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## Major Article

## Cost-benefit analysis of different air change rates in an operating room environment

Thomas Gormley PhD <sup>a,\*</sup>, Troy A. Markel MD <sup>b</sup>, Howard Jones MD <sup>c</sup>, Damon Greeley PE <sup>d</sup>, John Ostojic IH <sup>e</sup>, James H. Clarke PhD <sup>a</sup>, Mark Abkowitz PhD, PE <sup>a</sup>, Jennifer Wagner PhD, CIC <sup>f</sup>

<sup>a</sup> Department of Civil and Environmental Engineering, Vanderbilt University, Nashville, TN

<sup>b</sup> Department of Surgery, Riley Hospital for Children at Indiana University Health, Indianapolis, IN

<sup>c</sup> Department of Obstetrics and Gynecology, Vanderbilt University, Nashville, TN

<sup>d</sup> Global Health Systems Inc, Fort Mill, SC

<sup>e</sup> ARTEC Environmental Monitoring, Indianapolis, IN

<sup>f</sup> Prism Environmental Health and Safety, Discovery Bay, CA

## Key Words:

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Environmental quality indicators (EQIs)  
Cost of ventilation in operating rooms

**Background:** Hospitals face growing pressure to meet the dual but often competing goals of providing a safe environment while controlling operating costs. Evidence-based data are needed to provide insight for facility management practices to support these goals.

**Methods:** The quality of the air in 3 operating rooms was measured at different ventilation rates. The energy cost to provide the heating, ventilation, and air conditioning to the rooms was estimated to provide a cost-benefit comparison of the effectiveness of different ventilation rates currently used in the health care industry.

**Results:** Simply increasing air change rates in the operating rooms tested did not necessarily provide an overall cleaner environment, but did substantially increase energy consumption and costs. Additionally, and unexpectedly, significant differences in microbial load and air velocity were detected between the sterile fields and back instrument tables.

**Conclusions:** Increasing the ventilation rates in operating rooms in an effort to improve clinical outcomes and potentially reduce surgical site infections does not necessarily provide cleaner air, but does typically increase operating costs. Efficient distribution or management of the air can improve quality indicators and potentially reduce the number of air changes required. Measurable environmental quality indicators could be used in lieu of or in addition to air change rate requirements to optimize cost and quality for an operating room and other critical environments.

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### BACKGROUND

Lean measures are implemented within the health care industry to control costs while maintaining high quality. Evidence-based information is paramount to guide professionals to achieve the optimum balance for best hospital practices. This applies to hospital ventilation systems, which are important to ensure clean air within sterile environments, but at the same time, they also require

significant amounts of energy to operate. The required ventilation rates for operating rooms (ORs) have increased over the years with minimal data to suggest that more ventilation provides cleaner conditions or reduces surgical site infections (SSIs). Energy costs have continued to increase from both a financial and an environmental perspective.

Energy consumption for buildings is high in the United States and accounts for 40% of the total national energy usage. Heating, ventilation, and air conditioning (HVAC) is the largest component of that at 17%. Hospital buildings in particular have one of the highest energy demands because of their stringent heating and air conditioning requirements, the significant amount of diagnostic and therapeutic equipment available, and the need for 24-hour availability. Within the hospital, the OR suites are the most expensive to heat, cool, and ventilate.<sup>1</sup> This cost is associated with the stringent

\* Address correspondence to Thomas Gormley, PhD, Department of Civil and Environmental Engineering, Vanderbilt University, 2310 Hampton Ave, Nashville, TN 37215.

E-mail address: [thomas.gormley@mtsu.edu](mailto:thomas.gormley@mtsu.edu) (T. Gormley).

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need for climate control and vigorous rates of air exchanges to help maintain a healthy indoor environment.

ORs have specific requirements for the design, construction, and operation of the space and the systems serving the area. These are necessary to protect the patients and staff with one of the primary goals being to provide sterile conditions to help minimize the risk of SSIs. Proper ventilation of the physical space and filtration of the air are 2 primary practices within ORs to reduce the airborne transmission of contaminants. Ventilation is accomplished by systematically changing the air in the OR on a regular schedule. The new air is typically a mixture of fresh air (approximately 20%) from the outside environment and air recycled from the OR space that has been filtered to remove particles and contaminants (approximately 80%). The introduction of large quantities of conditioned and filtered air helps to dilute the number of contaminants within the room, while the proper placement of supply and return air devices directs the contaminants away from the sterile field.

