ORIGINAL ARTICLE

Evaluating a hospital's carbon footprint – A method using energy, materials and financial data

Brandon X. Lum*[1], Hubert M. Tay[2], Rachel X. Phang[2], Steven B. Tan[2], Eugene H. Liu[3,4]

[1] Corporate Planning & Development Department, National University Hospital, National University Health System, Singapore
[2] Department of Finance, National University Hospital, National University Health System, Singapore
[3] Yong Loo Lin School of Medicine, National University of Singapore, Singapore
[4] Department of Anaesthesia, National University Hospital, National University Health System, Singapore

Received: October 14, 2022 **Accepted:** November 18, 2022 **Online Published:** November 28, 2022
DOI: 10.5430/jha.v11n2p33 **URL:** https://doi.org/10.5430/jha.v11n2p33

ABSTRACT

Background: Healthcare systems have to prepare for climate change's health impact, while reducing healthcare's contribution to global warming. Most evaluations of healthcare's greenhouse gas emissions involve national level methodologies.
Objective: As sustainability metrics become a key factor in hospital management, the paper describes a method for quantifying emissions at a large tertiary care hospital in Singapore.
Methods: Hospital operational and financial data was used to determine the greenhouse gas effect of the hospital. Emission factors from government and academic sources were used for on-site and purchased energy emissions. Spend based emission factors from the environmentally-extended multiregional input-output (EE-MRIO) Eora database were used for other indirect emissions. This provided the total carbon footprint across the various scopes.
Results: The hospital had an annual carbon footprint of 245,962 tonnes of carbon dioxide equivalents (CO_2e). Scope 1 emissions accounted for 4,223 tonnes of CO_2e, scope 2 for 38,380 tonnes of CO_2e and scope 3 for 165,190 tonnes of CO_2e. Operating carbon totalled 207,793 tonnes of CO_2e, and 38,169 tonnes of scope 3 CO_2e was attributed to capital expenditure projects. Medical equipment, pharmaceutical supplies and electricity were the largest contributors to the hospital's carbon footprint.
Conclusions: Identifying key areas contributing to emissions can enable targeted approaches in reducing a hospital's carbon footprint, better preparing the hospital as the carbon economy evolves to include the healthcare sector.

Key Words: Carbon accounting, Sustainability, Healthcare carbon footprint

1. INTRODUCTION

The impact of climate change on global healthcare has been growing, with more extreme weather events occurring across the world.[1] Healthcare systems must prepare for impact of global warming and climate change on health of populations and the resilience of healthcare systems. Healthcare systems themselves are significant contributors of greenhouse gases, with estimates of up to 4.4% of global carbon footprint.[2] Hence, healthcare systems must also decarbonize their provision of healthcare to reduce their impact on global warming.

Healthcare systems emit greenhouse gases in their operations and procurement of goods and services, in all three scopes as defined by the Greenhouse Gas Protocol. Understanding

*Correspondence: Brandon X. Lum; Email: brandon_lum@nuhs.edu.sg; Address: Corporate Planning & Development Department, National University Hospital, National University Health System, Singapore.

a system's carbon footprint is a key metric and enabler for reducing its carbon footprint. However, healthcare's carbon footprint has mostly been quantified at national level,[3–5] or studied in specific healthcare products[6–9] but not measured for individual hospitals. A hospital's understanding of its own footprint is a key enabler to prioritize, implement and monitor its decarbonisation efforts.[10] This is currently difficult due to the significant scope 3 emissions in healthcare which cannot be quantified easily at the hospitals.

Singapore aims to achieve net zero by 2050,[11] and its Singapore Green Plan 2030 and GreenGov.SG plan provide the roadmap to guide government and public sector organizations, including public healthcare institutions. The National University Hospital (NUH) is a tertiary hospital and academic medical centre, serving a population of 1,400,000 in the Western part of Singapore. Quantification of the hospital's baseline carbon footprint was essential to understand and plan the magnitude of change required in its operations to achieve the national targets. This hospital's methodology can be adapted by other hospitals, using the energy, materials and financial data that most would already possess, to estimate their carbon footprints.

