MRI Transparency Document

Esmaeili, A., Twomey, J. M., Overcash, M. R., Soltani, S. A

Section 1: Study boundaries and Data Collection Methods

The study boundaries were the MRI room on a 12 hour basis in which at various times a patient enters and exits the room. Patient check in and waiting room activities are not considered. Data were collected on all activities within the boundaries identified. Data collection took the form of observations, time studies, real time metered power consumption, review of imaging department scheduling records, and review of technical manuals and literature. These were not plug studies as such information does not focus on the actual patient needs or actual medical decisions. Time studies were conducted to determine the duration spent setting up MRI room and equipment, preparing a patient for the delivery of MRI service, post processing of the images, and MRI room clean up. Table 1-1 lists data collection categories and sources.

Table 1-1: Collected data and method

	Data Collected	Source for Energy Information	Observations
Power	Siemens MRI Scanner	Portable power cell meter	4 days - 59 Patients
	Ancillary Devices	Equipment information/ratings	-
	Lighting	Equipment information/ratings	-
	HVAC	TRACE™ 700 Software	-
Materials	Medical Textiles	Sample amounts	59 Patients
	Medical Consumables	Sample amounts	59 Patients
	Cleaning products	Sample amounts	59 Patients

Section 2: Active and Standby Energy Calculations

In order to monitor the Siemens scanners energy consumption (January, 2012), a portable power meter was connected to the input wires of the machines. Portable Power Cell (PPC-3) measured the voltage and current use of equipment in order to calculate the power as an output in kW. The power cell reads the equipment power draw (kW) every 15 milliseconds (or 0.0000041667 hour) and therefore, a pattern, similar to power signature in Figure 2 of the manuscript, was recorded for every patient. Then, energy consumed is calculated by taking the area under the power-time curve. Here, Figure 2-1 is a detail view of active and standby energy calculation methods.

