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AN ASSESSMENT OF OUTPATIENT CLINIC ROOM VENTILATION SYSTEMS AND POSSIBLE RELATIONSHIP TO DISEASE TRANSMISSION

by

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DEDICATION

To My Family

AN ASSESSMENT OF OUTPATIENT CLINIC ROOM VENTILATION SYSTEMS AND POSSIBLE RELATIONSHIPS TO DISEASE TRANSMISSION

by

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Presented to the Faculty of The University of Texas

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in Partial Fulfillment

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AN ASSESSMENT OF OUTPATIENT CLINIC ROOM VENTILATION SYSTEMS AND POSSIBLE RELATIONSHIPS TO DISEASE TRANSMISSION

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The delivery of healthcare in the United States is shifting from a largely inpatient model to an outpatient services model, but the physical infrastructure for outpatient clinics or medical offices may not be as robust as inpatient hospitals regarding whole room ventilation requirements. Guidelines for the design of healthcare facilities and national standards for ventilation establish generally acceptable ventilation rates for outpatient clinics, but it is unclear if these standards are actually being integrated into these settings. Published peer-reviewed literature indicates that inadequate ventilation rates can be a risk factor in airborne transmission of infectious diseases in outpatient clinics, hospitals and residential buildings. This study examined whether outpatient clinics operating in a business occupancy setting were conducting procedures in rooms with ventilation rates above, at, or below thresholds defined in ANSI/ASHRAE/ASHE Standard 170 for Ventilation in Health Care Facilities, and whether lower ventilation rate and building characteristics increase the risk of transmission of infectious disease.

Ventilation rates were measured in outpatient clinic rooms categized by services rendered (general exam, treatment or procedure room; aerosol-generating or minor surgical procedures) to compare against national standards. Analysis included evaluation of the building characteristics (where the clinic resides) as determinants of ventilation rates and estimated risk of infectious disease transmission based on the measured ventilation rates. The results of this study suggest that a subset of clinics operating in business occupancy settings may be conducting procedures in rooms with ventilation rates that are below those defined in national standards for healthcare settings. When compared to the ANSI/ASHRAE/ASHE Standard 170 for Ventilation in Health Care Facilities standards, 11 of the 105 (10%) clinic rooms assessed did not meet the minimum requirement for general exam rooms, 41 of 105 (39%) did not meet the requirement for treatment rooms, 87 of 105 (83%) did not meet the requirement for aerosol-generating procedures, and 92 of 105 (88%) did not meet the requirement for procedure rooms or minor surgical procedures. While lower air change rates were observed in all building types, newer constructed one-story stand-alone buildings exhibited higher air change rates as compared to the other building types. Based on the measured ventilation rates and the procedures being performed, these outpatient clinic rooms could possibly facilitate transmission of infectious disease rather than protect workers and patients. National ventilation standards should be considered for all healthcare settings and factored into clinic design and clinic lease agreements, which is currently not the case, as suggested by the evidence in this study.

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BACKGROUND

Literature Review

Expansion of Outpatient Services

The provision of healthcare in the United States is shifting from a largely inpatient model to an outpatient services model. From 2004 – 2011, despite population growth, inpatient admissions declined 7.8% while the outpatient visits rose by 33.6%. In 2012, there were 675 million outpatient patient visits according to the American Hospital Association (Vesely, 2014). Leading factors for increasing numbers of outpatient healthcare settings include an aging population in need of more medical care, a shift towards the patient-centered medical home model, and advanced technologies, which allow for tests and procedures to take place outside an acute care setting (Fassler, 2017). Outpatient healthcare clinics are physically located in a variety of settings such as hospital outpatient departments, ambulatory surgery centers, free-standing urgent care or emergency departments, retail clinics and physician offices (Aliber, 2016). Medical real estate is flourishing due to the growth of the outpatient clinic model, converting retail space into healthcare settings with relative ease and efficiency (Diduch, 2018).

Outpatient clinics are also now providing an increased range of services from general exams to minor surgical procedures (Tidy, 2016). In turn, these services may carry with them an associated set of infectious disease exposure risks. Airborne transmission of microorganisms via nuclei droplet (less than 5 micrometers) are generated by humans when talking, breathing, sneezing or coughing or through procedures such as colonoscopies, tracheal intubation, suction during intubation, delivery of oxygen, bronchoscopy, and noninvasive ventilation. (Zemouri, *et al*, 2017). Tran's literature review cited studies included additional procedures such as suction of body fluids, endotracheal aspiration, nebulizer treatment, and collection of sputum, each presenting an increased risk of generating infectious bio-aerosols (Tran *et al*, 2012). Bronchoscopy, endotracheal intubation and open suctioning of the respiratory tract have been associated with transmission of *Mycobacterium tuberculosis*, SARS-CoV and *Neisseria meningitidis* to healthcare workers (Siegel *et al*, 2007). Marchand *et al* (2016) cultured oral, nasal and pulmonary flora from air samples during bronchoscopy that could be inhaled by medical staff and represent an occupational infection risk. Healthcare workers participating in procedures which generate respiratory aerosols were found to have a three-fold greater risk of respiratory infections than workers not performing those types of procedures (MacIntyre *et al*, 2014) *Clostridium difficile* was detected in air samples from a hospital ward during routine care (Roberts *et al*, 2008) and in the outpatient setting from recently infected patients shedding the bacteria during visits (Jury *et al*, 2013).

Regulatory oversight of outpatient services performed in medical offices vary by state, but overall are exempt from the stringent licensure requirements of hospitals and ambulatory surgical centers (ASC). Practices are predominantly regulated by the states' medical licensing board and are not focused on the physical site unless there are additional requirements for accreditation by organizations such as The Joint Commission (Murphy & Shtern, 2018). Urman, Punwani & Shapiro (2012) noted the trend of "practice drift" occurring in office-based providers where they deliver care outside their scope due to lack of federal oversight compared to ambulatory surgery centers and hospitals. This can lead to procedures being performed in settings in which they were not originally intended or designed to be performed.

Building Design, Codes and Ventilation Standards

The Facility Guidelines Institute (FGI) establishes guidelines for the planning, design and construction of hospitals, outpatient facilities, and residential healthcare and support facilities for the development of safe health and residential care-built environments. The FGI classifies outpatient facilities as any outpatient unit in a hospital, a freestanding facility, or outpatient facility in a multiple-use building (FGI, 2018). The American National Standards Institute (ANSI), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHREA) and the American Society for Health Care Engineering (ASHE)'s joint Standard 170 for Ventilation in Health Care Facilities incorporates the FGI definitions and set the minimum requirements intended for adoption by code-enforcing agencies (ANSI/ASHRAE,2017). The design parameters concerning ventilation of outpatient spaces as listed in Standard 170 for Ventilation in Health Care Facilities are summarized in Table 1. The International Building Code (IBC) and National Fire Protection Association (NFPA) are the primary construction codes and classify building types based on the ability of the occupants to evacuate the building in emergencies rather than the activities performed within the building. Healthcare facilities occupancy codes differ based on the number of occupants that are present simultaneously that are incapable of self-preservation in the event of an emergency. If the number of patients that cannot evacuate themselves is greater than five, then the occupancy is considered "hospital", driving more stringent requirements. Because the outpatient clinics generally have less than 5 patients incapable of self-preservation in an emergency, the clinics are typically classified as business (Group B) occupancy. This occupancy classification encompasses buildings used for office, professional or service-type transactions, including the storage of records and accounts. Banks, barbershops, dry cleaning, post offices, and civic administration have the same occupancy classification (ANSI/ASHRAE, 2017). Such structures have less demanding fire code requirements, simpler mechanical and electrical systems, and lower air changes per hour ventilation standards, making these clinics less expensive to build and operate than a hospital (ANSI/ASHRAE, 2016 & Carr, 2017). As health care specific building codes would not normally pertain to business occupancy, it is unclear if the health care ventilation standards are integrated into outpatient clinic design or lease agreements in these types of buildings. With more medical procedures transitioning to the outpatient setting, experts are expressing concerns that clinic designs should include ventilation standards based on the provided outpatient services (Banse, 2015), the challenges in implementing the ventilation standards due to shared patient care areas and administrative spaces (Banse *et al*, 2014), and the need for building occupancy code changes (Silvis, 2011).

The location of air supply and exhaust can also impact also air changes per hour. Existing guidelines recommend that the airflow should be primarily directional from the room ceiling to the healthcare workers' region, then to the patients' region, and lastly expelled through the exhaust vents that are located at the lower level of the room (Yuan, 2018).

Table 1: Design Parameters- Outpatient Spaces - ANSI/ASHRAE/ASHE Standard 170 for Ventilation in Health Care Facilities

Function of Space	Minimum Total Air Changes per Hour (ACH)	Pressure Relationship to Adjacent Areas
General Examination Room[a]	4	No Requirement
Treatment Room[b]	6	No Requirement
Procedure Room[c]	15	Positive
Bronchoscopy, sputum collection, and pentamidine administration	12	Negative

[a] room used for clinical exam and vitals, [b] exam room used for additional function (treatment or procedure), [c] not restricted environment but sterile instruments or field used.

Studies of Disease Transmission in Outpatient Studies Related to Ventilation

With an increased number of patient interactions occurring in the outpatient setting and the lack of systematic monitoring of infection transmission in these settings, Goodman and Solomon (1991) summarized 53 clusters of infections associated with the outpatient setting between 1961 and 1990. Nine were associated with airborne transmission among patients and health care workers in outpatient clinics or offices. There were relatively limited studies demonstrating a definitive association between transmission of airborne infections and the ventilation of buildings. Li *et al*’s (2007) literature review yielded several conclusive studies with strong and sufficient evidence to demonstrate this association; however, many studies did not directly measure ventilation. In 1985, the transmission of measles was documented from the source patient’s exam room throughout a pediatric clinic occurred with four air changes per hour throughout the clinic and directional airflow towards the return vent within the exam room. Bloch *et al* (1985) concluded that energy-efficient buildings and re-circulating air may predispose a clinic to airborne spread of infectious disease. The transmission of tuberculosis to staff members in a primary care health clinic occurred when the ventilation rate was 0.5 total air changes per hour (ACH). In the examination room, the supply exceeded the exhaust, causing air to move from the room into the hallways and was recirculated through the building. Thirty-nine patients with pulmonary tuberculosis were treated with sputum induction and aerosolized pentamidine during the time frame. The clinic stopped the procedures until construction of appropriate exhaust systems for specialized rooms could be completed (Calder *et al*, 1991). Herwaldt, Smith & Carter's (1998) review of outbreaks in the outpatient setting found that air in a Florida outpatient clinic was recirculated and ventilation was "low" or "without proper ventilation" during sputum induction and aerosolized pentamidine treatments. This affected 30 healthcare workers, 17 of which had a positive tuberculin skin test (TST) conversion for *Mycobacterium tuberculosis*. The review concluded that identification and isolation of patients and visitors with communicable diseases is difficult in the outpatient setting and that *Mycobacterium tuberculosis* can be transmitted easily in the outpatient setting.

Disease transmission has also occurred in the hospital setting when ventilation rates did not meet the national standards for ventilation, even though, the hospital building codes are more robust. Nardell's (1998) case study of a tuberculosis patient in a hospital undergoing aerosol-generating procedures in a room with ventilation rate well below acceptable standards resulted in 10 of 13 exposed workers having tuberculin conversion.

Tuberculin conversion of healthcare workers in another hospital was 3.4 times higher in general exam rooms when air change per hour (ACH) was less than two. Also, cough inducing procedures resulted in tuberculin conversion in workers unless performed in respiratory isolation rooms (Mendez *et al*, 2000).

Jiang *et al* (2003) noted significantly lower transmission rates of SARS with high ventilation rates in a hospital setting, although the exact ACH was not documented. In Grosskope & Mousavi's (2014) study in hospital general patient rooms, increasing air change rates from two to five air changes per hour reduced the concentration of aerosol less than 5 micrometers in size by up to 30%.

Disease transmission due to low ventilation rates has also been documented in additional settings. An increased risk of respiratory tract infections among occupants of a high-efficiency US Army barrack was observed with three air changes per hour (ACH) and 95% recirculation of air (Brundage *et al*, 1988).

Infection Risk Modeling

Various mathematical models of infectious diseases are used as a tool to study the mechanism by which diseases spread, to predict the future course of a disease outbreak and to evaluate strategies to control a disease outbreak (Daley & Gani, 2005). The Wells-Riley equation is used to model aerosol transmission under circumstances where the major transmission variables are known or estimable (Nardell, 1998).

The probability of infection = $1 – e^{-iqpt/Q}$ where:

i = number of infectious source cases

q = the number of infectious doses generated per source case per unit time (quanta/hr)

p = the average human respiratory rate, per person (m^3/hr)

t = the duration of exposure (hr)

Q = outdoor air supply rate (m^3/s)

The Wells-Riley model assumes constant quanta, that the air in the space is fully mixed, does not take into account distance from source to new case, and the respiratory rate is same for all persons and all susceptible persons are equally vulnerable (Yates *et al*, 2016 & Beggs *et al* 2003).

The Gammaitoni-Nucci model is a variation of the Wells-Riley model that incorporates non-steady quanta levels, but still assumes mixed air and all susceptible persons are equally vulnerable. The Gammaitoni-Nucci model is cited in 106 peer-reviewed publications and the authors have a H-index of 75 and 23 respectively.

The probability of infection = $1 – e^{[-(iqp/V)\ (Nt\ +\ e\text{-}Nt\ -1\ /\ N2)]}$

V = volume of the room (m^3)

N = room ventilation rate (air changes per hour)

Average adult human respiration rate is 12-20 breaths per minute with a tidal volume of 500mL resulting in a rate of 0.48 m^3/hr. A limitation is the varying values for quanta used throughout various publications. Beggs, Shepherd & Kerr (2010) used 12.7 quanta/hr for *Mycobacterium tuberculosis*, 100 quanta/hr for influenza and 570 quanta/hr for measles.

Knibbs *et al* (2011) used the Gammaitoni-Nucci model to estimate the risk of transmission for influenza in hospital consulting rooms after an infected patient vacated the room. Although a lower quanta and higher rate were used as compared to Beggs, Shepherd & Kerr (2010), the risk of transmission of influenza to a susceptible person placed into the room after the infectious person ranged from 3.6% to 20.7% depending on length of time each patient was in the room. Beggs, Shepherd & Kerr (2010) & Beggs *et al* (2003) studies illustrate risk exists based on ventilation rate, quanta and time of exposure, although the benefits of very high ventilation rates are marginal.

One room air change is estimated to remove 63% of air contaminants in an hour. A second air change removes 63% of the remaining 37%, therefore, a room with 7 ACH removes more than 99.9% of airborne contaminants in an hour, assuming the room is not re-contaminated (Nardell, 1998). Without a continuous and constant infectious quanta being introduced into the room, the Gammaitoni-Nucci model is a more appropriate model of infectious transmission risk.

Public Health Significance

Air changes per hour for a given indoor space should be determined based on a risk assessment of the use and conditions of the space (Memarzadeh, 2013). This study focuses on whole room ventilation within a group of outpatient clinics, which serve as the basis for the clinical practice of an academic health center, which provides approximately 2 million patient visits per year. The rapid expansion of the total number and geographic location of these medical clinics, associated with the medical practice used in this study, in the past years have included positioning clinics in a variety of buildings from medical office buildings to shopping center leased space. Prior to this project, the clinical spaces had not been evaluated to determine the effect ventilation may have on risk of disease transmission, based on the location and types of services provided in each of the clinics. Thus, the information generated in this study is an important step towards providing information on how whole room ventilation impacts disease transmission risk in order to protect patients and workers from transmission of disease in this setting. The data obtained could help in the design and review of existing and new clinical spaces to maximize patient and worker protection.