It is important to prepare the hospital system for a carbon economy, with increasing carbon tax, ESG reporting and other policies, that would impact both the operations and the financials of a hospital. While it is inevitable that carbon would be incurred in the provision of healthcare, yet it is important to ensure that the best value is achieved for the carbon incurred, ensuring reduced carbon impact without compromising clinical quality. Hence, being able to measure the carbon footprint of the hospital is key for hospital administration, to identify key focus areas and ascertain the resources required to move towards sustainability in the hospital.[12, 13]

2. METHODS

NUH is part of the National University Health System (NUHS), providing a full range of tertiary, secondary and emergency healthcare services. NUH has 1,250 inpatient beds, 35 operating theatres, and has approximately 900,000 outpatient clinic attendances and 100,000 emergency department attendances per year.

Data from 2019 was used to quantify NUH's carbon footprint, as this was the most recent year that was representative of normal operations and workload, and which would then serve as the baseline against which to compare future years. In 2020 and 2021, there were major changes in the type of work and workload, with large reductions of outpatient clinic and elective surgery work as the hospital concentrated on caring for COVID-19 patients.

The Greenhouse Gas Protocol (GHG-P) Corporate Standard was used to identify the types of emissions that were material and controllable in a hospital setting. The GHG-P classified emissions into three scopes: scope 1 comprises emissions on site in hospital, scope 2 are indirect emissions from the generation of purchased energy and scope 3 are all indirect emissions that occur in the hospital's supply chain.[14]

The carbon footprint analysis used a combination of quantity based data and spend based data. Data on quantities utilised were used for energy, water and supplies for which quantity-based emission factors were available. Data for expenditure on other goods and services were used with spend-based emission factors. These spend-based emission factors were referenced from the environmentally-extended multiregional input-output (EE-MRIO) Eora database.[15, 16] The contributions to the hospital's carbon footprint of different greenhouse gases were quantified in terms of carbon dioxide equivalents (CO_2e).

2.1 Scope 1

Volatile anaesthetic drugs such as desflurane and sevoflurane, and nitrous oxide gas have significant greenhouse gas effects and carbon footprint. These anaesthesia drugs are exhaled from patients' lungs after clinical use, and are currently not captured but emitted to the atmosphere where their greenhouse gas effect persists for long durations before these drugs are totally decomposed. The global warming potential factors over 100 years (GWP100) were used to calculate the carbon footprint of these drugs used in a year.[17] Other scope 1 emissions include the carbon dioxide gas used in laparoscopic surgery and from the combustion of natural gas in the hospital's kitchen and for heating water.

2.2 Scope 2

NUH scope 2 emissions were calculated through multiplying the electrical energy purchased in 2019, with the grid emission factor for electricity generation in Singapore. Most of the electricity in Singapore is generated from the combustion of natural gas. There is limited supply of renewable energy.

2.3 Scope 3

Scope 3 emissions, or indirect emissions from goods and services used, form the largest of 3 scopes in healthcare systems' emissions.

The carbon footprint for goods and services procured were calculated using spend–based emission factors. The spend-based method used NUH expenditure information and the environmentally extended–multi region input output (EE-MRIO) emission factors from the Eora global supply chain database (Eora). Multi region input output databases track global trade flows and transaction quantities between countries' major economic sectors.

The Eora EE-MRIO database traced the global supply chains of 190 countries. Through relating economic data with countries' carbon emissions data, the EE-MRIO provides carbon emissions data from the production and upstream supply chain activities of different sectors, goods and services in a country's economy. The Eora EE-MRIO database provided up-to-date Singapore-specific emission factors per unit of local currency (Singapore dollar) expenditure on goods and services. These emission factors include all embodied carbon from upstream emissions, required or utilized to produce a Singapore unit of currency's worth of the goods and services procured. By multiplying hospital expenditure for categories of goods or services with the relevant EE-MRIO emission factors, the carbon footprint for the hospital's supply chain could be estimated.

Through the use of pro-rating concordance matrices and interpolation, pro-rating a single data point of sectors in a country, Eora had developed a sector-wise emission inventory, using Gross Domestic Product as a proxy. Additionally, Eora had been validated against other footprint studies.[18,19] Eora annually updates and reviews the MRIO data, reducing the resulting time-lag from data collection, thus improving the accuracy of the reported figures.