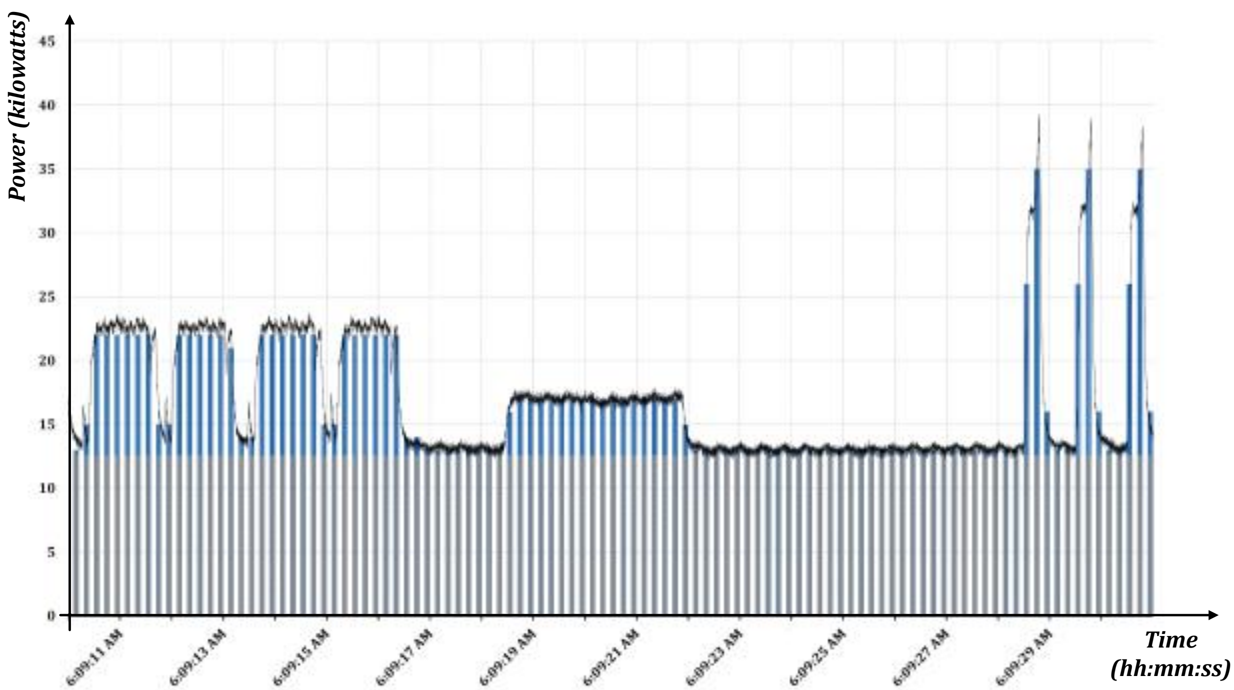

Figure 2-1: A schematic view of active and standby energy calculation methods

The gray patterned area, standby power, was subtracted from all the collected power data-points in the first step of the active energy calculation. The measured standby power for the scanner was 12.68 kW. Then, all power data-points recorded during the exam were multiplied by 0.0000041667 hour (15 milliseconds) to get energy. In Figure 2-1, the area of the blue solid bars is a representation for those values; however, for precise value in the schematic graph, the duration should be reduced to 15 milliseconds. The summation of these values during the exam duration will result to active energy (kWh). Table 2-1 summarizes the active energy for each of the observed exam types. It also includes the duration of the exams. The standby energy is the product of exam duration by standby power (12.68 kW).

Table 2-1: Summary of the Active Energy and Standby Energy Results per Exam Types

Anatomy	Exam Type	Number of Observed Patients	Average Exam Patient Duration (Minutes)	Average Active Energy (kWh)	Average Standby Energy (kWh)
Head	Brain WO	1	25	2.322	5.283
	Brain W and WO	7	38	3.617	8.031
	Brain W and WO attn IAC's	2	50	6.110	10.567
Neck/Cervical	Cervical WO	3	21	2.504	4.438
Chest/Thoracic	Thoracic WO	1	23	2.268	4.861
	Thoracic W and WO	1	45	4.166	9.510
Abdomen/Lumbar	Abdomen WO	1	39	2.063	8.242
	Lumbar WO	9	20	2.126	4.227
	Lumbar W and WO	8	48	6.097	10.144
Pelvis	Bony Pelvis W and WO	1	93	8.956	19.654
Upper Extremities	Shoulder WO	3	30	4.169	6.340
Lower Extremities	Knee	9	29	4.266	6.129
	Ankle	2	36	4.918	7.608
	Lower Long Bone	1	54	5.685	11.412
Breast	Dynamic Breast	10	40	4.271	8.453
	Weighted Average	**59**	**35.4**	**4.099**	**7.481**

Section 3: Idle Energy Calculations

Idle Energy is the energy consumed while the room is empty and waiting for the next patient; i.e. the scanner and all equipment are empty and idle. The idle energy during the working shift is a function of the scanner utilization ratio and could not be estimated per patient directly. Here in this study, first the idle energy for the outpatient facility was calculated and then the value per patient was estimated based on the observed utilization ratio of the room. To use this per patient value of idle energy in other facilities/hospitals, the calculations should be adjusted based on the duration of working shift, the utilization of the room and the use of machine during nights and weekends. In the second part of this section, the idle energy for 50% utilization ratio of the room during 8-hours shift will be presented.

3.1. The idle energy of Siemens MRI scanner at the study setting: The idle energy is the product of idle power and the no-patient time. Due to the nature of outpatient facility, the scanner does not need to be ready-to-use during nights and weekends, therefore, the technicians turn off the system partially and the only module of the scanner that stays ON is the magnet and cooling system. Based on the recorded data by power meter, Figure 3-1, the idle power of Siemens scanner decreases from 12.68kW to 8.08kW after working hours.