Study Objectives

This study examined whether outpatient clinics operating in business occupancy settings were conducting procedures in rooms with ventilation rates that were above, at, or below the rates defined in national standards. It also examined if and how low ventilation rate and building characteristics might increase the risk of transmission of infectious disease to both patients and workers. The following research was undertaken:

- Characterized procedure types and use of each clinical space
- Assessed room ventilation rates and airflow for each defined clinical space
- Identified building characteristics that may be determinants of ventilation rates
- Estimated the risk of infectious disease transmission based on current ventilation rates

Specific Aims

Through a cooperative arrangement with the academic health center medical practice group, an outpatient clinic portfolio of 100 clinics were chosen for evaluation. This study addressed the following aims:

Aim 1: Categorization of rooms within each clinic based on the services provided, such as general exam, treatment types, and procedure types:

a) Specialized procedures, identified per clinic
b) Rooms within each clinic, categorized based on services provided in each room (exam, treatment, procedure, aerosol-generating procedures or minor surgical)

Aim 2: Measurement of room ventilation rates, directional airflow and degree of air mixing for the above categorized clinical areas

a) Ventilation flow into the room, measured directly at supply source for total air changes for each room
b) Directional airflow and degree of air mixing, assessed by the visualization of smoke introduced at various points in the room

Aim 3: Comparison of Aim 2 measurements to national standards for ventilation in health care settings (ANSI/ASHRAE 170 Standards)

Aim 4: Identification of building characteristics and measurement of their associations as determinants of room ventilation rates

a) Ventilation rates compared to building characteristics such as type of building (medical office building, stand-alone or shopping center), building age, floors per building, and clinic square footage
b) Summarize the determinants (as defined above) graphically into a conceptual model
c) Estimate the association between building characteristics and ACH via linear regression modeling

Aim 5: Estimate the risk of infectious disease transmission based on the ventilation rates measured in Aim 2

a) Apply the Gammaitoni-Nucci equations to estimate risk of airborne infection based on ventilation rate results

METHODS

Study Design

This cross-sectional study was an assessment of room ventilation rates and airflow of rooms within outpatient medical clinics. Variables listed in Table 2 were established to identify relationships among these variables. Disease transmission risk was estimated based on these results. Clinic assessments were conducted by the manuscript author from May 2019 to August 2019.

Table 2: Table of Variables

Variable	**Source of Information**	**Method of Measurement (Units) or Categories**	**Variable Type**	**Independent (I) or Dependent (D)**
Type of Room	Communication from clinical staff/management during assessment	- Exam - Treatment - Procedure	Categorical	I
Types of Procedures	Communication from clinical staff/management during assessment	- General Exam - Minor Surgical - Aerosol-Generating	Categorical	I
Average Air Change per Hour (ACH)	Direct measurement	ACH calculated from CFM measurement via balometer at supply air and room volume (ft^3)	Continuous	D
Carbon Dioxide (CO_2)	Direct measurement	Parts per Million (ppm)	Continuous	I
Airflow direction from supply	Observation of smoke	- Towards Return - Towards Door - Towards Patient	Categorical	I
Airflow direction at door	Observation of smoke	- Into Room (Negative Pressure) - Out of Room (Positive Pressure)	Categorical	I
Airflow direction at patient	Observation of smoke	- Towards Return - Towards Door - No Defined Movement	Categorical	I
Air Mixing	Observation of smoke	Seconds from smoke initiation to dispersion - Poor (≥20 sec) - Fair (11-19 sec) - Good (≤10 sec)	Ordinal	I

Building Category	Building Leasing Office or Website	- Medical Office Building - Shopping Center - Stand-alone	Categorical	I
Building Age	Building Leasing Office or Website or Lease Agreement	Years since built	Continuous	I
Building Floors	Building Leasing Office or Website or Lease Agreement	Number of floors	Continuous	I
Clinic Square Footage	Lease Agreement	Reported square footage	Continuous	I
Risk of Disease Transmission	Calculation from ACH	Percent	Discrete	D

Study Setting

The study was conducted at an academic health center medical practice group, consisting of 100 outpatient physician offices within a major US metropolitan area. This medical practice group has more than 2,000 clinicians certified in more than 80 medical specialties and subspecialties. Specialties included family practices, pediatrics, orthopedics, surgery, cardiology, infectious disease, pulmonary, endocrinology, dermatology, gastroenterology, medical weight loss management, neurology, nephrology, urology, and women’s health. Each clinic varied in the number of specialties providing services in one clinic space. These clinics were geographically dispersed within a major medical center and within an outward radius of 30 miles in all directions. A letter of support to conduct this research in this setting was obtained from the medical practice group’s Chief Ambulatory Officer (Appendix A).

Study Population Size and Selection

The unit of study was defined as the clinic room, rather than an entire clinic. Each clinic assessed contained at least one exam room and at least one treatment or procedure room for measurement collection. There was little published guidance concerning acceptable sample sizes for pilot studies. General guidance was to use 10% of the sample required for a full study (Hertzog, 2008; however, Isaac & Michael (1995) suggest 10 to 30 participants as the sample size. For the envisioned regression analysis in Aim 4, which focuses on the building characteristics, there were three independent variables. A rough rule of thumb is 10 measurements per independent variable, resulting in 30 measurements needed. At the onset of this study, there was an estimation of two rooms measured for ACH per clinic, therefore, the minimum number of clinics to be assessed was 20. It was predicted that clinics would have more than one procedure or treatment room and that the total number of data collected would exceed the minimum measurement needed.

Clinic locations were sorted by building type, determined before the assessments and then randomized in Excel (Microsoft Corporation, Seattle, WA). The first 20 clinics from the randomized lists were selected to be contacted for participation so that there was equal distribution of building types in the clinics assessed. All clinics classified as shopping center or stand-alone were included in the study, with clinics in medical office buildings making up the remainder of the total clinics. Clinic management was contacted through email for participation. There was no requirement for any clinic to participate in the assessment. Clinics were excluded from the study if no procedures were performed at the clinic, other than general examinations. No clinics were excluded from the study and none refused participation. Clinic management scheduled times for the assessment and data collection that was convenient for the clinic. During the study, twenty-two clinic volunteered to participate in the study, resulting in a final study population of 105 clinic rooms.

Data Collection

Each clinic was accessed during normal work hours (9:00 AM to 5:00 PM). Air measurements (ACH, CO_2, air mixing and directional airflow) were taken during three daily visits for over four months (May 2019 through August 2019). For ACH and CO_2, three measurements were taken during each visit, resulting in a total of nine measurements. Air mixing and directional airflow were observed once during each visit.

Data were collected manually in a laboratory notebook using the Clinic Data Collection Sheets in Appendix B, transferred to an electronic format (Excel) and were saved on a secure, encrypted personal computer. The data was backed up on a secure, encrypted flash drive kept in a locked institutional office. Once the data collection was completed, the flash drive was turned over to the medical practice group’s Environmental Health and Safety program for permanent storage on the network drive. Clinics were numbered and did not include any information that could identify the clinic location.

Measurements of air changes per hour (ACH)

Total room air changes per hour were measured by using a balometer (Alnor Balometer Capture Hood, TSI Incorporated, Shoreview, MN). The balometer reported a reading in cubic feet per minute (CFM). The balometer was placed on the supply grill for the room, and its vent hood was switched to fit either the square diffuser or slot diffuser of the supply grill. If there were multiple supply grills in the clinic room, then each was measured and combined. Once the balometer was in place, continuous sampling was performed until the CFM reading was stable for fifteen seconds, before being recorded (Picture 2 in Appendix 3). This process was repeated two more times, resulting in three readings per clinic room visit. The sample mean of the nine readings was used to calculate the ACH for each clinic room. Room volume was calculated by obtaining measurements of the room height, length, and width in feet with a tape ruler. The following equation was used to calculate ACH (Fluke Corporation, 2006).

$$\text{ACH} = \text{CFM x } (60/\text{room volume ft}^3)$$

Measurements of Carbon dioxide (CO_2)

Indoor carbon dioxide (CO_2) concentration is a standard indicator of ventilation effectiveness. As building designs became more airtight to improve energy efficiency, air exchanged decreases. Occupied buildings with a low ventilation rate allow CO_2 to accumulate throughout the day while buildings with aggressive ventilation rates and good air mixing will prevent the accumulation of CO_2, resulting in a lower CO_2 concentration. Indoor carbon dioxide (CO_2) was measured with an indoor air quality monitor (Q-TRAK Model 7575, TSI Incorporated, Shoreview, MN). The Q-TRAK reported CO_2 in parts per million (ppm). The Q-TRAK was placed on a stable surface, such as a countertop in the clinic, as central to the clinic room as possible (Picture 3 in Appendix 3). CO_2 measurements were recorded at three points during each clinic room visit.

Air Mixing and Directional Airflow

Airflow direction was observed using a smoke tube (Dräger Air Current Tubes CH25301) to generate a puff of smoke at the air supply source and observing direction towards air return. Additionally, observing the smoke puff at the bottom of the closed room door confirmed room negative or positive pressure. Smoke puffed at the exam table and observation of the direction to the return illustrated flow of aerosols generated by the patient or procedure. Rate of air mixing was determined by generating a puff of smoke at the worker height breathing zone in the center of the clinic room and observing the time in seconds it took for the puff of smoke to disperse. If the smoke was no longer visible in less than 10 seconds, it indicated good mixing; 11-19 seconds indicated fair mixing; and, more than 20 seconds indicated poor mixing. This assumes a healthcare worker takes 12-16 breaths per minute.

Building Characteristics

Each clinic room was assigned to a mutually exclusive building category based on the observations during the clinic visit. The categorization of the clinic room was considered important as the ventilation conditions within each clinic site are impacted by the system provided to the entire structure. The categories included:

medical office building;

shopping center;

or stand-alone clinic building.

“Medical office building” was defined as the medical or dental clinic being the only occupants located within the building. “Shopping center” meant that the clinic was attached to non-medical commercial buildings. “Stand-alone clinic” was defined as the clinic building not being attached to any other buildings. Building age, number of floors, and total clinic square footage was obtained from the building lease management office, website or through clinic lease agreements.

Estimating Risk of Transmission

The Gammaitoni-Nucci model is a variation of the Wells-Riley model that incorporates non-steady quanta levels, but still assumes mixed air and all susceptible persons are equally vulnerable.

The probability of infection = $1 – e^{[-(iqp/V)\ (Nt + e\text{-}Nt -1 / N2)]}$

i = number of infectious source cases

q = the number of infectious doses generated per source case per unit time (quanta/hr)

p = the average human respiratory rate, per person (m3/hr)

t = the duration of exposure (hr)

V = volume of the room (m^3)

N = room ventilation rate (air changes per hour)

Average adult human respiration rate is 12-20 breaths per minute at a tidal volume 500mL resulting in a rate of 0.48 m^3/hr (Beggs, Shepherd & Kerr 2010). A limitation is the varying values for quanta used throughout publications. Beggs, Shepard & Kerr (2010) used

12.7 quanta/hr for *Mycobacterium tuberculosis*, 100 quanta/hr for influenza and 570 quanta/hr for measles.

Data Analysis

Descriptive statistics were used to summarize the categorical variables categorized rooms and specialized procedures (exam, treatment, procedure, aerosol-generating procedures and minor surgical). Air changes per hour were collected as a continuous variable but, did not have normal distribution. The sample mean, median and standard deviation of ACH measures for each room type where procedures were performed was calculated using Excel. Descriptive statistics were displayed graphically by a distribution plots to show variation in air changes per hour by room and procedure types. Descriptive statistics were used to summarize air supply vent type and directional airflow data. The Kruskal-Wallis test was used to examine any difference in median ACH among categories of rooms, procedures and building types. To eliminate repeated measurements for building age, building floors and clinic square footage, data per clinic was used to analyze the difference in each building characteristic and the building types via the Kruskal-Wallis test. Mixed-effects models were used to compare individual room air change per hour measurements with room type, procedure type, and building characteristic variables. Scatter and distribution plots were used to show variation in air changes per hour compared to CO_2 and air mixing categories, respectively. The relationship between air changes per hour and CO_2 and air mixing was determined using linear regression. The relationship between directional airflow and room type was determined using Fisher’s Exact test. To build the multiple regression models for

Aim 4, each building variable, besides building type, was first tested for correlation with the ACH by simple linear regression. Variables with a p-value of 0.2 or less were selected for the multiple linear regression model in a stepwise fashion to determine which variables were statistically significant at a p-value of 0.05, checking all linear regression assumptions. All graphs and statistical analyses were produced using STATA 2X client software (StataCorp, College Station, TX).

RESULTS

Description of Clinics

A population of 105 outpatient clinic rooms were assessed, residing within 22 clinics. Clinical staff identified rooms used as exam, treatment or procedure, and type of treatment or procedure (Table 3). Exam rooms were only used for general medical exams; no additional treatment or procedures. Various types of medical services were provided in treatment or procedure rooms. Procedure rooms were labeled and identified, whereas treatment rooms were exam rooms in which additional treatments or procedures were provided. Due to the numerous types of treatments available in the clinics, approximately half of the rooms accessed were identified as treatment rooms by the clinical staff.

Aerosol-generating procedures (AGP) included suctioning of body fluids and air passageways, nebulizing medications, and sputum induction. Minor surgical procedures included skin biopsy and other dermatological procedures such as skin tag and wart removal, incision and drainage, loop electrosurgical excision procedure (LEEP), fine needle aspiration, intrauterine device (IUD) and Nexplanon insertion, colposcopy, and vein ablation.

Over half of the clinic rooms were in multispecialty or community-based clinics, offering a variety of services. Other clinic rooms were in pediatrics (n=13), colorectal (n=7), dermatology (n=6), otorhinolaryngology (n=6), family medicine (n=5), women's health (n=5), and cardiovascular surgery (n=3) specialty clinics.

Table 3: Summary of Clinic Room Types and Procedures (n=105).

	Exam	Treatment	Procedure	Total
Total	25	57	23	105
Aerosol-Generating Procedures	NA	53	10	63
Minor Surgical Procedures	NA	4	13	17

Ventilation Rates

Air Supply Vents

Supply vents (diffusers) were located in the room ceilings and were either 2ft x 2ft square diffusers or slot diffusers. The majority of clinic rooms had square diffusers (84%), but clinic rooms with slot diffusers were all located within medical office buildings (Table 4 and Picture 1 in Appendix 3).

Table 4: Types of Supply Vents in Medical Office Building Clinic Rooms (n=45) by Room Type.

Supply Vent	Exam	Treatment	Procedure	Total
Square Diffuser	12	10	6	28
Slot Diffuser	5	5	7	17
Total	17	15	13	45

Continuous Airflow

Fifteen clinic rooms did not exhibit continuous airflow, but rather cycled on and off, which may be due to energy conservation initiatives. When this occurred, air measurements were conducted when the air was cycled on. We were unable to determine whether this cycling was due to the settings on the ventilation system for energy conservation or due to a failure in the ventilation system. These rooms were either in shopping centers or in stand-alone buildings; all medical office buildings accessed had continuous airflow (Table 5).

Table 5: Summary of Clinic Rooms with Cycled, Rather Than Continuous, Airflow (n=15).

	Shopping Center	**Stand-alone**	**Total**
Exam	2	1	3
Treatment	4 (Aerosol Generating)	6 (Aerosol Generating)	10
Procedure	2 (Minor Surgery)	0	2
Total	8	7	15

Air Changes per Hour

Mean ACH ranged from 0 ACH to 32.1 ACH for clinic rooms. The mean ACH value for all clinic rooms was 8.7 and the median was 6.8. The mean ACH values were highest in treatment rooms (9.2 ACH, median 6.9), then procedure rooms (8.4 ACH, median 7.6) as compared to exam rooms (7.8 ACH, median 6.5). Mean ACH for rooms conducting aerosol-generating procedures (9.1 ACH, median 7.0) and minor surgery (8.4 ACH, median 5.6) corresponded to treatment and procedure rooms respectively. (Figures 1 and 2 and Table 6).

The Kruskal-Wallis test was conducted to determine if median ACH results were different for room types and procedure types. Clinics were classified into three room categories: exam (n=25), treatment (n=57) and procedure (n=23), and into three procedure types: general exam (n=25), aerosol-generating procedures (n=63) and minor surgery (n=17). There was no statistically significant difference in ACH between room types (p = 0.89) or procedure types (p = 0.73) (Appendix 4). Additionally, there was no statistically significant difference in individual ACH between room types (Mixed-effects model, Treatment p=0.548 and Procedure p=0.804, compared to Exam) or procedure types (Mixed-effects model, Aerosol-generating p=0.638 and Minor Surgery p=0.776, compared to Exam) (Appendix 8).

Figure 1: Distribution Plot of Air Changes per Hour for All Clinic Rooms (n=105).