The carbon footprint from waste management was calculated for the different types of waste produced in NUH, and their respective emissions factors for waste management. The types of waste included chemical, biohazard, food and municipal general waste. Recycled waste was not included in the carbon footprint. The carbon emissions from the various waste types were derived through the multiplication of waste weight with the respective emission factors. In Singapore, all incineration plants are "waste-to-energy" plants, where heat from the incineration is harnessed to generate electricity. The resultant energy conservation ratio of 20%, was factored in calculating the carbon footprint for the incineration of municipal general waste.[20,21]

Carbon footprint resulting from business air travel was calculated by the number of flights taken in FY19 by the hospital staff. The flights were classified into three main categories, short haul (Asia & Australia), long haul (Europe, Africa and New Zealand) and super long haul (Americas), with a return flight time of 13, 26 and 40 hours respectively. A carbon emission factor of 250 kg CO_2e per flight hour per passenger was used.[22] Due to the larger sizing of business class seats, these journeys incurred three times more carbon than an economy class seat.[23]

In financial planning and budgeting, the hospital's expenditure is classified into operating expenditure and capital expenditure. Capital expenditure was for procuring items with large financial and "book" value, which were intended to be used over several years. Examples were the purchase of a MRI scanner, the renovation of a ward, the setting up of a new clinic. Separation of operational and capital expenditures enable correlation of the hospital's operating carbon footprint with its annual workload, separate from the embodied carbon in major purchases. While capital expenditure items are intended to be used over durations of several years, the emissions embodied in producing the items are all accounted for in the year of purchase. The emissions are not spread over the years of useful life duration, differing from financial accounting where depreciation is applied. This method of accounting for carbon footprint of capital expenditure is aligned with the guidance from GHG Protocol Corporate Standard.[14]

3. Results

The estimated carbon footprint of the hospital is detailed in Table 1. Scope 1 and scope 2 emissions accounted for 1.72% and 15.60% of the hospital's total emissions and carbon footprint respectively. Scope 3 emissions (indirect emissions from procured goods and services) formed 82.68% of the hospital's total carbon footprint. Operating emissions formed 84.48% of the hospital's total annual emissions in FY19, with 15.52% attributed to capital expenditure. The majority of scope 1 emissions were from the use of anaesthesia drugs, detailed in Table 2.

Among the anaesthetic drugs, desflurane and nitrous oxide had the highest carbon footprints, and accounted for most of the hospital's scope 1 emissions. While sevoflurane and desflurane usage were similar in kilogram terms, desflurane's GWP100 and impact are much higher due to desflurane's persistence in the atmosphere.

Similar to reports of reports of other countries' healthcare systems, scope 3 emissions formed the largest portion of the hospital's carbon footprint. Pharmaceuticals and medical supplies accounted for 16.43% and 18.02% respectively of total emissions.

Waste in total accounted for 2.72% of the hospital's carbon footprint. Municipal General Waste (Emissions Factor [EF] 1.1) accounted for the largest portion of annual waste generated at 4,428 tonnes, with Food Waste (EF 2.5), Chemical Waste (EF 2.09) and Biohazard Waste (EF 1.82) at 372, 120, 312 tonnes respectively.[24–26]

Table 1. NUH carbon footprint by category

Category	Scope	GHG Emissions (CO_2e tonnes)	Percentage
Anaesthetic and Medical Gases	1	4,126	1.68%
Town Gas	1	97	0.04%
Electricity	2	38,380	15.60%
Water	3	391	0.16%
Waste	3	6,686	2.72%
Metered Dose Inhalers	3	786	0.32%
Pharmaceuticals	3	40,411	16.43%
Lab Supplies	3	7,454	3.03%
Medical Supplies	3	44,322	18.02%
Non-Medical Supplies	3	1,801	0.73%
Purchased and Contracted Services (e.g., Security, Referral Services)	3	8,293	3.37%
IT Expenses	3	14,188	5.77%
Other Expenses (e.g., Telecommunications, Postage and Courier)	3	4,030	1.64%
Research and Development Expenses	3	12,092	4.92%
Catering	3	2,442	0.99%
Facility Management	3	10,386	4.22%
Repairs and Maintenance	3	9,221	3.75%
Air Travel	3	2,685	1.09%
Total Operating Carbon		**207,793**	**84.48%**
Medical Capital Expenditure (e.g., Medical Equipment, Ward beds, MRI scanners)	3	13,093	5.32%
Non-Medical Capital Expenditure (e.g., Infrastructure)	3	25,076	10.20%
Total Capex Carbon		**38,169**	**15.52%**
Total Carbon Footprint		**245,962**	**100.00%**

*Note***.** Grid emission factor for electricity generation in Singapore, 0.41 kg CO_2e per kWh, data from the Energy Market Authority of Singapore[27]. Carbon emission from capital expenditure accounted for 15.52% of the hospital's total carbon footprint. As capital expenditure varies according to the hospital's budget allocation and directions for new purchases annually, this figure is reported separately.