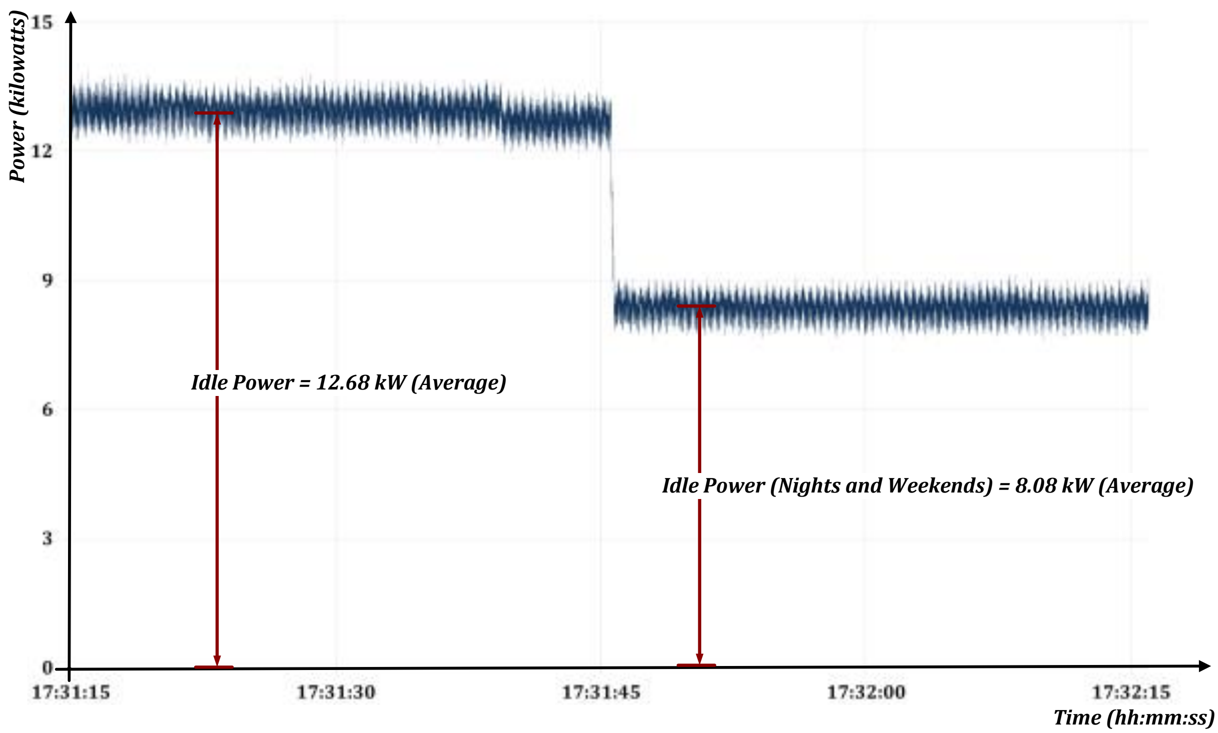

Figure 3-1: The reduction in required power of MRI machine after working hours

The MRI service was performed in the outpatient facility during 12-hours shift of working days. During observed 48 hours of operation, 59 exams were performed, with average duration of 35.4 minutes (0.59 hour); therefore 34.81 hours of operation in room (72.5% utilization ratio) were recorded. Considering average 21.5 working days (258 hours) per month with utilization ratio of

72.5% and patient treatment duration of 0.59 hour, the outpatient facility provided 317 MRI services per month (258*0.725/0.59 = 317 patients).

In calculation of Siemens MRI scanner's idle energy, the energy consumed during 27.5% of the working hours (71 hours per month) were added to idle energy of the scanner during 472 hours of nights and weekends per month (730 total monthly hours – 258 monthly working hours). Thus, the idle energy of 4,711 kWh per month and 14.86 kWh per patient were estimated for the outpatient facility.

3.2. The Idle energy of MRI room in a representative hospital: For a representative hospital, the MRI room is assumed to operate 8-hours per day and for the other 16 hours of each working day and during weekends and holidays remains ON and ready-to-use for rare emergency imaging cases. Assuming 50% utilization ratio will result to 86 hours of patient time per month, which is equivalent to performing 146 MRI services. Therefore, in a month with 730 total hours, for 644 hours the machine sits in the idle mode and consumes 12.68 kW per hour, the total of 8,165 kWh per month or 56.02 kWh per patient.