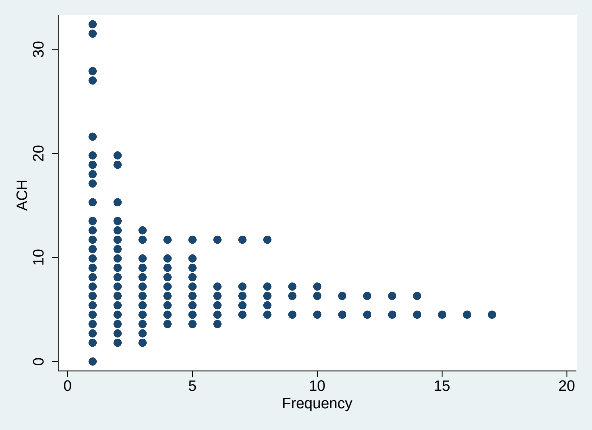


Figure 2: Distribution Plot of Air Changes per Hour per Clinic Room by Room Type (Left) and Procedure Type (Right), Kruskal-Wallis test, p>0.05

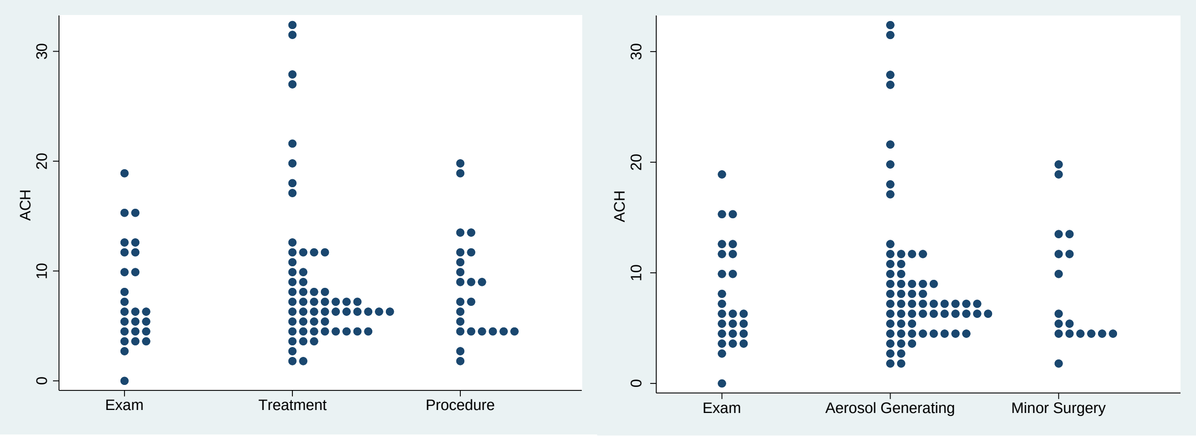


Table 6: Summary Table of Air Changes per Hour by Room Type and Procedure type, Kruskal-Wallis test, $p>0.05$.

	# Clinics	**Mean ACH**	**Median ACH**	**Std. Dev.**	**Min**	**Max**
Exam	25	7.8	6.8	4.64	0	18.5
Treatment	57	9.2	6.9	6.99	1.9	32.1
Procedure	23	8.4	7.6	4.87	1.7	19.7
Aerosol Generating	63	9.1	7.0	6.69	1.9	32.1
Minor Surgery	17	8.4	5.6	5.51	1.7	19.7

CO_2

Carbon dioxide levels (CO_2) ranged from 350 to 1,011 parts per million (ppm). The mean and median CO_2 values for all clinic rooms were 601ppm and 546 ppm, respectively. All clinic rooms were within the acceptable CO_2 values to indicate typical occupied indoor spaces with good air exchange (350-1,000ppm), except for two exam rooms which were slightly above 1,000 ppm (Figure 3). Simple linear regression indicated a statistically significant relationship between ACH and CO_2 (Prob>F = 0.0166). For each one-unit increase in CO_2, ACH increases by 0.008 units (Figures 4 and Appendix 5).

Figure 3: Distribution Plot of CO_2 by Room Type (Vertical lines indicate range of good air exchange), Linear regression $p<0.05$.

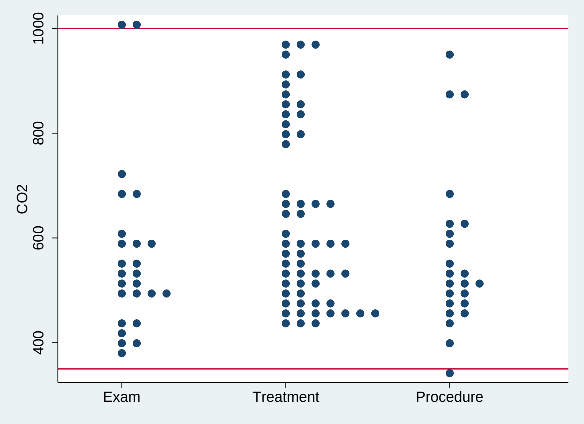
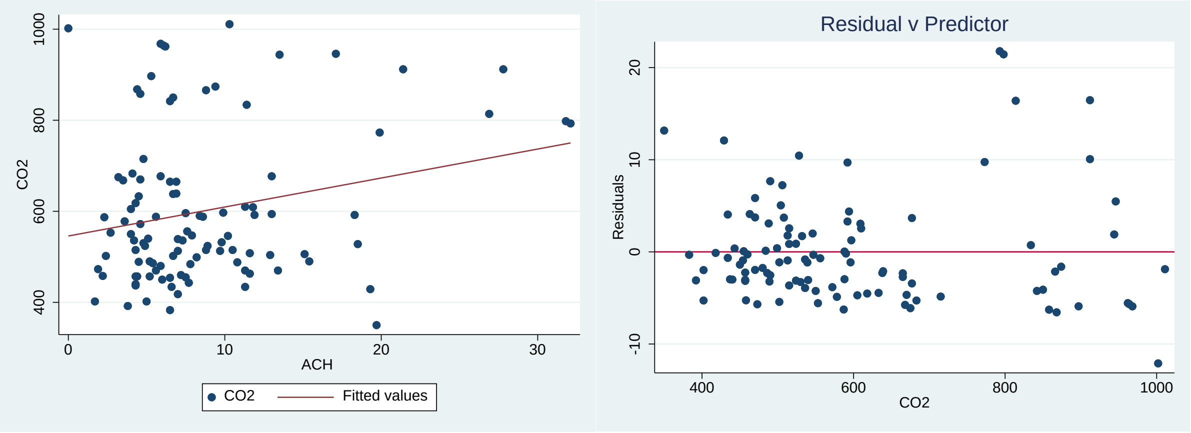


Figure 4: Linear Relationship for ACH and CO_2 (Left) and Residual v. Predictor Below (Right), Linear regression $p<0.05$.



Air Mixing

Good air mixing (smoke dispersal within 10 seconds) was observed in 10% of clinic rooms. Fair air mixing (smoke dispersal between 11 and 20 seconds) was observed in 28% of clinic rooms. Poor air mixing (smoke dispersal greater than 20 seconds) was observed in 62% of the clinic rooms. This trend is similar across room types (Table 7 and Figure 5).

Simple linear regression indicated a statistically significant relationship between ACH and Air Mixing (Prob>F = 0.000). For each one second increase in air mixing time, ACH decreased by 0.40 units. Since a lower air mixing reported number (in seconds) results in better air mixing and lower ACH means there is less airflow, as air mixing increases, ACH is expected to decrease (Figures 6 and Appendix 5).

Table 7: Air Mixing Frequency by Room Type

Room Types	**Good Air Mixing (0-10 sec)**	**Fair Air Mixing (11-19 sec)**	**Poor Air Mixing (20+sec)**
Exam	3 (12%)	7 (28%)	15 (60%)
Treatment	8 (14%)	16 (28%)	33 (58%)
Procedure	0 (0%)	6 (26%)	6 (74%)

Figure 5: Distribution Plot of Air Mixing (seconds) per Clinic Room by Room Type (Left) and Procedure Type (Right) (Vertical lines indicate time frames for Good, Fair and Poor air mixing)

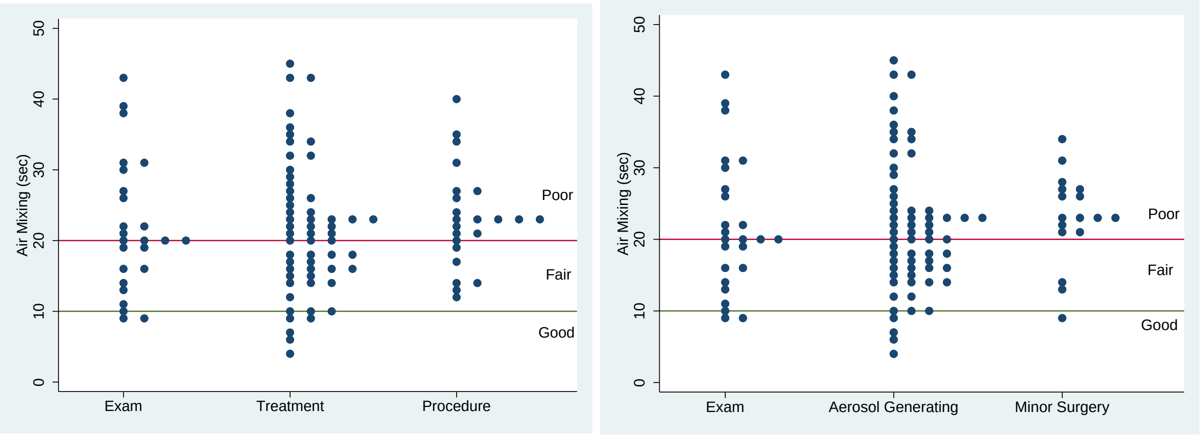
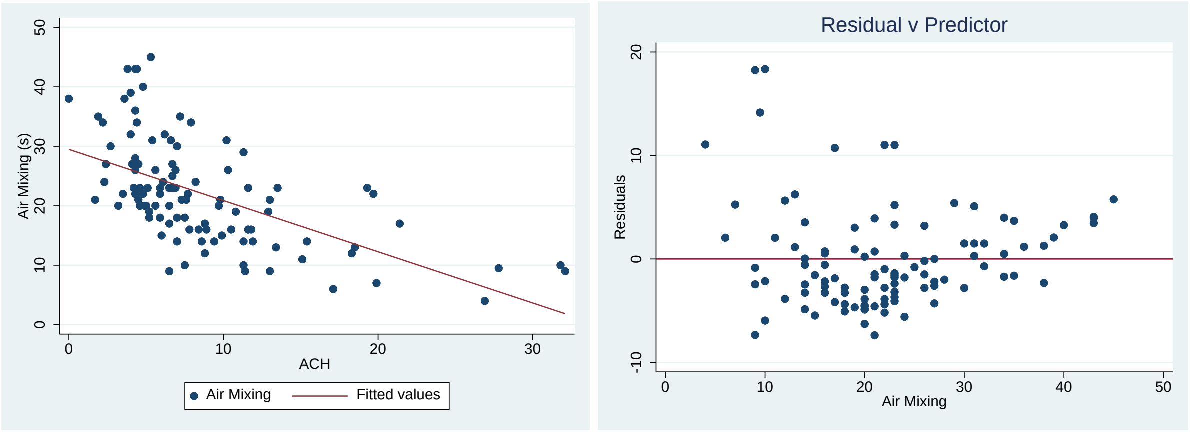


Figure 6: Linear Relationship for ACH and Air Mixing (Left) and Residual v. Predictor Below (Right), Linear regression $p<0.05$



Directional Airflow

Air from the supply vent moved towards the door in 68% of clinic rooms and towards the patient in 20% of clinic rooms. No significant association was determined between the airflow direction at the supply vent and room types, (Fisher’s exact test, p=0.419). (Table 8, Figure 7 and Appendix 6).

In 78% of clinic rooms, directional airflow at the door was into the room, with the remaining percentage having airflow out of the room. No significant association was determined between the airflow direction at the door and room types, (Fisher’s exact test, p=0.210). (Table 9, Figure 7 and Appendix 6).

Airflow from the patient was towards the door in 46% of clinic rooms and 32% indicate no direction, indicating no movement away from the patient/provider. This test imitated the generation of an aerosol from the patient. No significant association was determined between the airflow direction at the patient and room types, (Fisher’s exact test, p=0.770). (Table 10, Figure 7 and Appendix 6)

Table 8: Airflow Direction from Supply Vent by Room Type, Fisher's exact test p>0.05

Room Types	Towards Door	Towards Patient	To Floor	Along Ceiling	No Movement
Exam	14	8	1	0	2
Treatment	43	9	1	1	3
Procedure	15	4	2	1	1
Total	**72**	**21**	**4**	**2**	**6**

Table 9: Airflow Direction at Clinic Room Door by Room Type.

Room Types	Into Room	Out of Room
Exam	17	8
Treatment	48	9
Procedure	17	6
Total	**82**	**23**

Table 10: Airflow Direction at Patient by Room Types.

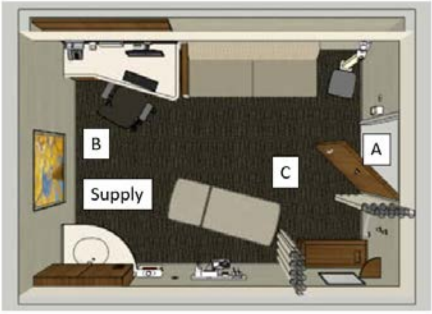
Room Types	Towards Door	Towards Return	To Floor	Along Ceiling	No Movement
Exam	11	4	1	0	9
Treatment	29	4	4	2	18
Procedure	9	3	2	2	7
Total	**49**	**11**	**7**	**4**	**34**

Figure 7: Left: Directional airflow from supply is toward the door (68%) or towards patient (20%). Middle: Directional airflow is into the room (78%). Right: Directional airflow from the patient is towards the door (46%) or indicates no movement or stationery (32%), Fisher's exact test p>0.05

https://images.app.goo.gl/dSb9ZSCaEYRz77JRA

In 68% of clinic rooms, the air return (or intake) was at the room's door, meaning directly at the door inside of the clinic room. Air from the supply or patient that was directed towards the door may also be directed towards the return. 15% of clinic rooms did not have an air return present in the clinic room. In 10% of the rooms, the return was located on the opposite side of the room to the door and near the supply. 7% had air returns located near the door but not directly at the door and between with air supply and the door. No returns were located on the clinic floor. No significant association was determined between the return placement and room types, (Fisher's exact test, p=0.215). (Figure 8 and Appendix 6)

Figure 8: Return Air Vent Placement within Clinic Room. A) Return at Door, B) Return Opposite of Door, C) Return Near Door (between Supply and Door) and Supply, Fisher's exact test p>0.05



Comparison to ANSI/ASHRAE Standards

Ten percent of the clinic rooms assessed did not meet the minimum ANSI/ASHREA Standard 170 of four air changes per hour (ACH) for general exam rooms. This finding was not limited to a specific room type; 16% of exam, 9% of treatment and 9% of procedure rooms did not meet the four ACH standards. Ten percent of clinic rooms used for aerosol-generating procedures and 6% of clinic rooms used for minor surgeries did not meet the four ACH standard.

Clinic rooms identified as treatment rooms were exam rooms where additional services beyond a general exam were conducted. Treatment rooms (n=57) included both aerosol-generating procedures (n=53) and minor surgeries (n=4). Only 67% meet the ANSI/ASHREA Standard 170 of six ACH for treatment rooms.

Clinic rooms identified as procedure rooms were not rooms with restricted environments, but used sterile instruments or required a sterile field. Procedure rooms (n=23) included both aerosol-generating procedures (n=10) and minor surgeries (n=13). Only 9% met the ANSI/ASHREA Standard 170 of 15 ACH for procedure rooms.

The aerosol-generating procedures included suctioning of body fluids and air passageways, nebulizing medications, and sputum induction in this study. While all of these procedures are not listed in the ANSI/ASHRAE Standard 170, they are commonly performed in isolation (AII) rooms which have the same ACH standard. Of rooms where aerosol-generating procedures occurred, only 13% met the ANSI/ASHREA Standard 170 of 12 ACH for bronchoscopy, sputum collection, pentamidine administration and isolation (AII) rooms.

