4. Operating theatre energy and design

Section key points

- Operating theatres are 3-6 times more energy intensive than clinical wards.
- The majority of theatre energy consumption relates to theatre maintenance (heating, ventilation, and air conditioning).
- There are three main types of ventilation systems: turbulent mixed airflow (least energy), temperature controlled airflow, laminar air flow (most energy).
- Shutdown checklists can be used to prompt staff to switch off theatre equipment out of hours and should be accompanied by turn-on checklists and safety protocols to ensure items are on when required.
- There are opportunities at the stage of theatre design (or retrofit) for installation of motion sensors to control lights, temperature, and ventilation, alongside energy efficient appliances and machinery, and automatic/pedal-controlled taps for surgical scrub.
- At the hospital level, contracts should be drawn with providers of renewable electricity, and installation of combined heat and power facilities.
- There are opportunities across the hospital for installing LED lighting and improving insulation.

4.1 Energy use in the operating theatre

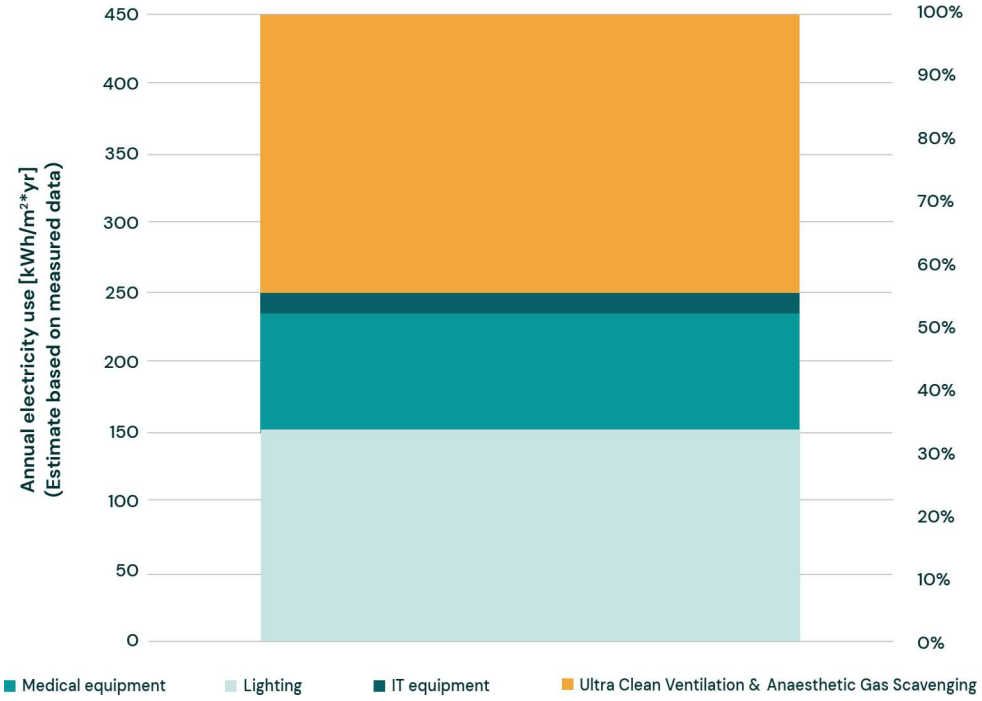
Energy use makes up 10% of the NHS carbon emissions footprint,[22] and rising energy prices may be an additional driver for hospitals to reduce their energy demand.

End-use data suggests that **operating theatres** are one of the most **energy intensive** areas of hospitals, using three to six times more energy than clinical wards.[42] The majority (90-99%) of operating theatre energy consumption relates to **theatre maintenance** (heating, ventilation and air conditioning), whilst the contribution from plug-loads and lighting is estimated at 1.5%-8.4%.[42] Another study found nearly half the energy use was to power the theatre ventilation and anaesthetic gas scavenging systems (AGSS), with the remainder from lighting, information technology and medical equipment, Figure 6),[232] with these items often left on when the theatre is not in use.

From 2017 to 2021 we have seen a 27.3% reduction in carbon emissions associated with building energy in the NHS.[233] If we are to further reduce this, it is important that **energy is derived from renewable sources**. At the time of writing, only 55% of NHS organisations procure 100% renewable electricity.[234] Furthermore, hospitals can install solar panels and generate renewable energy on-site.

It is also essential that healthcare organisations reduce energy consumption through installation of energy efficient appliances and machinery such as **light-emitting diode (LED) lighting, building management systems, heat recovery, insulation, and combined heat and power facilities**. Many of these energy initiatives are associated with cost savings over time (often relatively quickly), representing win-wins for both the public purse and the environment. Energy efficient appliances and machinery should be installed when new theatres are developed, but the environmental impact of replacing existing systems will depend on factors including how long existing systems have been in place: premature obsolescence needs to be balanced against energy savings associated with new systems.

