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Switching off for future—Cost estimate and a simple approach to improving the ecological footprint of radiological departments

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ABSTRACT

Purpose: Besides diagnostic imaging devices, in particular computed tomography (CT) and magnetic resonance imaging (MRI), numerous reading workstations contribute to the high energy consumption of radiological departments. It was investigated whether switching off workstations after core working hours can relevantly lower energy consumption considering both ecological and economical aspects.

Methods: Besides calculating different theoretical energy consumption scenarios, we measured power consumption of 3 workstations in our department over a 6-month period under routine working conditions and another 6-month period during which users were asked to switch off workstations after work. Staff costs arising from restarting workstations manually were calculated.

Results: Our approach to switching off workstations after core working hours reduced energy consumption by about 5.6 %, corresponding to an extrapolated saving of 3.2 tons in carbon dioxide (CO_2) emissions and 2100.70 USD/year in electricity costs for 227 workstations. Theoretical calculations indicate that consistent automatic shutdown after core working hours could result in a potential total reduction of energy consumption of 38.6 %, equaling 22.2 tons of CO_2 and 14,388.28 USD/year. However, staff costs resulting from waiting times after manually restarting workstations would amount to 36,280.02 USD/year.

Conclusions: Switching off workstations after core working hours can considerably reduce energy consumption and costs, but varies with user adherence. Staff costs caused by waiting time after manually starting up workstations outweigh energy savings by far. Therefore, an energy-saving plan with automated shutdown/restart besides enabling an energy-saving mode would be the most effective way of saving both energy and costs.

1. Introduction

Producing nearly 4 million tons of waste per year, the healthcare system in total is a great burden for the environment [1]. Against the background of climate change, action is therefore essential as the worldwide average temperature has already risen about 1 °C above preindustrial levels [2]. This rise in temperature can be attributed almost entirely to man-made greenhouse gas emissions [3]. Large parts of the world's emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide can be traced back to energy production, meaning saving energy also reduces the amount of greenhouse gases and air pollution [4]. In order to prevent a further increase in global warming, emissions of greenhouse gases, in particular carbon dioxide (CO_2), must be reduced very rapidly [5].

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging; CO_2, carbon dioxide; W, Watt; RIS, radiology information system; kWh, kilowatt hours; RAM, Random-Access Memory; SSD, solid-state-drive; ISO, International Organization for Standardization.

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Investigators from other medical specialties such as surgery have already addressed this problem. One study proposes to reduce the need for resources in surgery by changing the usage of the heating system for the operating room or by improving recycling [1].

In radiology departments the main contribution to climate change is caused by high electricity consumption due to the use of energy-intensive equipment such as computed tomography (CT) scanners, magnetic resonance imaging (MRI) systems, or interventional suites [6]. Moreover, there are numerous reading workstations, which typically consist of a computer with 3 monitors. In our department, most reading workstations are running 24 h/7 days irrespective of whether they are used or not. Keeping in mind that there are several hundred workstations at a university hospital, this means a huge waste of energy contributing to the environmental footprint of radiology. Studies suggest that a computer left on 24/7 produces 1471 kg/year of CO_2; if the computer is turned off after work and on weekends, energy consumption is reduced to 315 kg/year CO_2 [4].

Evidently, radiology departments have great potential for reducing energy consumption. To begin with, it only takes to switch off a reading workstation. In addition to compute theoretical scenarios, we measured the power consumption of reading workstations in our radiology department before and after employees were told to switch off their workstation after core working hours.

2. Materials and methods

The reading workstations for which we measured energy consumption consisted of a desktop computer (Fujitsu Esprimo D956/E94 + DTF (8GB RAM, Inteli5−6500 3,2 GHz), Fujitsu, Tokyo, Japan), two medical-grade diagnostic monitors (EIZO RadiForce RX250, EIZO, Hakusan, Japan), and a third monitor for the radiology information system (RIS) (Fujitsu B22T-7 Pro, Fujitsu, Tokyo, Japan) (see Fig. 1). The workstation's power status was recorded and measured in watt (W) (workstation on, standby mode, and workstation off). Based on these measurements and considering shift planning for all sites belonging to our university department (comprising three major university campuses and several smaller hospitals), extrapolations were made for various theoretical work scenarios. Scenario 1: Workstations running 24/7 without standby mode enabled. Scenario 2: Workstations being turned on during the 9 -h core working time 5 days a week between 7.30 a.m. and 4:30 p.m. and then turned off. Scenario 3: All radiology workstations are switched on during the 9 -h core working hours (7:30 a.m. to 4:30 p.m.). After core working time, most of the workstations are turned off, only 15 workstations remain on for late shift (4:30 p.m. to 10 p.m.), 6 workstations for night shift (10 p.m. to 7:30 a.m.), and an additional 6 workstations for 24 -h shifts at weekends and on national holidays.