Of rooms where minor surgeries occurred, only 12% meet the ANSI/ASHREA Standard 170 of 15 ACH for procedure rooms. (Refer to Figures 9 and 10). Even if these procedures could be considered “treatment”, only 41% of the rooms met the six ACH standard for treatment rooms.

Figure 9: Distribution Plot of Air Changes per Hour That Meet ANSI Standards by Room Type (Left) and by Procedure Type (Right) (Vertical Lines Indicate ANSI Standards for Exam, Treatment, Aerosol-Generating Procedures and Procedure Rooms).

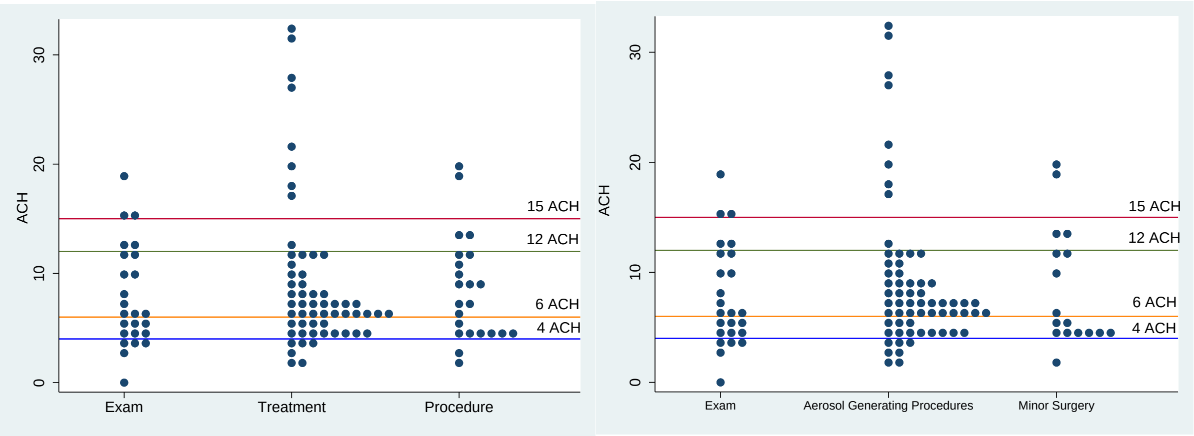
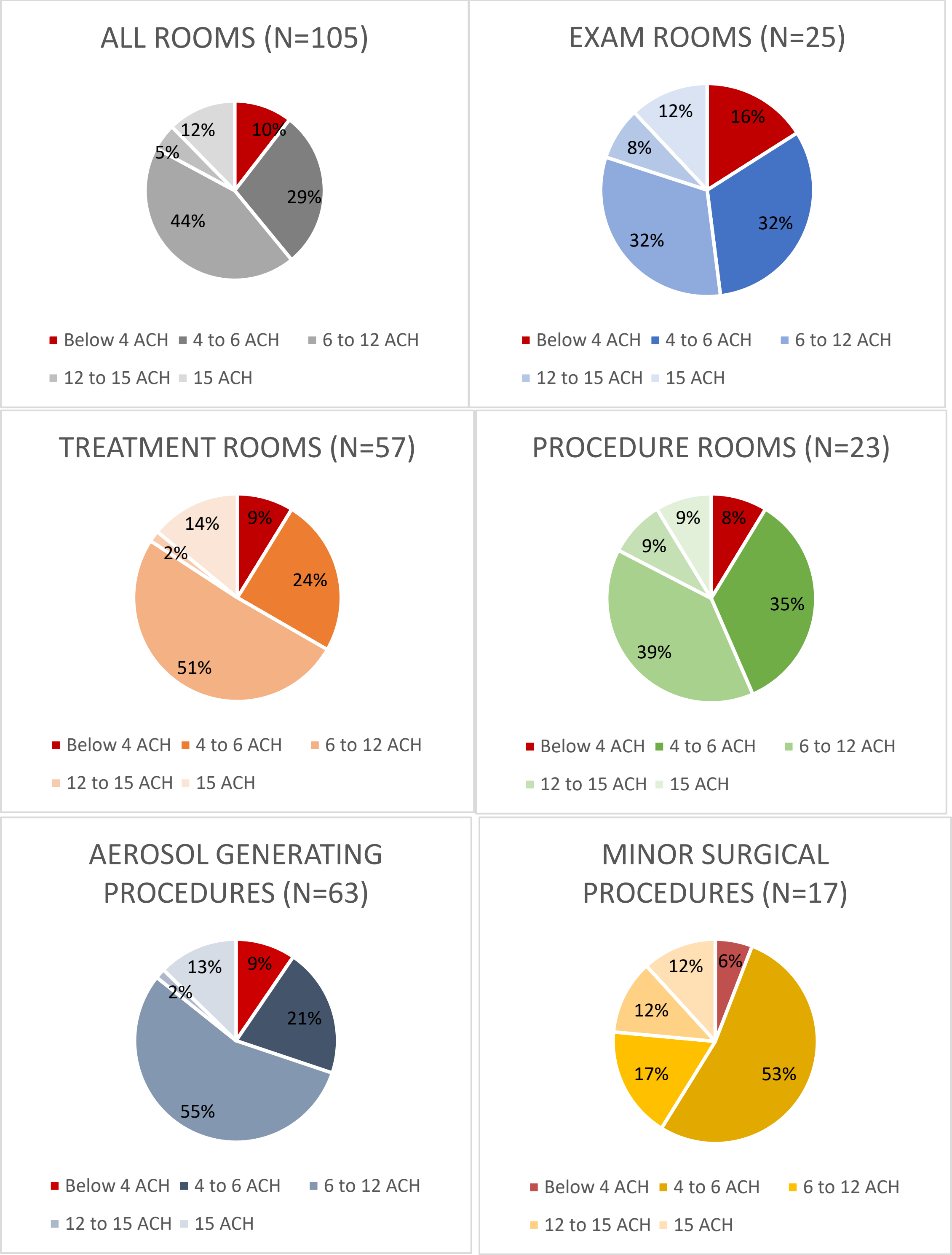


Figure 10: Percentage of Clinic Rooms Meeting the ANSI Standards by Room Type and Procedure Type.



Building Characteristics

Building Types

Forty-two percent of clinic rooms were in clinics located within medical office buildings with a mean air change of 8.8 ACH ± 4.66, median 7.6 ACH, and a range of 1.7 to 17.9 ACH. Twenty-nine percent of clinic rooms were located within shopping center buildings with a mean air change of 6.4 ACH ± 2.86, median 5.9 ACH, and a range of 2.2 to 13 ACH. The remaining 29% of clinic rooms were located within stand-alone buildings with a mean air change of 10.7 ACH ± 8.97, median 6.8 ACH, and a range of 0 to 32.1 ACH. Exam, treatment and procedure rooms were equivalently allocated in medical office buildings but disproportionately favoring treatment rooms in shopping center and stand-alone buildings. Stand-alone clinic rooms had the widest range for ACH (Table 11).

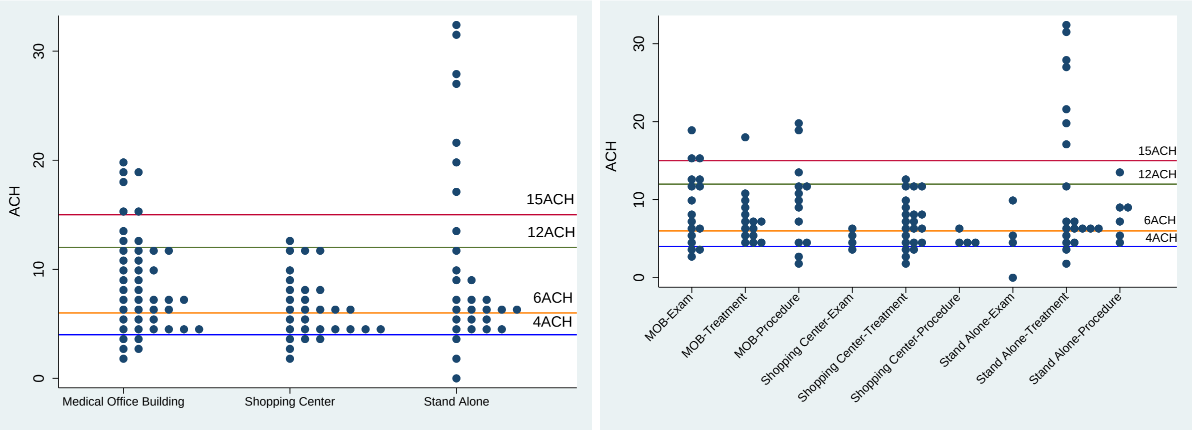
Of the 10% of clinic rooms that did not meet the minimum ANSI/ASHREA Standard 170 of four ACH for general exam rooms, these rooms were equally distributed in the building types (medical office building n=4, shopping center, n=4, and stand-alone n=3) (Figure 11).

There was no statistically significant difference in median ACH and the three building types (medical office building (n=45), shopping centers (n=30) and stand-alone buildings (n=30)), (Kruskal-Wallis test p=0.06). (Appendix 4). Additionally, there was no statistically significant difference in individual ACH between building types (Mixed-effects model, Shopping Center p=0.138 and Stand-alone p=0.678, compared to Medical Office Building) (Appendix 8).

Table 11: Summary Table of Air Changes per Hour by Room Type and Building Type, Kruskal-Wallis test, p>0.05

	Total Rooms	Exam	Treatment	Procedure	Mean ACH	Std. Dev.	Median ACH	Min	Max
Medical Office Building	45	17	15	13	8.8	4.66	7.6	1.7	17.9
Shopping Center	30	4	22	4	6.4	2.86	5.9	2.2	13
Stand-alone	30	4	20	6	10.7	8.97	6.8	0	32.1

Figure 11: Distribution Plot of Air Changes per Hour That Meet ANSI Standards by Building Type (Left) and by Room Type and Building Type (Right) (Vertical Lines Indicate ANSI Standards for Exam, Treatment, Aerosol-Generating Procedures and Procedure Rooms)



Building age

The mean building age was 29 years ± 24.4 years with a range of 3 to 71 years. Stand-alone buildings were the newest built (mean age 20 years) and medical office buildings were the oldest buildings (mean age 39 years). There was no statistically significant difference in median building age and the three building types (medical office building (n=11), shopping centers (n=5) and stand-alone buildings (n=6)), (Kruskal-Wallis test p=0.08) (Appendix 4). Additionally, there was no statistically significant difference in individual ACH between building age (Mixed-effects model, p=0.803) (Appendix 8).

Building Floors

Most stand-alone and shopping centers were single-story buildings, except one stand-alone building clinic which had two floors. The remaining clinics were in multiple floor medical office buildings. The mean building floors per building was 5 floors ± 7.3 with a range of 1 to 33 floors. Medical office buildings had the most floors per building (mean was eleven floors) while shopping centers and stand-alone buildings had 1 floor per building.

There was a statistically significant difference in the number of floors in a building and the three building types (medical office building (n=11), shopping centers (n=5) and stand-alone buildings (n=6)), (Kruskal-Wallis test p=0.0004). A Dunn post-hoc test revealed that the number of building floors was statistically different in the shopping center buildings compared to the medical office buildings (p = 0.0006) and statistically different in the stand-alone buildings compared to the medical office buildings (p = 0.0002). However, there were no statistically significant differences between the stand-alone buildings and shopping center buildings (p =0.4807) (Appendix 4). There was no statistically significant difference in individual ACH between building floor (Mixed-effects model, p=0.201) (Appendix 8).

Clinic Square Feet

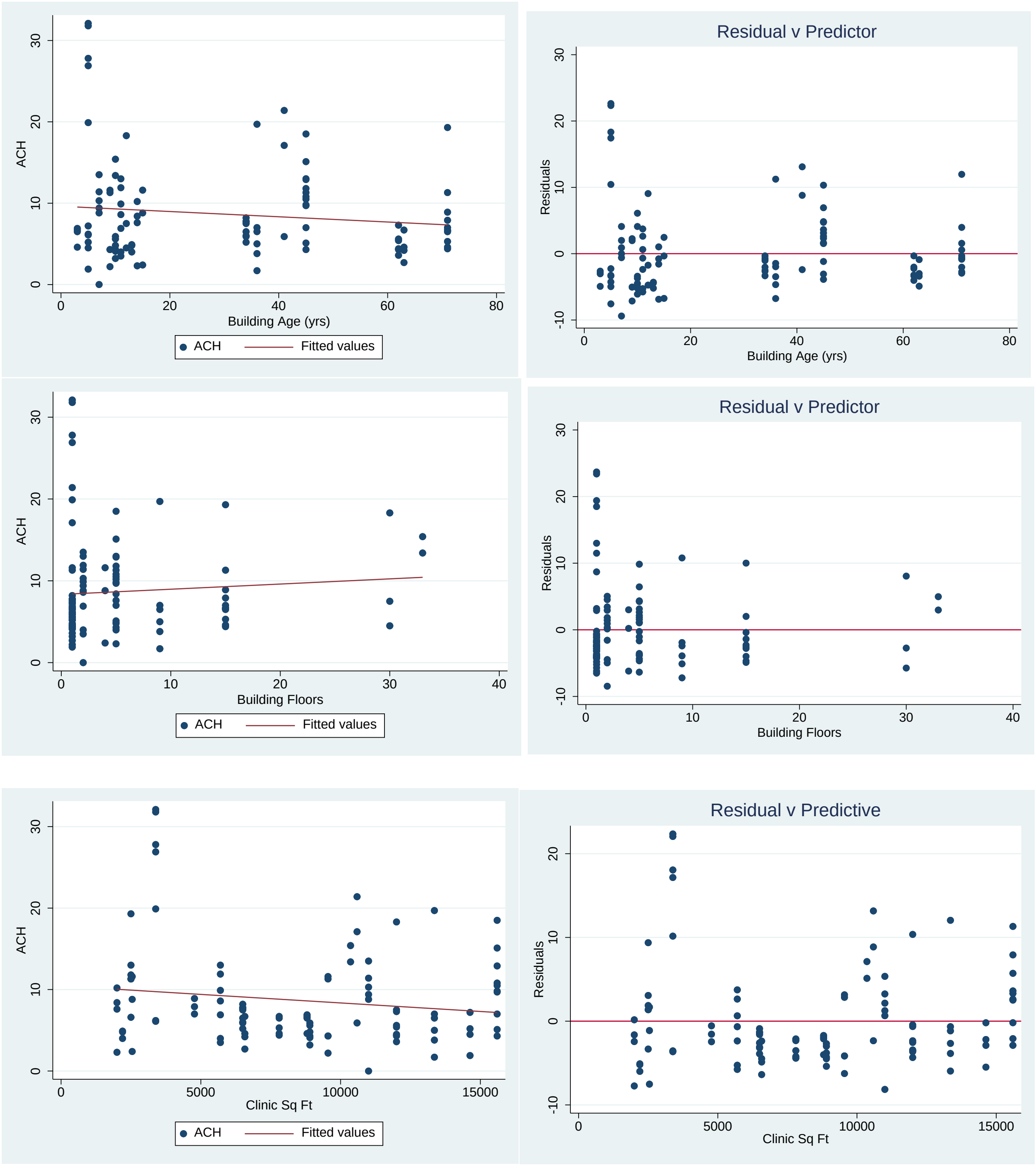
The mean clinic size was 8,475 square feet ± 4,285 with a range of 2,000 to 15,600 square feet. Clinics in medical office buildings ranged from 2,000 to 15,600 square feet, clinics in shopping centers ranged from 5,700 to 9,500 square feet and clinics in stand-alone buildings ranged from 3,385 to 14,630 square feet.

There was no statistically significant difference in clinic square footage and the three building types (medical office building (n=11), shopping centers (n=5) and stand-alone buildings (n=6)), (Kruskal-Wallis test p=0.2478). (Appendix 4). Additionally, there was no statistically significant difference in individual ACH between clinic square footage (Mixed-effects model, p=0.464) (Appendix 8).