Figure 6: Contributions to typical operating theatre energy consumption



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4.2 Optimising the maintenance of theatre environment

A collaborative approach between clinical and estates teams will help ensure appropriate energy use. This may include opting for renewable energy sources, use of heat pump systems, and analysing energy use in different areas (enabling air handling and climatic control to be optimised).

Anaesthetic Gas Scavenging Systems (AGSS) account for the majority of anaesthetic equipment energy consumption, and are often operating even when theatres are not in use.[235] AGSS may be switched off when operating theatres are not in use (or potentially where purely intravenous sedation, regional or Total Intravenous Anaesthesia (TIVA) techniques are used), where these are switch operated. Appropriate safety systems and standard operating procedures should be in place to ensure AGSS are switched back on when required. An open source calculator has been developed to estimate carbon and financial savings associated with switching off AGSS.[236]

Advanced ventilations systems play an integral role in controlling temperature, humidity, and airborne contamination within the operating theatre. Staff shed around 10,000 skin particles per minute and this is the main source of airborne contamination in the operating room.[237] The likelihood of developing a surgical site infection is however influenced by multiple variables, with the health state of the patient, and type of intervention being the main risk factors.[238]

The three main ventilation systems (Figure 7) used in operating theatres are:[239]

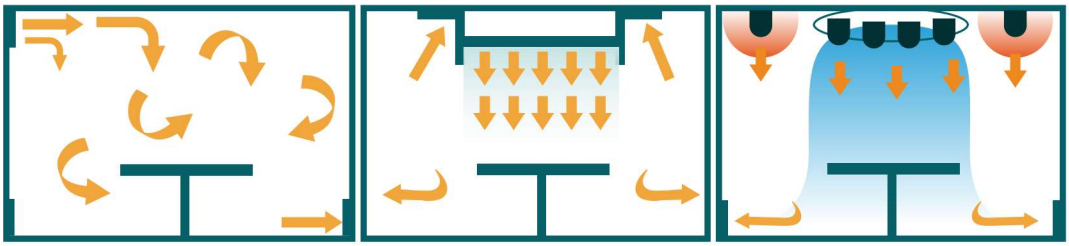
1. **Turbulent Mixed Airflow (TMA)**
   In TMA air is drawn into the theatre through high-efficiency particulate air (HEPA) filters. This method of ventilation relies on the dilution principle, with turbulent mixing of clean and contaminated air exponentially leading to lower counts of airborne microbes. TMA **uses the least amount of energy** of the three systems, but does not create ultraclean conditions.

2. **Laminar Air Flow (LAF)**
   LAF pushes air through HEPA filters in a unidirectional flow in a 2.75m^2 box around the operating table. This ultraclean zone around the patient can be affected by presence of equipment in and around the zone, and the opening and closing of doors. LAF uses the most energy of the three systems.

3. **Temperature Controlled Airflow (T_cAF)**
   T_cAF is the newest of the three systems and uses cool HEPA filtered air above the operating table which, due to its higher density than the warmer air around this zone, flows downwards. T_cAF **can achieve ultra clean conditions using less energy** than LAF.

It is desirable to opt for the lowest carbon ventilation system that is clinically appropriate for the procedure being performed. Although the National Institute for Health and Care Excellence (NICE) in the UK acknowledges lack of high quality evidence for the efficacy of ultra clean ventilation in preventing joint infections, it recommends its use for joint replacements[240] (along with the British Orthopaedic Association).[241] Two meta-analyses of laminar airflow compared with conventional ventilation found no reduction in surgical site infection for knee or hip arthroplasty, or for abdominal or open vascular surgery.[242,243]

Figure 7: Schematic showing the airflow principles of the three ventilation systems



(A) Turbulent Mixing Airflow (B) Laminar Airflow (C) Temperature-Controlled Airflow

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NHS Health Technical Memorandum 03-01,[244] provides advice and guidance on the design, installation and operation of specialist ventilation systems used in healthcare settings, including how many air changes per hour are required in each setting (Table 4). Within theatres, out of hours ventilation will often unnecessarily run in either a full power or low power mode ('set back', and a mode which varies in energy intensity between trusts). **Turning off theatre ventilation overnight or when unoccupied** is appropriate, and quickly reversible: an operating theatre can achieve safe operating conditions from a flow and temperature perspective after 20 (LAF) to 30 minutes (T_cAF) of full power ventilation.[245,246]

Table 4: Health Technical Memorandum 03-01 standards for minimum number of air changes per hour for various hospital settings[244]

Location	Air changes per hour
Anaesthetic room	15
Operating theatre (including UCV theatres)	22
Cranial surgery theatres	35
Preparation room	22
Sterile Pack Store	6
Recovery	15
Endoscopy	10

CASE STUDY: Switching off theatre ventilation systems overnight

Setting	Nuffield Health (Private) theatres
Intervention	Switching theatre ventilation from a low powered 'set back mode' to off overnight
Outcome	Adheres to HTM 03-01 guidelines
	↓ 15-36 tonnes of CO_2e/year per theatre ↓ If rolled out to the 3000 operating theatres in the NHS this could lead to national carbon savings of 108,000 tonnes of CO_2e per year
	↓ £30,000 per theatre per year Roll out as above associated with cost savings of £90 million per year.