Ammeters (Brennstuhl Energiemessgerät Power Meter PM 231, Brennenstuhl, Tübingen, Germany) were installed at three different workstations in the department (see Fig. 2). Over an initial 6-month period, the power consumption of these workstations was measured continuously, and the measuring device was read at various time points unnoticed by its users. Subsequently, users were briefed to switch off the workstations after core working hours. In addition, reminders were attached to the workstations to shut them down at the end of the working day. After the briefing, the second 6-month measurement period started. The measured energy consumption was extrapolated to calculate total annual energy consumption for all 227 workstations running in the department. This extrapolation was based on the mean consumption of two of the measured workstations during the two 6-month periods. (One workstation happened to be used more frequently for 24 h services in the second measurement period, therefore the operating time was significantly longer than in the first period so that this workstation was excluded from further calculations.)

In order to make the measurement results more tangible, the cost difference on the basis of current electricity prices was calculated as well as an approximate estimate of the amounts of carbon dioxide (CO_2) that would have resulted from electricity generation based on our country's energy mix. Energy consumption was measured in kilowatt hours (kWh). The average price per kWh was 0.34 USD/kWh in Germany in 2019 [7].

Furthermore, we measured the mean time for the workstations to start up as well as the time until the standby mode was enabled. The personnel costs resulting from the „waiting time" of a manual restart were calculated based on the hospital's current salary tables given a day with a fully staffed department [8].

A descriptive statistical evaluation was performed with IBM SPSS

Fig. 1. Photography of a representative workstation consisting of a desktop computer, two medical-grade diagnostic monitors and a third monitor for the radiology information system (RIS).

Fig. 2. Photography of an ammeter that was used for the measurements.

Statistics 24 for Windows 10 (IBM Corp., Armonk, NY; USA).

3. Results

Average power uptake of a workstation is shown in Fig. 3. Energy consumption in standby mode is reduced about 53.8 % compared to a continuously running workstation (117.4 W when switched on vs 54.2 W in standby mode and 18.2 W when switched off; the average time until standby mode is enabled is 14 min). These measurements were the basis for extrapolating three scenarios for all 227 workstations of the department (see Fig. 4). Scenario 1: The workstations run 24/7 without standby mode of monitors. For this scenario, we calculated an annual consumption of 233,375.76 kW h, corresponding to 123.0 tons of CO_2 emissions. Scenario 2: The workstations are turned on during the 9 -h core working time 5 days and are then turned off. This scenario would reduce consumption by about 74.1 %–60421.95 kW h, corresponding to 31.8 tons of CO_2. Scenario 3: All radiology workstations are switched on during the 9 -h core working hours on workings days. After core working time, most of the workstations are turned off, only 15 workstations remain on for late duty, 6 workstations for night duty, and an additional 6 workstations for 24 h shifts on weekends and national holidays. Energy consumption would be 66,901.00 kW h/year (equivalent to 35.3 tons of CO_2), a reduction of 71.3 % compared to scenario 1. This scenario is considered to be ideal and feasible for radiology departments.

During the first 6-month measurement period, power consumption per workstation was 480.3 kW h/year. After the briefing, power consumption was reduced by about 5.6%–453.2 kW h/year per workstation. For the total of 227 workstations running our department, we extrapolated a total consumption of 109,021.36 kW h/year before the energy briefing, causing energy costs of 37,241.7 USD. After briefing users to switch off the workstations after work, extrapolated consumption would be 102,871.7 kW h/year (see Fig. 2), resulting in a saving of 2100.7 USD and 3.2 tons of CO_2. Potential saving in the ideal but realistic situation (scenario 3) would be an additional 35,970.69 kW h (see Fig. 2), meaning a further reduction of 35.0 % or 19.0 tons of CO_2 and an additional cost saving of 12,287.58 USD/year. Compared to our initial situation, in total, the power consumption of our workstations could be reduced by 38.6 %, accordingly 22.2 tons of CO2 emissions could be avoided and 14,388.28 USD in electricity costs could be saved per year.