Section 4: Ancillary Devices and Lighting Fixtures Energy Calculations

In addition to the MRI scanner, there are an injection system and a computer station for communication between technicians and other departments/doctors and transferring the images to doctors electronically. The energy consumption of these pieces of equipment was categorized in ancillary devices group in Table 4-1. For these pieces, the standby power is used and the value of power for each entry in the Table was taken from equipment rating provided by the manufacturer. Also, the imaging department is equipped by lighting fixtures to illuminate 31.12 square meter of the area and the energy consumptions were reported in Table 4-1. For both groups, similar assumptions to idle energy regarding the hours of use for the outpatient facility and a representative hospital were made.

Table 4-1: Ancillary Devices and Lighting Energy Consumption

	Equipment Brand	Required Power (kW)	Outpatient Facility monthly hours of use	Monthly Energy Consumption	Hospital monthly hours of use	Monthly Energy Consumption
Ancillary Devices	MR injection system (Spectris Solaris EP)	2.237	258 hours	577 kWh	730 hours	1,633 kWh
	Computer (HP Compaq 8200 USDT)	0.180	258 hours	46 kWh	730 hours	131 kWh
	Monitor- (ViewSonic Optiquest Q17)	0.035	258 hours	9 kWh	730 hours	26 kWh
	Monthly Energy Consumption		632 kWh		1,790 kWh	
	Per Patient Energy Consumption		1.99 kWh		12.28 kWh	
Lighting Fixtures	One 100W Incandescent Lamps	0.100	258 hours	26 kWh	730 hours	73 kWh
	Three 60W Incandescent Lamps	0.180	258 hours	46 kWh	730 hours	131 kWh
	Six 65W Sylvania Lamps	0.390	258 hours	101 kWh	730 hours	285 kWh
	Monthly Energy Consumption		173 kWh		489 kWh	
	Per Patient Energy Consumption		0.55 kWh		3.36 kWh	

Section 5: Heating, Ventilation and Air Conditioning (HVAC)

The estimation of HVAC energy consumption in a particular area of a building with central HVAC units which serve the whole building is a challenge (Neto and Fiorelli, 2008). Moreover, healthcare facilities require a clean environment, which is partly achieved by having HVAC remove humidity and control room pressure 24 hours a day/365 days a year. Essentially the HVAC energy is just determined by the room size which is generally not tailored for any specific scanner, when the building design was done years ago. Note that the HVAC energy consumption is excluded from the reported patient-care results in the manuscript. This was mainly because the HVAC energy consumption is largely constant and varies neither with fluctuation of occupants during the day nor with the radiology department activities. As such, the HVAC energy is generally not medical-based energy and thus not under the control of the radiology department staff. However, the values are discussed here for transparency.

The heating, ventilation, and air conditioning (HVAC) energy consumption for the imaging department was estimated using the TRACE™ 700 software package. This software package requires a variety of information as input for the energy simulation. These include the geometry and geographical location of the building, the indoor temperature, and the type of the HVAC system. The output of the simulation is the energy intensity of the building, signifying the energy consumed by the HVAC per unit area of the building. Using the energy intensity and the room area, Table 5-1, the monthly HVAC energy consumption was calculated to be 1601kWh, equivalent to 5.05kWh per patient.

Table 5-1: The HVAC energy consumption

Energy Estimation Factors	MRI department Values
Room Area	335 Square Feet
Energy Intensity per Month	4.78 kWh/ft^2
Monthly Energy Consumption	1601.3 kWh/month
Number of Patient per Month	317 patients
Per Patient Energy Consumption	5.051 kWh per Patient

Section 6: Utilization Ratio Sensitivity Analyses

Patient-care energy consumption values include 5 elements; 1) active, 2) standby, 3) idle, 4) ancillary, and 5) lighting energies. Using different calculation methods, three elements were estimated on monthly basis, while active and standby energy values are per patient basis. Therefore, if there is an increase in the number of service deliveries during a month, the share of idle, ancillary and lighting energy per patient will decrease while, per patient active and standby energy remains the same . To explore the effect of changing in the number of patients on the final results, the in-hospital energy use per patient has been plotted in Figure 6-1 for different levels of utilization. The monthly number of patients associated to these utilization ratios in the outpatient facility and hospital also stated in the plot. This utilization dependent plot makes the results adjustable for further use by other healthcare facilities utilization studies. The other assumptions in this manuscript about the shift duration and partially turning off the equipment remained the same for the outpatient facility and the hospital.