Table 2. NUH anaesthetic and medical gas carbon footprint

Anaesthetic and Medical Gases	Usage in 2019 (kg)	GWP_{100} Factor	CO_2e (tonnes)
Desflurane	534	2,540	1,356
Sevoflurane	512	130	67
Nitrous Oxide	9,328	289	2,696
Carbon Dioxide	6,896	1	7

Note. GWP_{100} - Global warming potential over 100 years

4. Discussion

The described methodology enables quantification of the hospital's comprehensive carbon footprint. This enables prioritization, implementation and monitoring of decarbonisation efforts, as the hospital strives to mitigate its contribution to global warming and climate change. Existing data is available for national healthcare systems, or in specific hospital settings, but a methodology for individual hospitals has to our knowledge not been described previously.[3–5, 10, 28]

NUH does not own a fleet of vehicles and does not burn natural gas on-site for heating. Hence its scope 1 emissions are largely due to anaesthetic gases. As anaesthetic drugs differ hugely in their carbon footprint, choosing drugs and techniques with lower footprint, can greatly reduce the scope 1 emissions of a hospital. Lower carbon choices include using regional anaesthesia and intravenous anaesthesia techniques instead of using inhalational anaesthetic techniques.

If inhalational anaesthetic drugs are needed, choosing sevoflurane and avoiding desflurane can reduce greenhouse gas impact by a factor of over 50. This is because desflurane not only has a higher GWP100 but is also three times less potent than sevoflurane, hence needing much higher quantities to deliver an equivalent depth of anaesthesia.

The use of nitrous oxide for labour analgesia can be avoided with epidural analgesia and other techniques, but there are at present limited alternatives for nitrous oxide's fast and short acting effect and ease of administration.

In Singapore, electricity is almost entirely generated from burning natural gases. There is limited space for generation of solar power in land scarce Singapore. Hence efforts to reduce a hospital's scope 2 emissions need to focus on using energy efficient systems, reducing electricity waste, and optimizing the use of energy in infrastructure and air conditioning. At the point of writing, NUH is reviewing legacy settings in buildings systems, and implementing "setback" settings in operating rooms when not in use.[29,30]

Scope 3 emissions from the hospital's supply chain and procured services are far larger than scope 1 and 2 emissions. Healthcare systems need their suppliers to work on reducing the embodied carbon and energy used in producing the goods and services procured. Transparency of the carbon in medical products is currently very limited, but future hospital procurement can include environmentally sustainable metrics and requirements.

As scope 3 emissions were derived from both purchased goods and services, the appropriate spend data and the relevant Eora emission factors had to be used to effectively extract accurate information of carbon emissions. Using the example of IT spend, we have first segregated the IT services provided (purchased services) and the IT software and hardware spend (purchased goods). The relevant emission factors were then applied to the purchased services and the purchased goods to calculated the carbon footprint.[31]

It is also very important for clinical staff to reduce waste and lower value treatments, to reduce the carbon footprint of healthcare. At this time, while it is impossible to deliver health without incurring emissions, hospitals can strive for maximal value from the emissions incurred. This is similar to striving for value for money in value based healthcare, without affecting clinical quality and patient safety.

Expenses that were excluded in the scope 3 emissions were the hospital's own manpower costs, depreciation and amortization, as well as any finance or tax related expenses. Employee commuting emissions were not included in our scope 3 as there was no verifiable data for FY19.

A limitation of quantification of the hospital's scope 3 emissions using spend based data, and emission factors from the Eora database, is the dependence on the accuracy and granularity of the databases. As the Eora emission factors are averages representative of the broader market, the emissions involved in individual suppliers' products may be quite different and varied. Additionally, the granularity of the Eora emission factors categorises several products into a similar category, which could affect the accuracy of the factors used. However, in extensive consultations with many vendors at this time, most have indicated that they are unable to provide the carbon footprint of specific products or services supplied to NUH. Hence using EE-MRIO databases would be the most practicable method at this time, until the point where product specific data or activity based data could be used.