The mean time to start a workstation after shut-down with complete log-in procedure and loading of programs and radiological work lists was 02:25 min. The waiting time for manually starting the reading workstations every morning results in estimated staff costs of 36,280.02 USD/year when the department is fully staffed (18 senior radiologists, 18 consultants, 53 residents) and 252 regular working days per year are assumed.

4. Discussion

Our extrapolations for different scenarios of workstation operating times reveal a considerable energy-saving potential. Continuously running workstations (24/7) without standby mode enabled (scenario 1) have an enormous energy consumption and causing 123.0 tons of CO_2 emissions. Before the briefing, most workstations in our department were running 24/7 but automatically switched to standby mode when not used. Comparison with scenario 1 shows that presence of a standby mode reduces consumption by 53.3 %. Nevertheless, scenario 2 (workstations are turned on during the 9 -h core working time, five days a week) provides the best power savings, but is often unrealistic because many radiology departments are 24 -h facilities and some workstations must be available for late and 24 -h services. Scenario 3 (all radiology

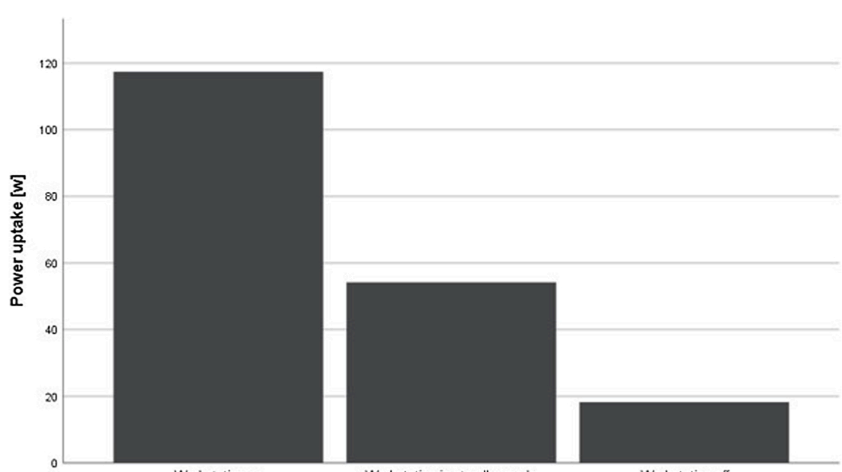

Fig. 3. Bar diagram illustrating the differences in energy consumption measured for a workstation in the on mode, standby mode, and off mode.

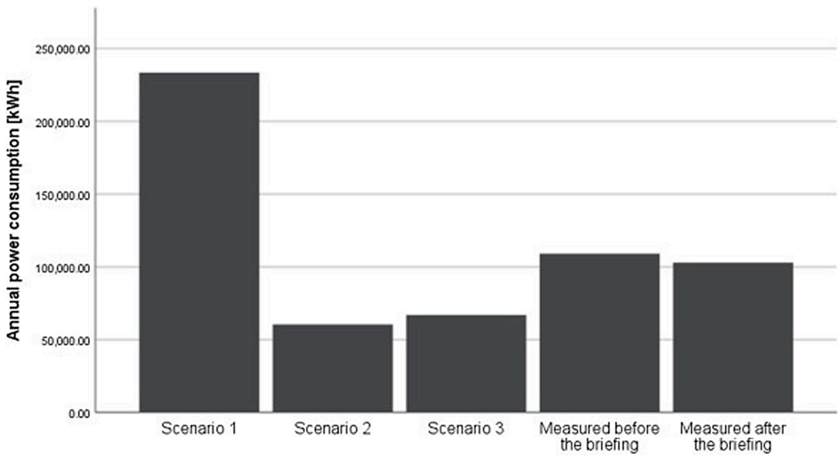

Fig. 4. Consumption in kWh in different scenarios. Scenario 1: Workstations run 24 h /7 days without the monitors going into standby mode. Scenario 2: Workstations are turned on for the 9-h core working time 5 days a week between 7.30 a.m. and 4:30 p.m. and are then turned off. Scenario 3: All radiology workstations are switched on during the 9 -h core working hours (7:30 a.m. to 4:30 p.m.) 5 days a week. After core working time, most of the workstations are turned off, only 15 workstations remain on for late shifts (4:30 p.m. to 10 p.m.), 6 workstations for night shifts (10 p.m. to 7:30 a.m.), and an additional 6 workstations for 24 h shifts.

workstations are switched on during the 9 -h core working shifts; after core working time the workstations are turned off, only 15 workstations remain on for late duty, 6 workstations for night duty, and an additional 6 workstations for 24 -h shifts on weekends and national holidays) provides a realistic picture and would reduce energy consumption by 71.3 % compared to scenario 1.