Multiple Linear Regression of ACH and Building Variables

There was not a statistically significant relationship between ACH and building age (years) (Prob>F = 0.2049). For each one-year increase in building age, ACH decreased by 0.32 units. There was not a statistically significant relationship between ACH and building floors per building (Prob>F = 0.4407). For each one-floor increase in building floors per building, ACH decreased by 0.63 units. There was not a statistically significant relationship between ACH and clinic square feet (Prob>F = 0.1309). For each one-square foot increase in clinic square feet, ACH decreased by 0.0002 units. (Figure 12 and Appendix 7)

Figure 12: Linear Relationships for ACH and Building Age, Building Floors and Clinic Square Footage (Scatterplot on Left and Residual v Predictor on Right), Multiple linear regression $p<0.05$

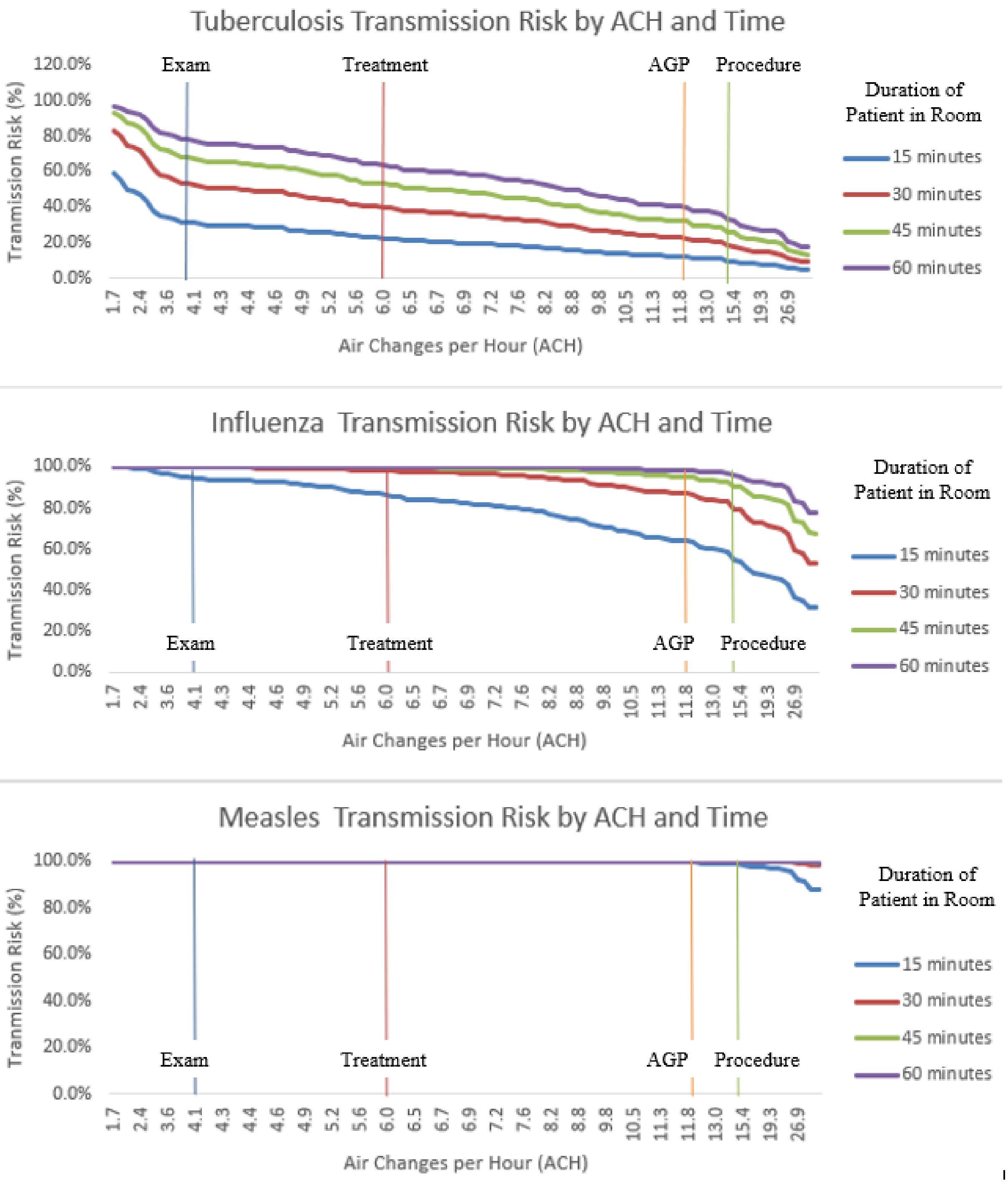


Gammaitoni-Nucci Model for Infectious Disease Transmission

In rooms with a minimum of four ACH, transmission of tuberculosis to susceptible persons in the room for 15 minutes would be 32%, increasing to 78% at one hour. When increased to six ACH, the transmission rate for tuberculosis to susceptible persons decreases to 22% in a 15-minute exposure time, increasing to 64% at one hour. If rooms with 12 ACH are used to provide clinical services to tuberculosis patients, the transmission rate is 12% for 15-minute exposure time, increasing to 41% at one hour.

Transmission of influenza to susceptible persons in the room is 95% in rooms with a minimum of four ACH, 86% in rooms with six ACH, but reduces to 65% in rooms with 12 ACH for a 15-minute exposure time. Transmission increases to at or near 100% after an hour. Transmission of measles only slightly reduces from 100% with 15 AHC. (Figure 13).

Figure 13: Transmission Risk Models Based on Measured ACH and Calculated by the Gammaitoni-Nucci Model (ANSI Healthcare Ventilation Standards for Exam, Treatment, Aerosol-Generating Procedures (AGP) and Procedure Rooms Demarked Vertically)



DISCUSSION

The results obtained from this study characterized the procedure types and use of clinical space for a small sample of outpatient clinic facilities. Overall, the results indicate that the outpatient clinics do not fully meet healthcare ventilation standards as listed in the Standard 170 for Ventilation in Health Care Facilities. Additional ventilation measurements and observations of air movement in these clinic rooms proved to be indicators of air changes per hour. Building characteristics were evaluated and found to not be determinants of ventilation rates. Lastly, the observed ventilation rates were used to estimate infectious disease transmission risk in the outpatient-clinic setting. These coalesced results indicated that a greater number of outpatient clinics in equivalent settings across the United States are likely not be meeting healthcare ventilation standards. Thus, these settings may have an increased risk of transmission of infectious diseases due to the lack of ventilation.

Air measurements

This study confirmed that the included outpatient clinic settings are not designed to supply ventilation rates based on the types of procedures or services provided in specific rooms, even though the procedures being performed in these settings are increasingly complex and represent a potentially higher risk of infection (Tidy, 2016). While room measurements were consistent from day to day, there was no difference in air change per hour (ACH) by room type or by treatment or procedures performed. CO_2 measurements and air mixing rates can be used as indicators of ACH. With increased air change rates, CO_2 levels are not allowed to crest at levels that could impact the health of persons occupying the room. In addition, as air change rates increase, time for smoke to disperse decreases, resulting in better air mixing.

Outpatient clinic rooms in this study do not align with design recommendations for healthcare airflow in that air did not flow from the ceiling to the healthcare worker, then to the patient, but rather from the supply to the door and/or return with no consideration of the path to or from the patient to the healthcare worker. In addition, the exhaust or return was never located on the floor, but always in the ceiling (Yaun, 2018). In addition, no directional airflow observations were associated with a particular room type.

Not all clinic rooms exhibited continuous airflow, but the air supply cycled on and off. This situation not only made measurements difficult to obtain but indicated a peaked ACH for a limited time period before declining back to 0 ACH. In addition, these rooms were used for a variety of services (exam, treatment, aerosol-generating procedures and minor surgeries), potentially increasing the risk of disease transmission.

ANSI/ASHRAE 170 Standard

From all rooms evaluated in this study, 90% met the ANSI/ASHRAE 170 minimum standard for general exam rooms (4 ACH). If these rooms are used for any additional treatments or procedures, only 61% met the minimum standard for treatment rooms (6 ACH). If aerosol-generating procedures were to be performed in these rooms, only 17% would meet the minimum standard of 12 ACH, which is a concern. Similarly, if any surgeries, needing a sterile field or sterile instruments, were conducted in these rooms, only 12% would meet the minimum standard of 15 ACH. Lower ACH in outpatient clinic rooms conducting more advanced procedures can lead to an increased risk of spread of infectious diseases. This study echoes the concern that ventilation standards are not being met and should be integrated into clinic design and reaffirms that there are challenges in compliance with ventilation standards in non-hospital settings (Banse *et al*, 2014 & 2015).

Building Characteristics

Building characteristics, age, number of floors and clinic square footage, were not associated with air changes per hour (ACH). However, variation in ACH was observed by type of building. Clinic rooms in stand-alone buildings had higher ACH than rooms in shopping centers or medical office buildings. Stand-alone buildings were newer than the other building types and similar to shopping center buildings in having fewer floors than medical office buildings. In addition, clinics established in stand-alone and shopping center buildings had more rooms used as treatment rooms, while clinics in medical office buildings segregated general exam rooms and specific procedure rooms from treatment rooms.

The majority of the clinics studied were in leased spaces such as in medical office buildings or shopping centers. In these cases, the building owner is responsible for setting the ventilation for the leased clinical space. Engineers determine the cubic feet per meter needed for each room, based on general business occupancy standards, mechanical plans, and square footage. Consideration for the intended use and services provided for the individual clinic rooms is not incorporated into setting the ventilation rates in leasing contracts.

Disease Transmission Risk

While not all transmission risk can be reduced by ventilation, such as with measles, it can aid in reducing the risk of transmission for tuberculosis and influenza. The infectious disease transmission models based on the ACH values in this study, created from the Gammatoni-Nucci Model, indicated that outpatient clinic rooms would facilitate transmission rather than protect workers and patients when ACH does not meet the ventilation standard based on procedures performed in the rooms. Increased ventilation along with personal protective equipment is the best practice to reduce transmission of infectious diseases in any healthcare setting.

An additional concern is the increasing role outpatient clinics play in response to evaluating persons under investigation (PUI) during outbreaks of emerging infectious diseases. These responses commonly recommend patient evaluations be conducted in a negative pressure isolation room, required to have 12 ACH. When working in outpatient clinic space with a lower than minimum standard ACH, the ability to safely perform assessments and potential care to a PUI may inadvertently increase the risk to workers and the potential spread of the disease within the clinic.

Limitations

Several limitations are inherent to this study. Clinics that had cycled air instead of continuous airflow may have observed ACH levels that do not reflect the airflow at any given time of the day, but rather the airflow in those rooms is near zero until the air supply turns on and then may be on for a fixed time before returning to zero. Due to the majority of the clinics being in leased space, access to the main ventilation system was not possible. Therefore, the study was designed to measure ventilation within the clinic space without measuring ventilation rates for the entire building. Statistical analysis for building variables may have bias due to repeated observations for building age, floors and square footage since may clinic rooms were within the same clinic or building. As many clinics share space with multiple specialties throughout the week, multiple procedures are performed in the same rooms, making the rooms difficult to categorize. Due to the nature of outpatient visits, it is difficult to track nosocomial infections and disease spread from exposure in the outpatient clinic which would support the infectious disease transmission risk modeling.

Future Studies

Future studies assessing the ventilation of outpatient clinics could possibly explore each clinic specifically to determine the needs based on procedures specific to clinical specialties and differences in ventilation rates by room within the clinic. As there is a large retail market for medical office buildings and a majority of the study population of clinics were located within medical office buildings, ventilation assessments could be done to model airflow within the building system, assessing HVAC zoning and direct measurements from the HVAC system. As was done in our study, these future studies should analyze data with the mixed-effects model when measurements are repeated within the dataset. This study was unable to access patient and employee health records; however, future studies could track outpatient visits with infectious diseases, ventilation rates, length of visit, and follow employee health records to better evaluate real-time transmission. To aid in future studies, a phone application could be generated to calculate ACH for clinic rooms, based on ventilation measurements (CFM) and room volume. The application would allow for quick determination if the ventilation is sufficient to meet the ventilation standards based on the services provided in the clinic room and the estimated risk of transmission of tuberculosis, influenza, and measles.

CONCLUSION

This study found that a subset of outpatient clinics, operating in business occupancy settings, may be conducting procedures in rooms with ventilation rates below those defined in national standards for healthcare settings. Overall, 11 of 105 clinic rooms did not meet the minimum requirement for general exam rooms, 41 of 105 did not meet the requirement for treatment rooms, 87 of 105 did not meet the requirement for aerosol-generating procedures and 92 of 105 did not meet the requirement for procedure rooms or minor surgical procedures. If this study is representative of outpatient clinics in general, it is projected that 10% of all clinic rooms would not meet the minimum requirements for general exam rooms, 40% would not meet the requirements for treatment rooms and over 80% performing more advanced procedures, including aerosol-generating and minor surgeries, would not meet the higher standards set by ANSI/ASHRAE. In some cases, outpatient clinic rooms were not designed for the specialized procedures they are performing, and therefore, are not meeting the ventilation standards for these procedures. Lower ACH in outpatient clinic rooms conducting more advanced procedures could lead to an increased risk of spread of infectious diseases and constrain patient care when evaluating persons of interest for emerging infectious diseases. While lower air change rates were observed in all building types, the observation that newer built, one-story stand-alone buildings had higher air change rates compared to the other building types, may be due to better control of the ventilation system. National ventilation standards should be considered for all healthcare settings and factored into clinic design and clinic lease agreements, which is not currently the case, as determined by this study. Air changes per hour for a space should be determined on the basis of a risk assessment of the procedures being performed in the space and clinics should evaluate air ventilation per room to reduce infectious disease transmission risks while designing, building or remodeling outpatient clinic spaces.

APPENDICES

Appendix 1: Letter of Support

TO: Robert Emery, DrPH, CSP
Professor of Occupational
Health
The University of Texas School of Public Health

FROM: Tracy Fry-Longoria,
Chief Ambulatory Officer

DATE: 12/15/2018

RE: Support for Ms. Kristin King's Doctoral Research Proposal

I am writing on behalf of the leadership team of clinical practice group [redacted] to express our endorsement for Ms. Kristin King's proposal to conduct an assessment of our clinics ventilation rates and airflow. Our clinical practice group consists of more than 100 clinical sites with more than 80 medical specialties and sub-specialties.

We have partnered with the [redacted] to provide a healthy and safe environment for our workers and patients.

Once Ms. King's research proposal is approved through the necessary university review boards, she will have access to the clinical space needed for the assessment. Once the data is collected and analyzed we will arrange for her to make a presentation to describe her findings and recommendations.

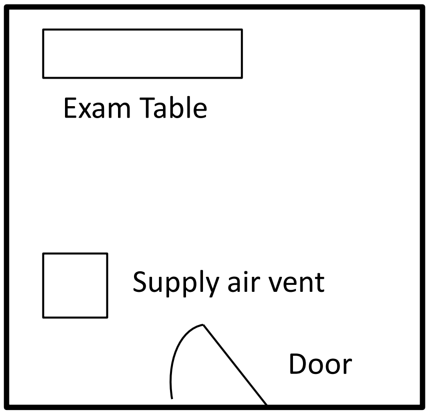
Tracy Fry-Longoria
Chief Ambulatory Officer

CC: Andrew Casas, CEO

Appendix 2: Clinic Data Collection Sheets

Clinic #	**Specialty**	**Room Category**	**Procedures Performed**	**Building Category**	**Age**	**Floors**	**Occupancy**

	Length (ft)	**Width (ft)**	**Height (ft)**	**Room Volume (ft^3)**	
Date/Time	**CFM (1)**	**CFM (2)**	**CFM (3)**	**CFM Avg (A)**	**ACH (A)**
Date/Time	**CFM (4)**	**CFM (5)**	**CFM (6)**	**CFM Avg (B)**	**ACH (B)**
Date/Time	**CFM (7)**	**CFM (8)**	**CFM (9)**	**CFM Avg (C)**	**ACH (C)**



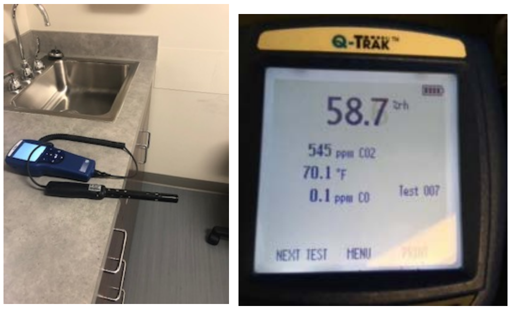
Date/Time	**Mixing Time**	**Direction Supply**	**Direction Door**	**Direction Table**
Date/Time	**Mixing Time**	**Direction Supply**	**Direction Door**	**Direction Table**
Date/Time	**Mixing Time**	**Direction Supply**	**Direction Door**	**Direction Table**

Appendix 3: Air Measurement Pictures

Picture 1: Square Diffuser (left) and Slot Diffuser (Right)

Picture 2: Alnor Balometer Set-up and Measurement Using 2x2 Capture Hood (Left) and Slot Capture Hood (Right)

Picture 3: Q-TRAK CO_2 Measurement



Appendix 4: Kruskal-Wallis test

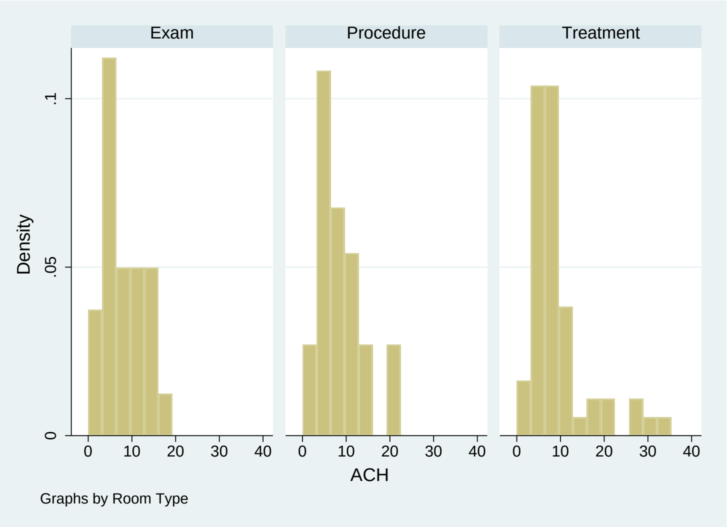
Kruskal-Wallis test was used to show any difference in median ACH among categories of rooms, procedures and building types and any difference among continuous building variables and building types.