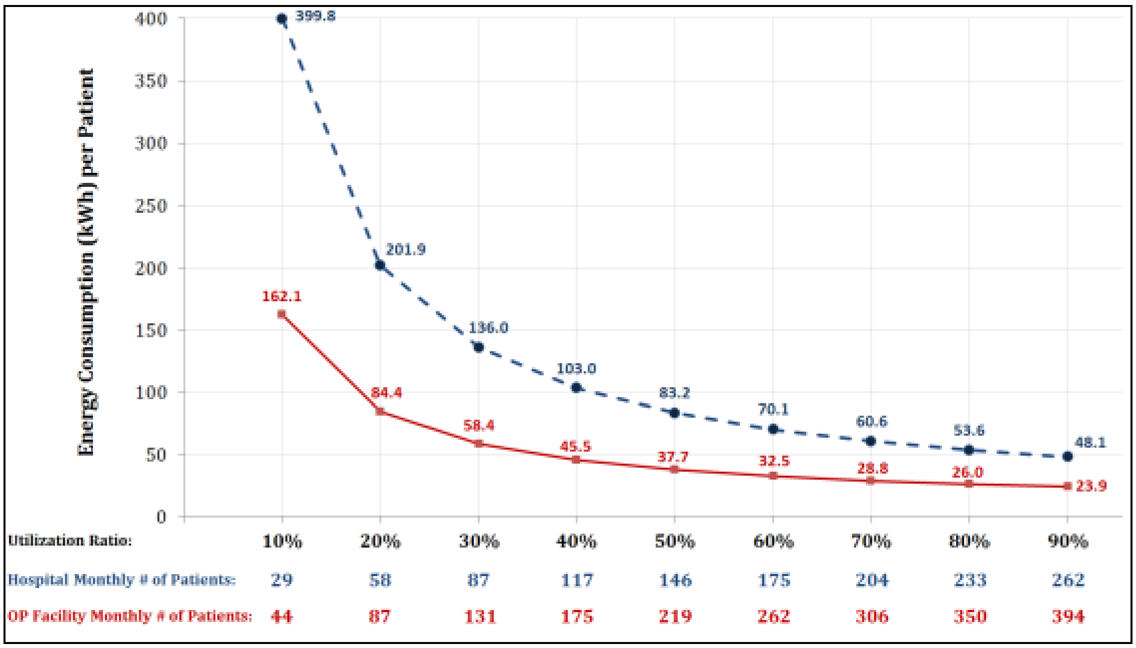

Figure 6-1: Dependency of the patient-based process energy consumption on room utilization (for one MRI machine)

Section 7: Consumable Cradle-to Gate Energy Consumption

7.1. Reusable Textile Materials Energy Consumption: Patient gowns, shorts, fitted-sheets, and pillow-covers are the medical textiles that their usage was recorded during observation for MRI room. In this study, the natural resource energy for medical textiles includes the manufacture of product, laundry of reusable textiles, packaging, and transport (hospital to laundry round trip) processes were considered (Overcash, 2012; Overcash and Griffing, 1998-2014). Table 7-1 shows recorded amounts and cradle-to-gate natural resource energy (nre) in reusable medical textiles. .