In this study in a department using 227 workstations, power consumption measured after users were told to manually switch off the workstations after work, was about 55.9 % lower than for all 227 workstations running 24/7 without standby mode (102,871.7 kW h/year vs 233,375.76 kW h in scenario 1). Compared to our initial situation before the briefing, that is with workstations running with sleep mode enabled (consuming 109,021.36 kW h/year), energy consumption was still reduced by about 5.6 % or 6149.7 kW h/year. Nonetheless, there remains a gap of potential savings of 35,970.69 kW h/year (a further reduction of approx. 35 % or a total reduction of 38.6 %) compared to the ideal but realistic scenario (66,901.00 kW h/year in scenario 3). It is therefore save to assume that many users did not shut down the workstations despite the briefing. The main disadvantage of shutting down the workstations is the waiting time when manually restarting them. Many radiologists refrain from shutting down workstations precisely because of this relatively long waiting period, which may diminish productive working time. A solution to get as close as possible to the energy consumption we extrapolated for the realistic ideal scenario (scenario 3) is to combine automated shutdown/restart of workstations with use of a power-saving mode.

Nevertheless, it has been shown that power consumption in radiology departments can be considerably reduced even through simple actions like turning off workstations not in use [4,9,10]. Similarly designed studies also found that most computers and workstations in a radiology department are not switched off after work. McCarthy et al. analyzed a radiology department equipped with a smaller number of workstations (without sleep mode) than ours and found a relatively high estimated saving potential of 72,530 kW h/year, equal to 51.2 tons of CO_2 or the emissions of 10 passenger cars (10). Another study carried out in a university department based its calculations on the assumption that no workstations were ever turned off and identified a savings potential of 83.866.6 kW h, representing energy and cost savings of 76.31 % (5) – a constellation and finding very similar to what we found for our fictional scenarios 1 and 2 (74.1 %). All workstations in our department, however, have a standby mode. As stated before, we found that consumption of a workstation in standby mode is about 53.8 % less than that of a running workstation (117.4 W when switched on vs 54.2 W in standby mode).

Astonishingly, the study of McCarthy et al. found no positive change in user behavior after a departmental teaching session [9]. In conjunction with the rather small reduction in energy consumption we found after the briefing in our study (5.6 %), it is therefore evident that in a clinic's daily routine the effectiveness of this simple measure crucially depends on how well users adhere to this measure. This also underlines the advantages of power saving modes and, at best, an automated switch-off function.

Ecologically, simple briefing to switch off workstations in our study prevented the unnecessary emission of around 3.2 tons of CO_2, equal to the annual emissions of 2 cars. To compensate for this amount of emitted CO_2, 240 trees would otherwise have to be planted per year [11]. Economically, the simple action resulted in a potential interpolated cost saving of 2100.7 USD (calculation based on 227 workstations). Rigorous implementation of daily shutdowns in our department would prevent 22.2 tons of CO_2 from being emitted and would save of up to 14,388.28 USD in energy spendings.

However, starting up the workstations takes time. The cost for this "waiting time" in terms of lost working time amounts to 36,280.02 USD/year. These costs outweigh the financial savings from power consumption by far but could be prevented by the installation of automated shutdown/restart mechanisms of workstations.

The main limitation of this study is that we measured actual energy consumption only for three workstations. Furthermore, one of the workstations had to be excluded, as it was used more frequently during 24 -h shifts in the second measurement period, thus reducing comparability of the two 6-month measurement periods. Moreover, we did not check how well users followed our instructions and actually switched off workstations after core working hours. Data in the literature indicate that there is a short peak in power consumption when turning on a switched off workstation [9]. However, this effect is considered very small and was therefore neglected in our study. For the extrapolations we did not take hardware differences into account, because any resulting differences in energy consumption would be very small.