It is estimated that \$9.8 billion is spent annually on hospital-acquired infections, with SSIs contributing the most to the overall cost at 33.7%.<sup>2</sup> OR air quality is only part of a complex list of factors that can contribute to SSIs; therefore, direct connections between air quality and surgical infections are difficult to prove.<sup>3</sup> However, intuitively, the more pathogens present in the air, the greater the chance for contamination of the surgical site, surgical instrumentation, and surrounding environmental surfaces. Furthermore, there is ample evidence to support the potential for airborne transmission of harmful pathogens.<sup>4,5</sup>

The requirements for air changes in hospital ORs have changed frequently over the years. In 1967, the requirement was 12 air changes per hour (ACH), it increased to 25 ACH in 1974, and then back to 15 ACH in 1987. Today, the requirements are primarily defined in The Guidelines for Design and Construction of Hospital and Outpatient Facilities<sup>6</sup> and ASHRAE 170.<sup>7</sup> In the 2010 edition of the guidelines, the 2 standards were combined resulting in an increase from 15 to 20 ACH required in new ORs built in many states in the United States. Additionally, the requirement for the number of these air changes to be fresh, outside air, as opposed to recirculated, increased from 3 to 4 ACH. Although these are the minimum requirements, in practice, most hospitals use 20–30 ACH for their ORs with known anecdotal outliers using 40 ACH, despite minimal evidence to suggest that a greater number of air changes will provide cleaner air. On the other extreme, the State of California code currently allows for the use of 12 ACH in OR systems that provide 100% outside air; however, this approach is not used frequently.<sup>8</sup>

Requirements for air change rates vary in other countries and some even use other standards, such as ISO classifications from the International Organization for Standardization.<sup>9</sup> These numerical quantifications and ISO classifications for particles and microbial colony forming units (CFU) are standard practice for pharmaceutical and semiconductor cleanrooms. Despite the variations in OR ventilation rates, SSI rates remain surprisingly similar among modern countries. Surgical infection rates averaged 1.9% in the United States, 2.2% in Europe, 1.6% in Germany, 1.4% in England, 1.6% in France, and 2.0% in Portugal.<sup>10</sup>

Given the variation in required air change rates in hospital ORs with similar SSI rates and the high energy costs of providing more ACH, research in this field could help clarify the appropriate balance between the costs and benefits of different ventilation rates. This practical, evidence-based data could help guide policy to define the codes and the practical applications for the estimated 30,633 ORs in the United States.<sup>11</sup>

We therefore hypothesized that (1) higher air change rates in an OR would not necessarily provide cleaner air, and (2) higher air change rates would be associated with increased theoretical costs.

## MATERIALS AND METHODS

### *Environmental quality indicator testing*

Three different ORs in 3 different hospitals in 2 different states were chosen for experimentation. The ORs in 2 hospitals (OR A and OR B) were associated with academic medical schools. Both had high efficiency particulate arresting (HEPA)/minimum efficiency reporting values (MERV) 17 filters in the supply grilles supplying the rooms and were 59.3 and 51.5 m<sup>2</sup>, respectively. The third OR (OR C) was located in a private community hospital, had MERV 14 filters in the air handling unit, and was 505 ft<sup>2</sup>. The layout of all 3 ORs was generally the same, but the actual number and location of the supply air diffusers varied along with the location of overhead lights and equipment booms. Studies took place from the summer of 2015 to the spring of 2016.

Assessment of environmental quality indicators (EQIs) was performed as previously described.<sup>11</sup> A 1-hour scripted and simulated medical procedure was enacted to mimic the dynamic conditions of actual surgeries in an OR. Air velocity was measured using TSI Model 9565-P Thermoanemometers (TSI Incorporated, Shoreview, MN) at key locations in the ORs to provide insight into the direction and speed of the air being used for ventilation to provide clean conditions for surgery. The velocities were measured at the face of the supply grilles and the return grilles, and at 2 additional critical locations, the OR table (sterile field) and the back instrument table (back table).

Bioscience viable surface air samplers (SAS180) were placed at both the surgical operating field and at the back instrument table to detect microbial contaminants. Petri plates with tryptic soy agar media were used in the samplers and were changed in regular cycles to collect microbial data during the entire mock procedure. The viable microbial samples were sent under chain of custody to a third-party microbiology laboratory for qualitative and quantitative analysis of bacteria. Bacterial genus were identified and quantified as CFU per cubic meter.

Particle contamination was measured using a Climet Model CJ-750T 75 LPM particle counter. ISO 14644 standards were used, which required measuring the number of particles at 9 points based on the size of the space. The particle sizes recorded were 0.3, 0.5, 1.0, and 5.0  $\mu\text{m}$  in particles per cubic meter.

Testing was performed at 15, 20, and 25 ACH during the mock surgical procedure. The air change rates were measured using a standard HVAC test and balance hoods (ADM860C; Shortridge). In addition, the building automation systems were used to set and monitor the ventilation rates, relative humidity, pressure relationships, and temperatures in the ORs. The measurements were taken at each supply and return grille in cubic feet per minute (CFM), and the air change rates, in ACH, were calculated based on the actual size of each individual OR. Although the layout of supply grilles varied slightly in each OR, all 3 ORs had 2 low wall return grilles.

### *Cost analysis*

The higher ventilation rates require a substantial amount of additional air to be conditioned, filtered, and supplied to the OR. The ventilation rate is calculated by using the following formula: volume of the room in cubic feet multiplied by the ventilation rate in ACH gives the cubic feet per hour, which is converted into CFM, which provides the amount of air that must be provided through the ceiling grilles. It is typically around 2,000–2,500 CFM for an OR which is supplied at 25–35 ft/min as measured at the face of the grille. The number of supply grilles may vary depending on the engineer's design.

The operating costs at each facility varied by hospital as a result of the differences in the cost of energy and the type of systems in

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