Quantification of the hospital's emissions and carbon footprint will enable the hospital to target its decarbonisation work. This would also guide the hospital to work within a carbon 'budget' as countries and organizations are compelled to work within carbon limits. Such quantification is also needed to guide costing of carbon footprint, and financial preparation for carbon taxes and carbon markets.

5. CONCLUSIONS

In summary, the reported methodology for carbon accounting at hospital level can be adapted by other healthcare organizations, and can be tailored with appropriate emission factors databases. This methodology enables benchmarking across hospitals, and relating carbon incurred to care delivered, to achieve value in healthcare, in financial and carbon terms. This allows a hospital to be prepared for the changing carbon economy, both in environmental and financial sustainability.

ACKNOWLEDGEMENTS

We would like to thank our colleagues at National University Health Systems (NUHS) for the support in our drive to achieve sustainable healthcare. The information provided by our colleagues from NUH Finance, Anaesthesia, Materials Management Department, Group Hospitality and Group Facilities Management, was crucial in deriving the carbon footprint in NUH.

CONFLICTS OF INTEREST DISCLOSURE

The authors declare they have no conflicts of interest.

REFERENCES

[1] Climate Change Committee. UK Climate Change Risk Assessment 2017 Synthesis Report: Priorities for the Next Five Years. London: Adaptation Sub-Committee of the Committee on Climate Change; 2016. [Cited 2022 Jun 5]. Available from: https://www.theccc.org.uk/UK-climate-change-risk-assessment-2017

[2] Karliner J, Slotterback S, Boyd R, et al. Health care's climate footprint: the health sector contribution and opportunities for action. European Journal of Public Health. 2020 Sep; 5: 165-843. https://doi.org/10.1093/eurpub/ckaa165.843

[3] Tennison I, Roschnik S, Ashby B, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. Lancet. Planet. Health. 2021 Feb; 5: e84-92. PMid: 33581070. https://doi.org/10.1016/S2542-5196(20)30271-0

[4] Malik A, Lenzen M, McAlister S, et al. The carbon footprint of Australian health care. Lancet. Planet. Health. 2018 Jan; 2(1): e27-35. PMid: 29615206. https://doi.org/10.1016/S2542-5196(17)30180-8

[5] Wu R. The carbon footprint of the Chinese health-care system: an environmentally extended input-output and structural path analysis study. Lancet. Planet. Health. 2019 Oct; 3(10): e413-9. PMid: 31625513. https://doi.org/10.1016/S2542-5196(19)30192-5

[6] McAlister S, Ou Y, Neff E, et al. The Environmental footprint of morphine: a life cycle assessment from opium poppy farming to the packaged drug. BMJ Open. 2016 Oct; 6(10): e013302. PMid: 27798031. https://doi.org/10.1136/bmjopen-2016-013302

[7] Grimmond TR, Bright A, Cadman J, et al. Before/after intervention study to determine impact on life-cycle carbon footprint of converting from single-use to reusable sharps containers in 40 UK NHS trusts. BMJ Open. 2021 Sep; 11(9): e046200. PMid: 34580089. https://doi.org/10.1136/bmjopen-2020-046200

[8] Vanović T, Meisel HJ, Som C, et al. Material flow analysis of single-use plastics in healthcare: A case study of a surgical hospital in Germany. Resour. Conserv. Recy. 2022 Oct; 185: 106425. https://doi.org/10.1016/j.resconrec.2022.106425

[9] Leissner S, Ryan-Fogarty Y. Challenges and opportunities for reduction of single use plastics in healthcare: a case study of single use infant formula bottles in two Irish maternity hospitals. Re-sour. Conserv. Recy. 2019 Dec; 151: 104462. https://doi.org/10.1016/j.resconrec.2019.104462

[10] Sherman JD, Thiel C, MacNeill A, et al. The green print: advancement of environmental sustaina-bility in healthcare. Resour. Conserv. Recy. 2020 Oct; 161: 104882. https://doi.org/10.1016/j.resconrec.2020.104882

[11] National Climate Change Secretariat Singapore. Carbon Tax. [Assessed on 2022 Oct 12]. Available from: https://www.nccs.gov.sg/singapores-climate-action/carbon-tax/

[12] IFLR. A closer look at Singapore's mandatory corporate ESG disclosures and associated legal risks. [Assessed on 2022 Oct 12]. Available from: https://www.iflr.com/article/2a646mpixhlq5fi7f5wqo/a-closer-look-at-singapores-mandatory-corporate-esg-disclosures-and-associated-legal-risks