Table 7-1: Medical Textiles Cradle-to-Gate Energy Consumption

	Unit	Sheets	Pillow Cases	Shorts	Gowns	Total
Reusable Medical Textiles	(grams/patient)	286.2	109.9	76.8	52.2	**525.1 grams**
CTG Life Cycle Energy	(nre-MJ/patient)	7.01	2.69	1.88	1.28	**12.865 nre-MJ**
CTG Life Cycle Energy	(nre-kWh/patient)	1.95	0.75	0.52	0.36	**3.574 nre-kWh**

The natural resource energy consumption related to the medical textiles is calculated as 3.574nre-kWh per patient for MRI room at the outpatient facility

7.2. Disposable Materials Energy Consumption: The consumable use rates were recorded over the observed time. The list of products consumed per patient for service delivery at the outpatient facility is reported as Table 7-2. Then, these products are expressed as chemical or material constituents based on the information published by manufacturer or found on the internet generally from the material safety data sheets (MSDS).

Table 7-2: Disposable materials rate of consumption during delivery of MRI service

Cradle-to-Gate Energy	(nre-MJ per kg)	0.0008	7.6	33.5	62.6	30	5.6	*	**	27.9	19.7	33	21.6	9.75	
Products-Materials Matrix		**Water**	**NaCl**	**Ethylene-propylene block copolymer**	**Isopropyl Alcohol**	**airlaid cellulose**	**Glass**	**Gadopentate dimeglumine**	**Maglumine & Diethylenetriamine**	**butiadiene**	**acrylonitrile**	**Polypropylene (PP)**	**PVC**	**Cotton**	**Constituents Total Mass (grams/patient)**
Saline	(grams/patient)	39.63	0.04												39.67
Injector&Tube	(grams/patient)			21.97											21.97
Super Sani Cloth	(grams/patient)				5.64	4.61									10.25
Contrast Container	(grams/patient)						9.07								9.07
Contrast (Magnivest)	(grams/patient)	5.17						3.29	0.01						8.47
Syringe	(grams/patient)			7.81											7.81
Gloves	(grams/patient)									3.32	3.32				6.64
Saline Package	(grams/patient)											6.41			6.41
Super Sani Container	(grams/patient)												5.48		5.48
Injector Package	(grams/patient)											4.27			4.27
Coban Roll	(grams/patient)													2.63	2.63
Rubber Band	(grams/patient)									1.13	1.13				2.25
Autoguard	(grams/patient)											1.22			1.22
Conncector	(grams/patient)											0.46			0.46
Total Constituents Consumption	(grams/patient)	44.81	0.04	29.78	5.64	4.61	9.07	3.29	0.01	4.45	4.45	12.36	5.48	2.63	126.60
CTG Life Cycle Energy	(nre-MJ/patient)	4.E-05	3.E-04	0.998	0.353	0.138	0.051	-	-	0.124	0.088	0.408	0.118	0.026	**2.303 nre-MJ**
CTG Life Cycle Energy	(nre-kWh/patient)	1.E-05	8.E-05	0.277	0.098	0.038	0.014	-	-	0.034	0.024	0.113	0.033	0.007	**0.640 nre-kWh**

From the materials compositions, the values of these cradle-to-gate (CTG) natural resource energies, i.e. the energy consumed for producing the materials, were obtained from the LCI database (Overcash and Griffing, 1998-2014). For the solid consumables, the after-use energy consumption, which is related to disposal, was excluded in this study as most are inert plastics and only incur a small energy use for landfill operations. In hospitals, the solid medical waste regulated by EPA should be disposed of by either hazardous waste incineration or steam autoclave sterilization with sanitary landfill (EPA, 2005). For the liquid wastes, the wastewater treatment is likewise not included because of a lack of organic content data.

References

EPA (2005), "Profile of the healthcare industry", available at: nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300066FC.TXT (accessed 12 May 2017).

Neto, A. and Fiorelli, F. (2008), "Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption", *Energy and Buildings,* Vol. 40 No. 12**,** pp. 2169-2176.

Overcash, M. (2012), "A comparison of reusable and disposable perioperative textiles: sustainability state-of-the-art 2012", *Anesthesia & Analgesia,* Vol. 114 No. 5**,** pp. 1055-1066.

Overcash, M. and Griffing, E. (1998-2014), *Life Cycle Inventory (lci) Database,* VA: Environmental Clarity, Reston, VA.