measurement software profiler (Intel Power Gadget) was used, the experiment suffers from mono-method bias. Using another profiler was not possible due to time constraints as well as incompatibility with hardware.

IX. Conclusion

The impact of applying sufficiency tactics can be analyzed through the survey responses and experiment results. The survey results enlighten us about respondents' willingness for the regular practice of some tactics and reasons behind not preferring some of them. For example, Tactic 3 is the least preferred to practice according to responses but it has more proof of reducing energy consumption according to literature. Results of the experiment on Tactic 5 indicate that although energy consumption of the client side increases with the number of open tabs in a browser only for the case "without streaming", resource consumption of the network side rises significantly in all cases. This analysis provides scope for future research on the client side and possible experiment on the server side to determine the overall impact. Moreover, experimental research can be performed to analyze evidence of the benefit of applying other tactics preferred in the survey. Simple strategies like Tactics 4 and 5 are selected by most participants in the survey although before participating they probably never thought of the benefit these can bring. Thus, this research does not only explore the impacts of digital sufficiency tactics on user and software sufficiency levels, but it also contributes to raising awareness among flexible professionals.

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