ACH by Room type

Shapiro-Wilk W test was used to test for normality. by roomtype, sort : swilk ach

Variable (ACH)	Obs	W	V	z	Prob>z
Exam	25	0.94403	1.555	0.903	0.18336
Treatment	57	0.74120	13.503	5.594	0.0000
Procedure	23	0.91733	2.162	1.568	0.05841

Since the probability is less than 0.05, it is not normally distributed.



Kruskal-Wallis equality-of-populations rank test kwallis ach, by(room type)

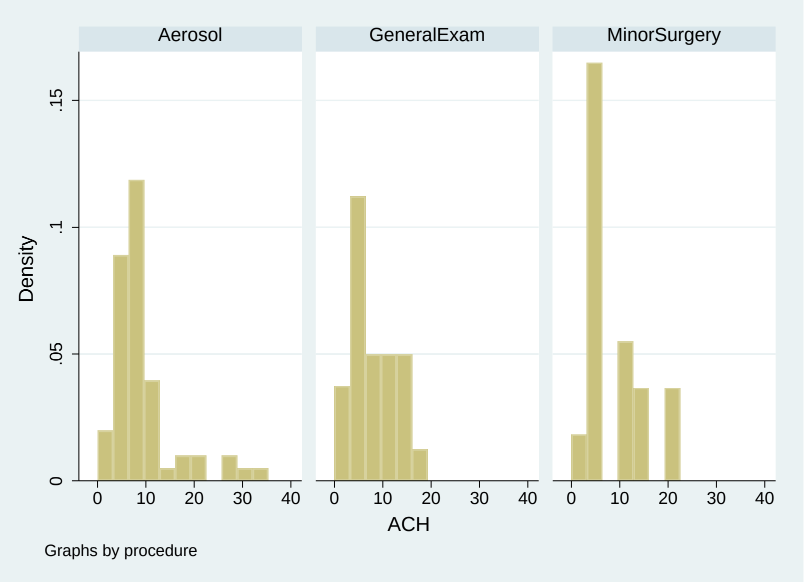
Room type	Obs	Rank Sum
Exam	25	1262.50
Treatment	57	3070.50
Procedure	23	1232.00
Chi-squared = 0.223 with 2 d.f.		
Probability = 0.8946		

ACH by Procedure Type

Shapiro-Wilk W test was used to test for normality. by procedure, sort : swilk ach

Variable (ACH)	Obs	W	V	z	Prob>z
General Exam	25	0.94403	1.555	0.903	0.18336
Aerosol Generating	63	0.74722	14.289	5.749	0.0000
Minor Surgery	17	0.8524	3.118	2.268	0.01167

Since the probability is less than 0.05, it is not normally distributed.



Kruskal-Wallis equality-of-populations rank test kwallis ach, by(procedure)

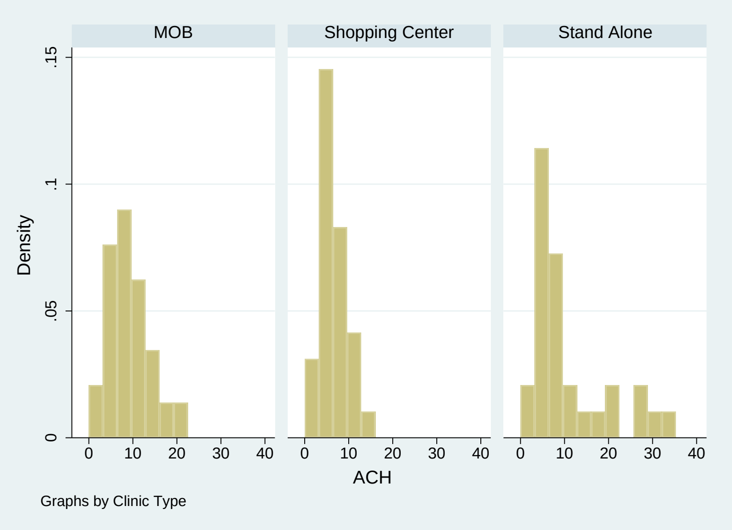
Procedure type	Obs	Rank Sum
General Exam	25	1262.00
Aerosol Generating	63	3459.00
Minor Surgery	17	843.50
Chi-squared = 0.625 with 2 d.f.		
Probability = 0.7318		

ACH By Building Type

Shapiro-Wilk W test was used to test for normality. by clinictype, sort : swilk ach

Variable (ACH)	Obs	W	V	z	Prob>z
Medical office building	45	0.93549	2.794	2.177	0.01473
Shopping center	30	0.92932	2.247	1.674	0.4710
Stand alone	30	0.80586	6.171	3.763	0.0008

Since the probability is less than 0.05, it is not normally distributed.



Kruskal-Wallis equality-of-populations rank test kwallis buildingageyrs, by(clinictype)

Building type	Obs	Rank Sum
Medical office building	45	2596.00
Shopping center	30	1260.50
Stand alone	30	1708.50
Chi-squared = 5.473 with 2 d.f.		
Probability = 0.0648		

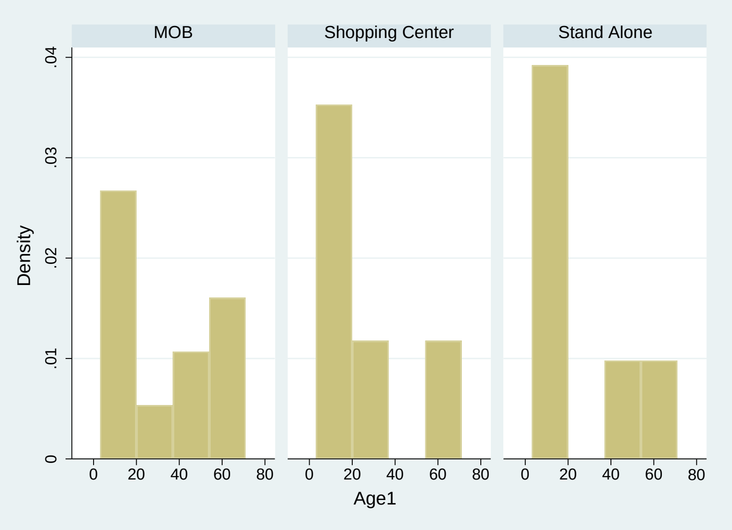
Building Age by Building Type

(To reduce repeated measures, clinic data was used, not by room)

Shapiro-Wilk W test was used to test for normality. by clinictype, sort : swilk buildingageyrs

Building age	Obs	W	V	z	Prob>z
Medical office building	11	0.93667	1.025	0.045	0.48214
Shopping center	5	0.78934	2.487	1.505	0.06615
Stand alone	6	0.76754	2.879	1.889	0.02942

Since the probability is greater than 0.05, it is normally distributed. But does not meet the other assumptions for one-Way ANOVA



Kruskal-Wallis equality-of-populations rank test kwallis buildingageyrs, by(clinictype)

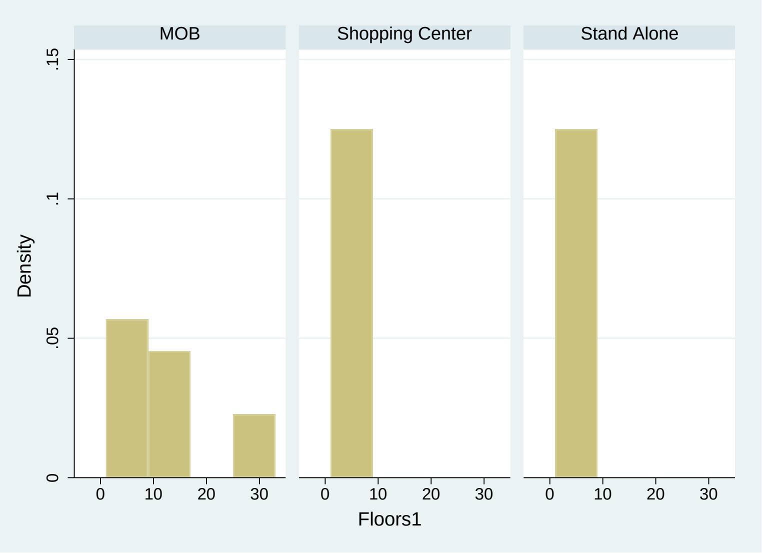
Building type	Obs	Rank Sum
Medical office building	11	158.50
Shopping center	5	51.50
Stand alone	6	43.00
Chi-squared = 5.050 with 2 d.f.		
Probability = 0.08		

Building Floors by Building Type

Shapiro-Wilk W test was used to test for normality. by clinictype, sort : swilk buildingfloors

Building floors	Obs	W	V	z	Prob>z
Medical office building	11	0.83255	2.711	1.956	0.02522
Shopping center	5	0.77083	2.705	1.686	0.04588
Stand alone	6	0.63295	4.546	3.055	0.00112

Since the probability is less than 0.05, it is not normally distributed.



Kruskal-Wallis equality-of-populations rank test kwallis buildingfloors, by(clinictype)

Building type	Obs	Rank Sum
Medical office building	11	187.00
Shopping center	5	30.50
Stand alone	6	35.50
Chi-squared = 15.785 with 2 d.f.		
Probability = 0.0004		

Dunn test

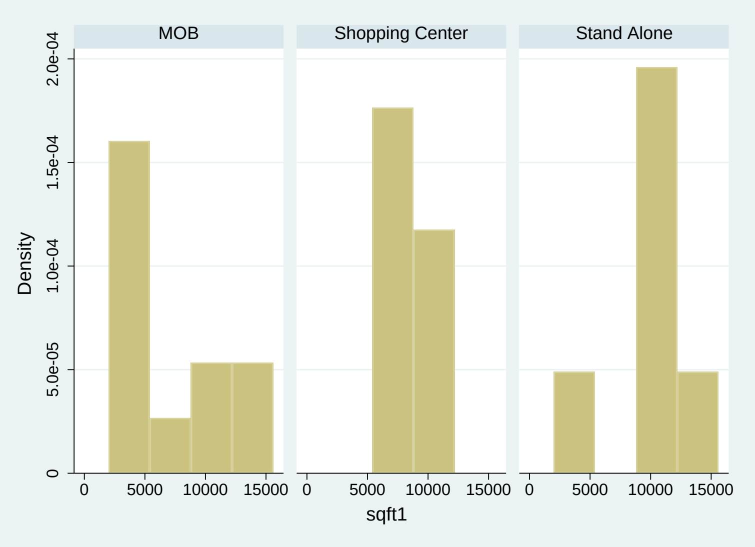
	Medical office building	Shopping center
Shopping center	0.0006	
Stand alone	0.0002	0.4807

Clinic Square Feet by Building Type

Shapiro-Wilk W test was used to test for normality. by clinictype, sort : swilk clinicsqft

Clinic square feet	Obs	W	V	Z	Prob>z
Medical office building	11	0.84761	2.467	1.754	0.03972
Shopping center	5	0.87591	1.465	0.550	0.29118
Stand alone	6	0.92646	0.911	-0.133	0.55306

Since the probability is less than 0.05, it is not normally distributed.



Kruskal-Wallis equality-of-populations rank test kwallis clinicsqft, by(clinictype)

Building type	Obs	Rank Sum
Medical office building	11	108.50
Shopping center	5	54.00
Stand alone	6	90.50
Chi-squared = 2.584 with 2 d.f.		
Probability = 0.2748		

Appendix 5: Linear regression for Air Measurements

CO_2

Source	SS	df	MS	Number of obs = 105
Model	207.167368	1	207.167368	F (1, 103) = 5.93
Residual	3601.09207	103	34.9620589	Prob > F = 0.0166
Total	3808.25943	104	36.6178792	R-squared = 0.0544
				Adj R-squared = 0.0452
				Root MSE = 5.9129

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
co2	.0085429	.0035095	2.43	0.017	.0015827	.0155032
_cons	3.543629	2.186781	1.62	0.108	-.7933351	7.880593

Air Mixing

Source	SS	df	MS	Number of obs = 105
Model	1302.99042	1	1302.99042	F (1, 103) = 53.37
Residual	2505.26902	103	24.3230002	Prob > F = 0.0000
Total	3808.25943	104	36.6178792	R-squared = 0.3421
				Adj R-squared = 0.3358
				Root MSE = 4.9318

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
airmixing	-.3974571	.0543036	-7.32	0.000	-.5051554	-.2897588
_cons	17.42783	1.288704	13.52	0.000	14.87199	19.98367

Appendix 6: Fisher Exact Tests for Air Direction by Room Type

Fisher’s Exact test was selected as statistical method to find the association between two categorical variables when the same size per cell may be less than 5.

Directional airflow at supply vent

Enumerating sample-space combinations:				
Stage 5: enumerations = 1				
Stage 4: enumerations = 6				
Stage 3: enumerations = 39				
Stage 2: enumerations = 165				
Stage 1: enumerations = 0				
Air Supply	Room Type			Total
	Exam	Treatment	Procedure	
Towards Door	14	43	15	72
Towards Patient	8	9	4	21
To Floor	1	1	2	4
Along Ceiling	0	1	1	2
No Movement	2	3	1	6
Total	25	57	23	105
Fisher’s exact = **0.419**				

Directional airflow at clinic room door

Enumerating sample-space combinations:				
Stage 3: enumerations = 1				
Stage 2: enumerations = 7				
Stage 1: enumerations = 0				
Air Door	Room Type			Total
	Exam	Treatment	Procedure	
Into Room	17	48	17	82
Out of Room	8	9	6	23
Total	25	57	23	105
Fisher’s exact = **0.210**				

Directional airflow at Patient

Enumerating sample-space combinations:				
Stage 5: enumerations = 1				
Stage 4: enumerations = 8				
Stage 3: enumerations = 62				
Stage 2: enumerations = 299				
Stage 1: enumerations = 0				
Air Supply	Room Type			Total
	Exam	Treatment	Procedure	
Towards Door	11	29	9	49
Towards Return	4	4	3	11
To Floor	1	4	2	7
Along Ceiling	0	2	2	4
No Movement	9	18	7	34
Total	25	57	23	105
Fisher’s exact = **0.770**				

Return Placement by Room Type

Enumerating sample-space combinations:				
Stage 5: enumerations = 1				
Stage 4: enumerations = 3				
Stage 3: enumerations = 58				
Stage 2: enumerations = 688				
Stage 1: enumerations = 0				
Return Placement	Room Type			Total
	Exam	Treatment	Procedure	
At Door	16	41	14	71
Near	0	4	3	7
No Return Present	6	5	5	16
Opposite Door	3	7	1	11
Total	25	57	23	
Fisher’s exact = **0.215**				

Appendix 7: Linear regression for building variables

To build the multiple regression analysis for building variables, first each building variable was tested for correlation with the ACH by simple linear regression. Variables with a p-value of 0.2 or less were used in in linear regression model in a stepwise fashion to determine which variables were statistically significant at a p-value of 0.05. Goodness of fit test included.