[13] Energy Market Authority. Expert study affirms net-zero feasibility for Singapore Power Sector by 2050. [Assessed on 2022 Jun 5]. Available from: https://www.ema.gov.sg/media_release.aspx?news_sid=20220321Ex6rcvZaw8dl

[14] World Resources Institute/World Business Council for Sustainable Development's greenhouse gas protocol: a corporate accounting and reporting standard, revised edition. [Assessed on 2022 Jun 5]. Available from: http://pdf.wri.org/ghg_protocol_2004.pdf

[15] Lenzen M, Kanemoto K, Moran D, et al. Mapping the structure of the world economy. Environ. Sci. Technol. 2012 Aug; 46(15): 8374-81. PMid: 22794089. https://doi.org/10.1021/es300171x

[16] Kanemoto K, Moran D, Hertwich EG. Mapping the carbon footprint of nations. Environ. Sci. Technol. 2016 Oct; 50(19): 10512-7. PMid: 27587304. https://doi.org/10.1021/acs.est.6b03227

[17] Hanna M, Bryson GL. A long way to go: minimizing the carbon footprint from anaesthetic gases. Can. J. Anesth. 2019 Jul; 66(7): 838-9. PMid: 30877589. https://doi.org/10.1007/s12630-019-01348-1

[18] Peters GP, Minx JC, Weber CL, et al. Growth in emission transfers via international trade from 1990 to 2008. Proc. Natl. Acad. Sci. USA. 2011 May; 108(21): 8903-8. PMid: 21518879. https://doi.org/10.1073/pnas.1006388108

[19] GFN. National Footprint and biocapacity accounts. Global Footprint Network. 2010.

[20] Eggleston HS, Buendia L, Miwa K, et al. IPCC guidelines for national greenhouse gas inventories. 2006. [Assessed on 2022 May 30]. Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[21] Towards Zero Waste Singapore. The science behind incineration. 2022 [Assessed on 2022 Jun 5]. Available from: https://www.towardszerowaste.gov.sg/science_behind_inceneration/

[22] Carbon Independent. Carbon Emissions from Aviation. 2020 [Assessed on 2022 Jul 1]. Available from: www.carbonindependent.org/22.html

[23] Bofinger H, Strand J. Calculating the carbon footprint from different classes of air travel. World Bank Policy Research Working Paper; 2013. 6471 p. PMid: 23749470. https://doi.org/10.1596/1813-9450-6471

[24] US EPA. Understanding Global Warming Potentials. 2022 [Assessed on 2022 Jun 10]. Available from: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[25] Energy Market Authority. Singapore Energy Statistics, Energy Transformation. 2021 [Assessed on 2022 Jun 10]. Available from: https://www.ema.gov.sg/singapore-energy-statistics/Ch02/index2

[26] Porter SD, Reay DS. Addressing food supply chain and consumption inefficiencies: potential for climate change mitigation. Reg. Environ. Change. 2016 May; 16(8): 2279-90. https://doi.org/10.1007/s10113-015-0783-4

[27] Energy Market Authority. Singapore Energy Statistics, Electricity Grid Emissions Factors and Upstream Fugitive Methane Emission Factor. 2022 [Assessed on 2022 Jun 10]. Available from: https://www.ema.gov.sg/statistic.aspx?sta_sid=20140729MPY03nTHx2a1

[28] MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. Lancet Planet. Health. 2017 Dec; 1(9): e381-8. PMid: 29851650. https://doi.org/10.1016/S2542-5196(17)30162-6

[29] Gormley T, Markel TA, Jones H, et al. Cost-benefit analysis of different air change rates in an operating room environment. Am. J. Infect. Control. 2017 Dec; 45(12): 1318-23. PMid: 28893445. https://doi.org/10.1016/j.ajic.2017.07.024

[30] Jarvis I, Vahabi F. Operating room ventilation systems best practices guide for energy efficiency, health and safety, A greening health care research project. 2017; 1-8. [Assessed on 2022 May 30] Available from: https://www.enerlife.com/wp-content/uploads/2017/06/Enerlife-OR-Ventilation-Best-Practices-Guide-April-2017.pdf

[31] NHS England. NHS Standard Contract 2022/23. 2022 [Assessed on 2022 Jun 22] Available from: https://www.england.nhs.uk/nhs-standard-contract/22-23/