Source: Direct submission from Jonathan Groome

Healthcare staff can play a key role in reducing energy emissions. For energy and work intensive areas such as operating theatres and pathology laboratories, a more formalised approach using a **shutdown checklist** can give staff comprehensive instructions on what to turn off out of hours (including the AGSS in the theatre suite where possible) and be accompanied by safety protocols and 'turn on' checklists. This approach may associate with financial savings. For example, a single setting in the USA found that turning off equipment when not in use (including anaesthetic equipment and operating room lights) generated savings of US$33,000 and 343 metric tons of CO_2 per year.[247] Automation using **passive infrared (PIR) sensors** controlling lights, ventilation, and temperature can also help reduce energy consumption if located and configured appropriately, and can eliminate human error (for example by ensuring the HVAC system is operating when theatres are running). Submetering and use of dashboards to feedback to staff members may also assist measurement and change.

CASE STUDY: Adopting elective theatre shutdown list

Setting	Swansea Bay University Hospital Health Board
Intervention	'Shutdown' list poster used as prompt to turn off devices in elective operating theatres at end of day, including computers, anaesthetic machines, anaesthetic gas scavenging
Outcome	↓ 144.8 tonnes CO_2e / year
	↓ £26,000 per year
	Noise reduction, reduced light pollution

In 2022, a clinical team led by Elana Owen, Christine Range, and Gemma Hale, at the Swansea Bay University Health Board designed and implemented a Shutdown Check protocol in elective surgery theatres.

At the hospital, planned operating usually takes place during daytime hours and during the working week only, whereas emergency operating occurs around the clock. The team audited devices that can be turned off in elective operating theatres and created a "shutdown" list poster to promote turning things off.

Some machines need to be turned off and on again to activate their morning self-check, making the end-of-day shut-off routine an increase in workload, but staff members were supportive of this.

The team anticipates potential carbon savings of 44,774 kg CO_2e per year (equivalent to driving 129,000 miles in an average car) and cost saving of £26,000 annually (not including energy use of computers). There will also be an improvement in the immediate spatial environment in the vicinity of the theatres (for example, through reduced noise of ventilation systems).

Source: Centre for Sustainable Healthcare[248]

4.3 Optimising the built environment

It is important that when new hospitals and theatre suites are developed, they align with net zero ambitions and draw upon the NHS England Net Zero Building Standard, which provides guidance on development of sustainable, resilient and energy efficient buildings.[249] A **collaborative approach**, enacted by a multidisciplinary build team that includes healthcare workers, architects, contractors, engineers, and estates managers, involved in the whole life planning of the build is essential.[250] The UK Green Building Council framework definition of net zero buildings balances embodied emissions associated within construction and operational energy through the use of low carbon renewable energy sources, and **net export of renewable energy**.[251] A more recent approach adopted by the World Green Building Council looks at Net Zero Whole Life Carbon. It attempts to avoid future embodied carbon during and at the end of life, and account for **renovation, future adaptation, and circularity**.[252] Further research is required to determine circumstances in which it is more sustainable to renovate versus rebuild healthcare buildings and facilities.

Offsite, modular building of healthcare facilities can be an effective way to reduce onsite build time (limiting disruption to services), centralise expertise, and reduce emissions and costs.[253] Adopting this approach to the development of operating theatres could lead to 33% lower costs to the industry; 50% faster delivery due to a reduction in parts, fabrication, logistics and assembly; and a 50% reduction in emissions.[254]

A key part of reducing the whole life emission of healthcare builds is in ensuring that spaces created anticipate future developments in health pathways, for example through digitisation, the modernisation of medical equipment, and the developing needs of populations. Creating **flexible and multi-use spaces** such as theatres that can be converted to intensive care units, will also optimise building utility.

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R4.1 Ensure operating theatre equipment is switched off when not in use (e.g. Anaesthetic Gas Scavenging Systems, air handling units, lights, computers, other plug-ins)	Develop and use shutdown checklist (plus safety protocols) to prompt turning off equipment[a,b]	Install motion sensors to control lights, temperature control, and ventilation[b] Education[c]	Surgical team[a] Facilities and Estates[b] Educators[c]
R4.2 Improve environmental impact of operating theatre energy consumption		Opt for renewably sourced electricity[b] Install energy efficient appliances and machinery[b,d] Opt for clinically appropriate ventilation system with lowest energy consumption[b,d] Innovate towards energy efficient devices[e]	Facilities and Estates[b] Theatre managers[d] Industry[e]