ACH and Building Age

Source	SS	df	MS	Number of obs = 105
Model	59.2553915	1	59.2553915	F (1, 103) = 1.63
Residual	3749.00404	103	36.3980975	Prob > F = 0.2049
Total	3808.25943	104	36.6178792	R-squared = 0.0156
				Adj R-squared = 0.0060
				Root MSE = 6.0331

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
buildingageyrs	-.322363	0.252651	-1.28	0.205	-.0823436	0.17871
_cons	9.626149	.9480229	10.15	0.000	7.745969	11.50633

ACH and Building Floors

Source	SS	df	MS	Number of obs = 105
Model	22.0173561	1	22.0173561	F (1, 103) = 0.60
Residual	3786.24208	103	36.7596318	Prob > F = 0.4407
Total	3808.25943	104	36.6178792	R-squared = 0.0058
				Adj R-squared = -0.0039
				Root MSE = 6.063

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
buildingfloors	0.632743	0.817581	0.77	0.441	-0.988735	.2254222
_cons	8.340632	.7350001	11.35	0.000	6.882933	9.798332

ACH and Clinic Square Feet

Source	SS	df	MS	Number of obs = 105
Model	82.8328197	1	83.8328197	F (1, 103) = 2.32
Residual	3724.42661	103	36.1594817	Prob > F = 0.1309
Total	3808.25943	104	36.6178792	R-squared = 0.0220
				Adj R-squared = 0.0125
				Root MSE = 6.0133

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
clinicsqft	-.0002095	.0001376	-1.52	0.131	-.0004824	.0000634
_cons	10.45383	1.305548	8.01	0.000	7.864583	13.04308

Multiple regression for building variables

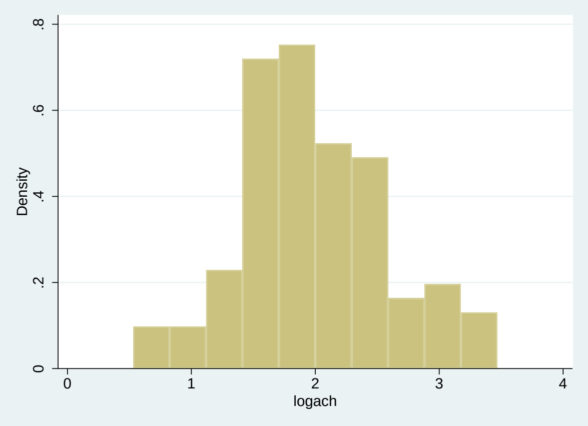
The only variables with p <=0.2 were building age years and clinic square footage.

Source	SS	df	MS	Number of obs = 105
Model	131.766049	2	65.8830246	F (1, 103) = 1.83
Residual	3676.49339	102	36.0440528	Prob > F = 0.1660
Total	3808.25943	104	36.6178792	R-squared = 0.0346
				Adj R-squared = 0.0157
				Root MSE = 6.0037

ach	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
buildingageyrs	-.029105	.0252386	-1.15	0.252	-.0791657	.0209557
Clinicsqft	-.0001956	.0001379	-1.42	0.159	-.0004691	.0000779
_cons	11.19189	1.452113	7.71	0.000	8.311629	14.07215

Appendix 8: Mixed-effects models for ACH

Transforming ACH to normal distribution.
gen logach = log(ach)
histogram logach



Mixed-effects model to compare the individual ACH measurements (room)

ACH by Room type
mixed logach i.roomtypecode || clinic:

Iteration 0: log likelihood = -86.131828					
Iteration 1: log likelihood = -86.131828					
Mixed-effect ML regression		Number of obs = 104			
Group Variable: **Clinic**		Number of groups = 22			
Obs per group:			Min = 2		
			Avg = 4.7		
			Max = 10		
Log Likelihood = -86.131828		Wald chi2(2) = 0.37			
		Prob > chi2 = 0.8310			
Logsqrtach	Coef.	Std. Err.	z	P>|z|	95% Conf Interval
Roomtypecode					
Treatment	-0.096061	0.1597226	-0.60	0.548	-0.4091119 0.2169892
Procedure	-0.037153	0.149385	-0.25	0.804	-0.3299427 0.2556357
_cons	2.042098	0.1379517	14.8	0.000	1.771718 2.312478
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval
Clinic: Identity Var(_cons)			0.1162919	0.0528739	0.0477021 0.2835056
Var(Residual)			0.2404937	0.0375556	0.1770841 0.3266086

LR test vs. linear model: chibar2(01) = 15.31 Prob >= chibar2 = 0.0000

ACH by Procedure type mixed logach i.proceduretypecode || clinic:

Iteration 0: log likelihood = -86.199543						
Iteration 1: log likelihood = -86.199543						
Mixed-effect ML regression		Number of obs = 104				
Group Variable: **Clinic**		Number of groups = 22				
Obs per group:			Min = 2			
			Avg = 4.7			
			Max = 10			
Log Likelihood = -86.199543		Wald chi2(2) = 0.22				
		Prob > chi2 = 0.8937				
Logsqrtach	Coef.	Std. Err.	z	P>|z|	95% Conf Interval	
Proceduretypecode						
Aerosol Generating	-0.693196	0.1471422	-0.47	0.638	-0.3577131	0.21907
Minor Surgery	-0.047907	0.1685391	-0.28	0.776	-0.3782379	0.28242
_cons	2.032341	0.1357406	14.97	0.000	1.766294	2.298388
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval	
Clinic: Identity Var(_cons)			0.1137687	0.0515813	0.0467841	0.2766605
Var(Residual)			0.2417321	0.037645	0.1781462	0.3280137

LR test vs. linear model: chibar2(01) = 15.04 Prob >= chibar2 = 0.0001

ACH by Building type mixed logach i.clinictypecode || clinic:

Iteration 0: log likelihood = -84.797599						
Iteration 1: log likelihood = -84.797599						
Mixed-effect ML regression		Number of obs = 104				
Group Variable: **Clinic**		Number of groups = 22				
Obs per group:			Min = 2			
			Avg = 4.7			
			Max = 10			
Log Likelihood = -84.797599		Wald chi2(2) = 3.24				
		Prob > chi2 = 0.1979				
Logsqrtach	Coef.	Std. Err.	z	P>|z|	95% Conf Interval	
Proceduretypecode						
Shopping Center	-0.298829	0.2016866	-1.48	0.138	-0.694128	0.0964691
Stand-alone	0.0810801	0.1950766	0.42	0.678	-0.301263	0.4634232
_cons	2.035418	0.1194316	17.04	0.000	1.801336	2.269499
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval	
Clinic: Identity Var(_cons)			0.0899041	0.0440919	0.0343813	0.2350913
Var(Residual)			0.2431103	0.0377744	0.179285	0.3296575

LR test vs. linear model: chibar2(01) = 11.44 Prob >= chibar2 = 0.0004

ACH by Building age mixed logach buildingageyrs || clinic:

Iteration 0: log likelihood = -86.278924					
Iteration 1: log likelihood = -86.278924					
Mixed-effect ML regression		Number of obs = 104			
Group Variable: **Clinic**		Number of groups = 22			
Obs per group:			Min = 2		
			Avg = 4.7		
			Max = 10		
Log Likelihood = -86.278924		Wald chi2(2) = 0.06			
		Prob > chi2 = 0.8029			
Logsqrtach	Coef.	Std. Err.	z	P>|z|	95% Conf Interval
buidindingageyrs	-0.000903	0.0036205	-0.25	0.803	-0.007999 0.006192
_cons	2.01033	0.1381909	14.55	0.000	1.739484 2.281182
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval
Clinic: Identity Var(_cons)			0.109986	0.0505235	0.0447021 0.270612
Var(Residual)			0.2434991	0.0379108	0.1794619 0.330386

LR test vs. linear model: chibar2(01) = 14.61 Prob >= chibar2 = 0.0001

ACH by Building floors mixed logach buildingfloors || clinic:

Iteration 0: log likelihood = -85.503313					
Iteration 1: log likelihood = -85.503313					
Mixed-effect ML regression		Number of obs = 104			
Group Variable: **Clinic**		Number of groups = 22			
Obs per group:			Min = 2		
			Avg = 4.7		
			Max = 10		
Log Likelihood = -85.503313		Wald chi2(2) = 1.46			
		Prob > chi2 = 0.2006			
Logsqrtach	Coef.	Std. Err.	Z	P>|z|	95% Conf Interval
buidindingfloors	0.0130939	0.0102309	1.28	0.201	-0.0069584 0.033146
_cons	1.900674	0.1071693	17.74	0.000	1.690626 2.110722
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval
Clinic: Identity Var(_cons)			0.1041634	0.0471266	0.0429148 0.252827
Var(Residual)			0.2414159	0.037325	0.1783033 0.326867

LR test vs. linear model: chibar2(01) = 15.22 Prob >= chibar2 = 0.0000

ACH by Clinic square footage mixed logach clinicsqft || clinic:

Iteration 0: log likelihood = -86.046227					
Iteration 1: log likelihood = -86.046227					
Mixed-effect ML regression		Number of obs = 104			
Group Variable: **Clinic**		Number of groups = 22			
Obs per group:			Min = 2		
			Avg = 4.7		
			Max = 10		
Log Likelihood = -86.046227		Wald chi2(2) =0.54			
		Prob > chi2 = 0.4637			
Logsqrtach	Coef.	Std. Err.	Z	P>|z|	95% Conf Interval
clinicsqft	-0.000015	0.0000205	-0.73	0.464	-0.0000551 0.0000251
_cons	2.103991	0.1857398	11.33	0.000	1.739948 2.468035
Random-effects Parameter			Estimate	Std. Err.	95% Conf Interval
Clinic: Identity Var(_cons)			0.1061194	0.0493077	0.0426864 0.2638152
Var(Residual)			0.2436631	0.0379195	0.1795783 0.330536

LR test vs. linear model: chibar2(01) = 14.39 Prob >= chibar2 = 0.0001

Appendix 9: Numerical Data

Room #	Clinic #	Specialty	Room Type	Procedure Classification	Procedure Type	ACH	SD	CO2	SD
1	1	Pediatrics	Treatment	AGP	Nebulized Medications	27.8	0.39	912	140
2	1	Pediatrics	Treatment	AGP	Nebulized Medications	31.8	0.39	798	7
3	1	Pediatrics	Treatment	AGP	Nebulized Medications	32.1	0.10	793	29
4	1	Pediatrics	Treatment	AGP	Nebulized Medications	19.9	0.13	773	25
5	1	Pediatrics	Treatment	AGP	Nebulized Medications	26.9	0.56	814	27
6	1	Pediatrics	Treatment	AGP	Nebulized Medications	6.2	1.28	962	139
7	1	Pediatrics	Treatment	AGP	Nebulized Medications	6.1	1.12	964	168
8	2	Multispecialty	Procedure	AGP	FNA/Derm/Neb Medication	9.7	0.17	513	33
9	2	Multispecialty	Procedure	AGP	FNA/Derm/Neb Medication	10.8	0.25	488	20
10	2	Multispecialty	Treatment	AGP	FNA/Derm/Neb Medication	10.5	0.34	515	29
11	2	Multispecialty	Exam	GE	General Exam	12.9	0.46	504	48
12	2	Multispecialty	Exam	GE	General Exam	15.1	0.26	506	36
13	2	Multispecialty	Treatment	MS	Biopsy	9.8	0.38	532	28
14	2	Multispecialty	Exam	GE	General Exam	18.5	0.55	528	24
15	2	Multispecialty	Treatment	AGP	Pulmonary/FNA/Derm	5.1	0.11	540	31
16	2	Multispecialty	Treatment	AGP	Pulmonary/FNA/Derm	7	0.22	513	42
17	2	Multispecialty	Treatment	AGP	Pulmonary/FNA/Derm	4.3	0.12	515	38
18	3	Multispecialty	Procedure	AGP	Biopsy, Suction Airways	7.2	0.11	460	38
19	3	Multispecialty	Treatment	AGP	Suction Airways	1.9	0.13	473	50
20	3	Multispecialty	Exam	GE	General Exam	5.2	0.11	490	59
21	3	Multispecialty	Exam	GE	General Exam	4.5	0.10	489	58
22	4	Multispecialty	Procedure	MS	Colposcopy	4.3	0.1	618	237
23	4	Multispecialty	Exam	GE	General Exam	4.8	0.37	715	55
24	4	Multispecialty	Procedure	MS	FNA	4.1	0.19	683	24
25	4	Multispecialty	Exam	GE	General Exam	3.2	0.12	675	40
26	4	Multispecialty	Exam	GE	General Exam	5.9	0.44	677	53
27	4	Multispecialty	Exam	GE	General Exam	5.6	0.19	588	13
28	5	Community Based	Treatment	AGP	ID, Neb, TB	13	0.2	677	131
29	5	Community Based	Treatment	AGP	ID, Neb, TB	11.9	0.54	592	45
30	5	Community Based	Treatment	AGP	ID, Neb, TB	6.9	0.19	665	126

Room #	Air Supply	Air Door	Air Patient	Air Mixing	Cycled Air (0CFM)	Reg/ Slot	Return Placement	Building Type	Building Age (yrs)	Building Floors	Clinic Sq Ft
1	Towards Door	Into Room	To Return	9.5	Y	R	Near	Stand-alone	5	1	3385
2	Towards Door	Into Room	To Door	10	Y	R	Opposite	Stand-alone	5	1	3385
3	Towards Door	Into Room	To Floor	9	Y	R	Opposite	Stand-alone	5	1	3385
4	Towards Door	Into Room	To Door	7	Y	R	Opposite	Stand-alone	5	1	3385
5	Towards Door	Into Room	To Door	4	Y	R	At Door	Stand-alone	5	1	3385
6	Towards Door	Into Room	To Floor	32	Y	R	At Door	Stand-alone	5	1	3385
7	Towards Door	Into Room	To Door	24	N	R	At Door	Stand-alone	5	1	3385
8	Towards Door	Out Room	To Door	20	N	R	No Return Present	MOB	45	5	15600
9	Towards Door	Into Room	To Door	19	N	R	No Return Present	MOB	45	5	15600
10	Towards Door	Out Room	To Door	16	N	R	No Return Present	MOB	45	5	15600
11	Towards Door	Out Room	To Door	19	N	R	No Return Present	MOB	45	5	15600
12	Towards Door	Out Room	To Door	11	N	R	No Return Present	MOB	45	5	15600
13	Towards Patient	Into Room	No Movement	21	N	R	No Return Present	MOB	45	5	15600
14	Towards Door	Into Room	To Door	13	N	R	No Return Present	MOB	45	5	15600
15	Towards Door	Into Room	No Movement	23	N	R	No Return Present	MOB	45	5	15600
16	Towards Door	Into Room	To Door	18	N	R	No Return Present	MOB	45	5	15600
17	Towards Door	Into Room	To Door	22	N	R	No Return Present	MOB	45	5	15600
18	Towards Door	Into Room	No Movement	35	N	R	Near	Stand-alone	5	1	14630
19	Towards Patient	Into Room	No Movement	35	N	R	At Door	Stand-alone	5	1	14630
20	Towards Door	Into Room	To Door	19	N	R	At Door	Stand-alone	5	1	14630
21	Towards Patient	Into Room	No Movement	21	N	R	At Door	Stand-alone	5	1	14630
22	Towards Door	Into Room	To Door	26	Y	R	At Door	Shopping Center	10	1	8900
23	Towards Door	Into Room	To Door	22	Y	R	At Door	Shopping Center	10	1	8900
24	Towards Door	Into Room	To Door	27	Y	R	At Door	Shopping Center	10	1	8900
25	Towards Door	Into Room	No Movement	20	N	R	At Door	Shopping Center	10	1	8900
26	Towards Door	Into Room	No Movement	22	N	R	At Door	Shopping Center	10	1	8900
27	Towards Door	Into Room	No Movement	20	Y	R	At Door	Shopping Center	10	1	8900
28	Towards Door	Into Room	To Door	21	N	R	At Door	Shopping Center	11	2	5700
29	Towards Door	Into Room	To Door	14	N	R	At Door	Shopping Center	11	2	5700
30	Towards Door	Into Room	No Movement	26	N	R	At Door	Shopping Center	11	2	5700