We measured energy consumption of workstations with the power saving mode (standby/sleep mode) enabled, which puts the device in a low-power state when not in use - a mechanism that proved to be a crucial advantage in terms of energy saving. The results show that workstations with standby mode have 53.8 % lower power uptake than running workstations. In general, newer hardware tends to be more energy-efficient [4,9]. Therefore, it is paramount to keep workstations updated to the latest technical standard including power saving options like a sleep or hibernate mode. In standby/sleep mode all processing functions are stopped, and open documents and applications are saved in the random memory access (RAM), which lowers power uptake while enabling an instant system reboot. In hibernate mode, RAM is copied to the computer's hard drive when not in use in order to reduce power consumption to zero; once the power is back on, all applications are backloaded into the RAM, so restarting takes a bit longer. In addition, workstation startup can be accelerated by using solid-state-drive (SSD) storage instead of conventional hard drives, thus reducing potential waiting times [4]. Nevertheless, certain workstations for on-call duty/emergency reading should not be fully switched off as even a short waiting time could endanger patients.

In addition to direct savings in the energy consumption of workstations, there are other aspects influencing the ecological footprint of radiology departments. Many radiology departments depend on air conditioning systems to cool down small rooms (often without windows) with many running machines. Especially in summer, heat production could also be reduced by switching off workstations not in use [9]. For a middle-sized radiology department of a hospital, potential savings of 11, 000 USD/year for using a power saving mode or turning off computers and air condition devices were estimated [9]. Furthermore, energy can be saved by using simple motion sensors for room lighting [4]. Besides the automated shutdown/restart of workstations, the automation of air conditioning systems and room lighting should therefore also be considered as efficient options of saving energy.

Manufacturers are also trying to adapt medical technology to the new requirements. In Europe, various companies such as Canon, GE Healthcare, Siemens Healthineers, and Philips have joined forces and founded the European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR), a European Trade Association [12]. Besides many other goals the association tries to contribute to sustainability in healthcare and to promote "Green Technology" [13]. A study published by COCIR investigating energy consumption of CT scanners found that it is possible to save up to 50 % when technical improvements such as low-power mode are enabled [14]. Modern scanners are designed to optimize power consumption for operation and ambient cooling [9]. Properly used off- and low-power modes can also save up to 64.5 % of energy consumption in X-ray [14, 15]. Moreover, the committee has proposed guidelines for the sustainable use of imaging equipment. Recommendations include that devices such as X-ray machines or CT scanners should be switched off or low-power modes should be activated, configurations should be optimal, and proper maintenance should be carried out by qualified personnel (16). Some manufacturers of CT or MRI scanners also label their products with recycling information, considering that up to 95 % of machine components can be used again [16]. In parallel, there are several International Organization for Standardization (ISO) standards that deal with such aspects as life cycles of hardware (ISO 14001) and environmental issues in product design and development (ISO 14062) [17,18].

In radiology departments, energy consumption of imaging equipment is deemed the main contribution to climate change [6]. Therefore, next to power saving, it is important to consider the use of renewable energy sources, which could be provided locally, e.g., by solar panels at building roofs, in order to reduce greenhouse gases [19,20].

This study shows that a simple measure such as instructing employees to shut down reading workstations after work every day could already save relevant amounts of energy in a radiological (university) department and thus reduce both energy costs and CO_2 emissions. Ecologically, further energy saving is possible in an ideal scenario, where all workstations would be rigorously switched off, whenever not in use. Economically, however, the waiting times occurring when workstations need to be restarted manually leads to high personnel costs, which far outweigh the energy cost savings. Our results therefore suggest that automated daily shutdown/restart of reading workstations in conjunction with enabling standby/hibernate mode is the most efficient ecologic and economic approach to power saving.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used during the current study are available from the corresponding author on reasonable request.

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Authors' contributions

LB has analyzed and interpreted the data and was the major contributor in writing the manuscript. HP has supported the conceptualization of this study; she has collected the data and supported the manuscript writing. LB and HP contributed equally. GB was the major contributor of the conceptualization of the study and supported the data interpretation and manuscript writing. BH was the main contributor to the project's administration. HCB supported the conceptualization. TA, MJ und UF supported the writing of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors report no declarations of interest.

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