Room #	Clinic #	Specialty	Room Type	Procedure Classification	Procedure Type	ACH	SD	CO2	SD
31	5	Community Based	Treatment	AGP	ID, Neb, TB	8.6	0.21	588	125
32	5	Community Based	Treatment	AGP	ID, Neb, TB	9.9	0.33	597	155
33	5	Community Based	Treatment	AGP	ID, Neb, TB	3.5	0.72	668	145
34	5	Community Based	Treatment	AGP	ID, Neb, TB	4	1.78	605	128
35	6	Family Medicine	Treatment	AGP	I&D, Nexplanon, IUD, fluid aspiration, vasectomy, colposcopy, biopsy, nebulized medications	6.5	0.12	842	77
36	6	Family Medicine	Treatment	AGP	I&D, Nexplanon, IUD, fluid aspiration, vasectomy, colposcopy, biopsy, nebulized medications	6.7	0.23	850	93
37	6	Family Medicine	Treatment	AGP	I&D, Nexplanon, IUD, fluid aspiration, vasectomy, colposcopy, biopsy, nebulized medications	4.6	0.11	858	106
38	6	Family Medicine	Treatment	AGP	I&D, Nexplanon, IUD, fluid aspiration, vasectomy, colposcopy, biopsy, nebulized medications	4.4	0.17	868	110
39	6	Family Medicine	Treatment	AGP	I&D, Nexplanon, IUD, fluid aspiration, vasectomy, colposcopy, biopsy, nebulized medications	5.3	0.19	897	130
40	7	Women’s	Procedure	MS	LEEP	13.4	0.37	470	75
41	7	Women’s	Exam	GE	General Exam	15.4	0.53	490	91
42	8	Community Based	Treatment	AGP	Nebulized Medication/TB/Measles	11.3	0.58	470	91
43	8	Community Based	Treatment	AGP	Nebulized Medication/TB/Measles	11.6	0.57	463	86
44	8	Community Based	Treatment	AGP	Nebulized Medication/TB/Measles	2.2	0.11	458	74
45	8	Community Based	Treatment	AGP	Nebulized Medication/TB/Measles	4.3	0.32	440	60
46	8	Community Based	Treatment	AGP	Nebulized Medication/TB/Measles	4.3	0.27	457	77
47	9	Community Based	Procedure	MS	OBGYN	5.4	0.98	486	21
48	9	Community Based	Treatment	MS	Lacerations	5.6	0.12	470	41
49	9	Community Based	Treatment	MS	Pap	4.3	0.24	437	25
50	9	Community Based	Treatment	AGP	Neb Med	3.6	0.2	578	41
51	9	Community Based	Treatment	AGP	Neb Med	7.3	0.4	536	29
52	9	Community Based	Procedure	MS	Minor Surgery	4.4	0.57	457	20
53	10	Community Based	Procedure	MS	Implantation of IUD or Nexplanon	5.9	0.16	480	37
54	10	Community Based	Treatment	AGP	Neb Med	5.2	0.07	457	32
55	10	Community Based	Treatment	AGP	Neb Med	6	0.67	450	33
56	10	Community Based	Treatment	AGP	Neb Med	8.2	0.75	499	21
57	10	Community Based	Treatment	AGP	Neb Med	7.8	0.28	484	27
58	10	Community Based	Treatment	AGP	Neb Med	7.7	0.18	443	17
59	10	Community Based	Treatment	AGP	Neb Med	7.5	0.22	455	30
60	10	Community Based	Treatment	AGP	Neb Med	6.5	0.31	454	24

Room #	Air Supply	Air Door	Air Patient	Air Mixing	Cycled Air (0CFM)	Reg/ Slot	Return Placement	Building Type	Building Age (yrs)	Building Floors	Clinic Sq Ft
31	No Movement	Into Room	Into Supply	14	N	R	At Door	Shopping Center	11	2	5700
32	Towards Door	Into Room	To Door	15	N	R	Opposite	Shopping Center	11	2	5700
33	Towards Door	Into Room	No Movement	22	Y	R	Near	Shopping Center	11	2	5700
34	No Movement	Into Room	No Movement	32	Y	R	At Door	Shopping Center	11	2	5700
35	Towards Door	Into Room	To Door	23	N	R	At Door	MOB	71	15	7803
36	Towards Door	Into Room	To Door	23	N	R	At Door	MOB	71	15	7803
37	Towards Door	Into Room	To Door	20	N	R	At Door	MOB	71	15	7803
38	Towards Door	Into Room	To Return	43	N	R	At Door	MOB	71	15	7803
39	Towards Door	Into Room	No Movement	45	N	R	At Door	MOB	71	15	7803
40	Towards Door	Out Room	To Return	13	N	S	At Door	MOB	10	33	10356
41	Towards Patient	Out Room	To Return	14	N	S	Opposite	MOB	10	33	10356
42	Towards Door	Out Room	To Return	29	Y	R	At Door	Shopping Center	9	1	9550
43	Towards Door	Into Room	To Door	16	Y	R	At Door	Shopping Center	9	1	9550
44	Towards Door	Into Room	No Movement	34	N	R	At Door	Shopping Center	9	1	9550
45	Towards Door	Into Room	No Movement	43	N	R	At Door	Shopping Center	9	1	9550
46	Towards Patient	Into Room	No Movement	36	N	R	At Door	Shopping Center	9	1	9550
47	Towards Door	Into Room	No Movement	31	N	R	At Door	Stand-alone	62	1	12000
48	Towards Door	Out Room	To Door	26	N	R	At Door	Stand-alone	62	1	12000
49	Towards Door	Out Room	To Door	28	N	R	At Door	Stand-alone	62	1	12000
50	Towards Door	Into Room	No Movement	38	N	R	At Door	Stand-alone	62	1	12000
51	Towards Door	Out Room	To Door	21	N	R	At Door	Stand-alone	62	1	12000
52	Along Ceiling	Into Room	Along Ceiling	34	N	R	Return Not Present	Stand-alone	62	1	12000
53	Towards Door	Into Room	To Door	23	N	R	At Door	Shopping Center	34	1	6500
54	Towards Patient	Into Room	No Movement	18	N	R	At Door	Shopping Center	34	1	6500
55	Towards Door	Into Room	To Door	15	N	R	At Door	Shopping Center	34	1	6500
56	Towards Door	Into Room	To Return	24	N	R	At Door	Shopping Center	34	1	6500
57	Towards Door	Into Room	To Door	16	N	R	At Door	Shopping Center	34	1	6500
58	Towards Door	Into Room	No Movement	22	N	R	At Door	Shopping Center	34	1	6500
59	Towards Door	Into Room	To Door	18	N	R	At Door	Shopping Center	34	1	6500
60	Towards Door	Into Room	To Door	20	N	R	At Door	Shopping Center	34	1	6500

Room #	Clinic #	Specialty	Room Type	Procedure Classification	Procedure Type	ACH	SD	CO2	SD
61	11	Colorectal	Exam	GE	General Exam	4.9	0.54	524	50
62	11	Colorectal	Procedure	AGP	Body Fluid Aspiration	4.8	0.18	530	30
63	11	Colorectal	Exam	GE	General Exam	4	0.25	550	30
64	12	Multispecialty	Treatment	AGP	Derm, Neb Med, IUD	6.5	0.23	665	69
65	12	Multispecialty	Treatment	AGP	Derm, Neb Med, IUD	6.9	0.76	639	45
66	12	Multispecialty	Treatment	AGP	Derm, Neb Med, IUD	4.6	0.27	670	32
67	12	Multispecialty	Treatment	AGP	Derm, Neb Med, IUD	6.7	0.34	638	28
68	13	Women’s	Procedure	MS	LEEP	19.3	1.08	429	64
69	13	Women’s	Exam	GE	General Exam	6.6	0.13	434	45
70	13	Women’s	Exam	GE	General Exam	11.3	0.37	434	55
71	14	Multispecialty	Procedure	AGP	Incision/Drainage, Nebulizer Medication	8.8	0.09	866	111
72	14	Multispecialty	Procedure	AGP	Incision/Drainage, Nebulizer Medication	9.4	0.2	874	134
73	14	Multispecialty	Procedure	MS	Echo/Cardio	13.5	0.45	944	46
74	14	Multispecialty	Treatment	MS	Ortho Injection	11.4	0.27	834	106
75	14	Multispecialty	Exam	GE	General Exam	0	0	1002	30
76	14	Multispecialty	Exam	GE	General Exam	10.3	0.22	1011	44
77	15	ENT	Procedure	MS	ENT, Frenuleomy	4.5	0.2	633	37
78	15	ENT	Treatment	AGP	Biopsy, nasal debridement	7.5	0.37	596	37
79	15	ENT	Treatment	AGP	Biopsy, nasal debridement	18.3	0.82	592	54
80	16	Dermatology	Exam	GE	General Exam	6.5	3.44	383	15
81	16	Dermatology	Procedure	MS	Derm	1.7	0.14	402	32
82	16	Dermatology	Procedure	MS	Derm	19.7	0.14	350	112
83	16	Dermatology	Exam	GE	General Exam	7	0.71	418	26
84	16	Dermatology	Exam	GE	General Exam	3.8	1.15	392	18
85	16	Dermatology	Exam	GE	General Exam	5	0.12	402	10
86	17	Pediatrics	Treatment	AGP	Neb Med	21.4	0.35	912	78
87	17	Pediatrics	Treatment	AGP	Neb Med	5.9	0.18	968	127
88	17	Pediatrics	Treatment	AGP	Neb Med	17.1	0.41	946	131
89	18	Multispecialty	Treatment	AGP	Neb Med	6.7	0.8	502	21
90	18	Multispecialty	Procedure	MS	OBGYN	4.2	0.19	536	83

Room #	Air Supply	Air Door	Air Patient	Air Mixing	Cycled Air (0CFM)	Reg/ Slot	Return Placement	Building Type	Building Age (yrs)	Building Floors	Clinic Sq Ft
61	Towards Patient	Into Room	To Return	20	N	R	At Door	MOB	13	5	2199
62	Towards Patient	Into Room	To Patient	40	N	S	At Door	MOB	13	5	2199
63	Towards Patient	Into Room	No Movement	39	N	S	At Door	MOB	13	5	2199
64	Towards Door	Into Room	To Door	17	N	R	Near	Stand-alone	3	1	8800
65	Towards Door	Into Room	No Movement	23	N	R	At Door	Stand-alone	3	1	8800
66	Towards Door	Into Room	To Door	23	N	R	At Door	Stand-alone	3	1	8800
67	Along Ceiling	Into Room	Along Ceiling	27	N	R	At Door	Stand-alone	3	1	8800
68	To Floor	Out Room	To Return	23	N	S	No Return Present	MOB	71	15	2500
69	Towards Door	Into Room	To Door	31	N	R	No Return Present	MOB	71	15	2500
70	Towards Door	Into Room	To Door	10	N	S	No Return Present	MOB	71	15	2500
71	Towards Door	Into Room	To Door	12	N	R	At Door	Stand-alone	7	2	11000
72	Towards Door	Into Room	To Floor	14	N	R	At Door	Stand-alone	7	2	11000
73	Towards Door	Into Room	To Door	23	N	R	At Door	Stand-alone	7	2	11000
74	Towards Patient	Into Room	To Floor	9	N	R	At Door	Stand-alone	7	2	11000
75	No Movement	Out Room	No Movement	38	Y	R	At Door	Stand-alone	7	2	11000
76	Towards Patient	Out Room	To Door	26	N	R	At Door	Stand-alone	7	2	11000
77	No Movement	Into Room	Along Ceiling	27	N	R	No Return Present	MOB	12	30	12000
78	Towards Patient	Out Room	To Door	10	N	S	Opposite	MOB	12	30	12000
79	Towards Patient	Out Room	To Door	12	N	S	At Door	MOB	12	30	12000
80	Towards Patient	Into Room	To Door	9	N	S	At Door	MOB	36	9	13356
81	Towards Patient	Into Room	No Movement	21	N	S	Opposite	MOB	36	9	13356
82	To Floor	Into Room	To Floor	22	N	S	At Door	MOB	36	9	13356
83	To Floor	Into Room	To Floor	30	N	S	At Door	MOB	36	9	13356
84	No Movement	Into Room	No Movement	43	N	R	At Door	MOB	36	9	13356
85	Towards Door	Into Room	To Return	20	N	R	At Door	MOB	36	9	13356
86	Towards Door	Out Room	To Door	17	N	R	At Door	Stand-alone	41	1	10589
87	Towards Door	Into Room	No Movement	18	N	R	Opposite	Stand-alone	41	1	10589
88	Towards Door	Out Room	To Door	6	N	R	Near	Stand-alone	41	1	10589
89	Towards Door	Into Room	To Door	25	N	R	At Door	Shopping Center	63	1	6575
90	Towards Door	Into Room	No Movement	23	N	R	At Door	Shopping Center	63	1	6575

Room #	Clinic #	Specialty	Room Type	Procedure Classification	Procedure Type	ACH	SD	CO2	SD
91	18	Multispecialty	Treatment	AGP	Neb Med	2.7	0.26	553	69
92	18	Multispecialty	Treatment	AGP	Neb Med	4.6	0.29	572	76
93	19	CV Surgery	Exam	GE	General Exam	11.8	0.19	609	40
94	19	CV Surgery	Exam	GE	General Exam	13	0.24	594	44
95	19	CV Surgery	Procedure	MS	Vein ablation	11.3	0.35	610	55
96	20	Colorectal	Procedure	AGP	CRC/Suction Body Fluids	2.3	0.31	587	43
97	20	Colorectal	Procedure	AGP	CRC/Suction Body Fluids	7.6	0.64	556	26
98	20	Colorectal	Exam	GE	General Exam	10.2	2.37	546	24
99	20	Colorectal	Exam	GE	General Exam	8.4	2.06	590	35
100	21	Pediatrics	Treatment	AGP	Neb Med	7.9	0.27	547	37
101	21	Pediatrics	Treatment	AGP	Neb Med	8.9	0.19	524	35
102	21	Pediatrics	Treatment	AGP	Neb Med	7	0.71	539	22
103	22	ENT	Procedure	AGP	Suction Body Fluids	8.8	0.21	515	65
104	22	ENT	Procedure	AGP	Suction Body Fluids	11.6	0.61	508	56
105	22	ENT	Exam	GE	General Exam	2.4	0.8	502	76

Room #	Air Supply	Air Door	Air Patient	Air Mixing	Cycled Air (0CFM)	Reg/ Slot	Return Placement	Building Type	Building Age (yrs)	Building Floors	Clinic Sq Ft
91	No Movement	Into Room	No Movement	30	N	R	Opposite	Shopping Center	63	1	6575
92	Towards Door	Into Room	To Door	20	N	R	At Door	Shopping Center	63	1	6575
93	Towards Door	Out Room	To Door	16	N	R	At Door	MOB	45	5	2500
94	Towards Door	Out Room	To Door	9	N	R	At Door	MOB	45	5	2500
95	Towards Door	Into Room	To Door	14	N	R	At Door	MOB	45	5	2500
96	Towards Patient	Out Room	No Movement	24	N	R	Near	MOB	14	5	2000
97	Towards Patient	Into Room	No Movement	21	N	R	Near	MOB	14	5	2000
98	Towards Patient	Into Room	No Movement	31	N	R	Opposite	MOB	14	5	2000
99	Towards Door	Out Room	To Return	16	N	R	Opposite	MOB	14	5	2000
100	To Floor	Into Room	No Movement	34	N	S	At Door	MOB	71	15	4773
101	Towards Patient	Into Room	No Movement	16	N	S	At Door	MOB	71	15	4773
102	Towards Patient	Into Room	To Floor	14	N	S	At Door	MOB	71	15	4773
103	Towards Door	Out Room	To Door	17	N	S	At Door	MOB	15	4	2544
104	Towards Door	Out Room	To Return	23	N	S	At Door	MOB	15	4	2544
105	Towards Patient	Into Room	No Movement	27	N	R	No Return Present	MOB	15	4	2544

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