

NIST GCR 06-887

Strategies to Reduce the Spread of Airborne Infections in Hospitals

Review of Recent Hospital Designs

Richard D. Hermans, P.E.
Martha J. Hewett
Chad Colsch

NIST

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

NIST GCR 06-887

Strategies to Reduce the Spread of Airborne Infections in Hospitals

Review of Recent Hospital Designs

Prepared for
National Institute of Standards and Technology
Gaithersburg, MD 20899-2100

By
Richard. D. Hermans, P.E.
Martha J. Hewett
Chad Colsch
Center for Energy and Environment

October 2006



U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Robert Cresonti, Undersecretary of Commerce for Technology

National Institute of Standards and Technology
William A. Jeffrey, Director

TABLE OF CONTENTS

DISCLAIMER	E-1
EXECUTIVE SUMMARY.....	E-2
Operating Rooms.....	E-2
Airborne Infection Isolation Rooms	E-4
Overall Quality Control.....	E-6
Discussion	E-7
OBJECTIVE	1
BACKGROUND	1
METHODOLOGY	2
Design and Selection of the Hospital Sample	2
Selection of Rooms for Review.....	3
Scope of Review	4
Data Collection.....	5
RESULTS.....	5
Sample Characteristics	5
Design of Operating Rooms.....	7
AIA Design Guidelines for ORs	7
Dilution	9
Filtration and Air Treatment	11
Air Distribution	12
Differential Pressure Control.....	13
Humidification	17
Minimization of Mold Growth in Ductwork.....	18
Special Purpose ORs	19
Design of Airborne Infection Isolation Rooms	20
AIA Design Guidelines for All Rooms.....	20
Anterooms	22
Dilution	24
Filtration and Air Treatment	27
Air Distribution	28
Differential Pressure Control.....	29
Humidification	34
Minimization of Mold Growth in Ductwork.....	35
Special Purpose All Rooms.....	35
Overall Quality Control.....	36
DISCUSSION	38
ACKNOWLEDGEMENTS	41
REFERENCES.....	41
ABBREVIATIONS (AS USED IN THIS REPORT).....	44
APPENDIX A. DATA TABLES	45

Disclaimer

Use of Non-SI Units in a NIST Publication

The policy of the National Institute of Standards and Technology is to use the International System of Units (SI units) in all its publications. However, in the North American construction and heating, ventilating and air-conditioning (HVAC) industries, certain non-SI units are so widely used instead of SI units that it is more practical and less confusing to include values in the customary IP units in this report.

Software

Certain software is identified in this paper in order to specify the procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the software identified is necessarily the best available for the purpose.

Executive Summary

Control of airborne infections in hospitals is critical both to effective health care and to the management of health care costs. Ten recent hospital projects were examined to determine the design features and parameters used to control airborne infections and whether these are consistent with accepted standards for health care construction. The projects were selected from those designed by engineers who had participated in a survey of design practice (Hewett and Hermans 2006). Half were new hospitals and half were additions. The review focused on design of general purpose operating rooms (ORs) (eight projects) and of airborne infection isolation (AII) rooms in non-critical-care nursing units (ten projects). It encompassed a wide range of issues relevant to control of airborne infections, including dilution, filtration, air distribution, control of space pressures, use of buffer zones, control of relative humidity, minimization of mold growth and quality control. The American Institute of Architects' 2001 *Guidelines for Design and Construction of Hospital and Health Care Facilities* served as the primary standard of comparison. More than 40 states and the Joint Commission on Accreditation of Healthcare Organizations reference the AIA guidelines for licensure or accreditation of hospitals, and the survey confirmed that more designers had been required to use this document and were familiar with it than any other. All but one of the projects had been designed after the 2001 edition of the guidelines was published, but the 2001 guidelines were not necessarily the basis of design for the particular projects reviewed.

Abbreviations used in this report are defined at the end.

Operating Rooms

OR designs were generally consistent with 2001 AIA guidelines (Table E-1). In all eight projects with ORs, the total and outdoor air change rates exceeded the guidelines, often substantially. Design total air change rates varied by a factor of two, and design outdoor air change rates varied by a factor of four. Two projects failed to meet the AIA guidelines regarding distance from the outdoor air intake to any exhaust.

All but one project met the guideline for pre-filter efficiency. All projects met the guideline for final filter efficiency, and most exceeded it. All designs met the guideline for filter placement and for filter fit and sealing.

OR air distribution was generally consistent with the guidelines, except that one project had returns that were not well separated. For four projects the return inlet height could not be determined, but this may have been due to the fact that only mechanical and not architectural plans were available. The AIA guidelines do not address the type of supply outlet. Several types were used, with the most common providing laminar vertical discharge.

Table E-1. Comparison of operating room designs with AIA 2001 guidelines.

General purpose ORs (n=8)	AIA Guideline	Range	Median	Gdl Met	Not met	Indeterminate	NA
DILUTION							
Total air change rate, h ⁻¹	≥ 15	16.1-29.3	23.3	8	0	0	0
Outdoor air change rate, h ⁻¹	≥ 3	3.2-14.0	5.5	8	0	0	0
Minimum distance from OA intake to any exhaust, ft (m)	≥ 25 (≥ 7.6)	20-53 (6-15.9)	40 (12)	6	2	0	0
FILTRATION							
Pre-filter efficiency, %	≥ 30	25-35	30	7	1	0	0
Final filter efficiency, %	≥ 90	90-99.97	97.5	8	0	0	0
Filter placement	(a)			8	0	0	0
Filter fit and seals	Airtight, pos seal			8	0	0	0
AIR DISTRIBUTION							
Supply location	Ceiling, near ctr			8	0	0	0
Number of returns	≥ 2	2-2	2	8	0	0	0
Return height	Near floor			4	0	4	0
Return location	Far apart			7	1	0	0
PRESSURE CONTROL							
Pressure difference, in. wg (Pa)	≥ 0.01 (≥ 2.5)		(b)	1	0	7	0
Supply – return, cfm (L/s)	Airflow out	100-420 (47-197)	200 (94)	8	0	0	0
Ceiling	Monolithic			8	0	0	0
HUMIDIFICATION							
Humidification	RH 30 – 60% (c)			8	0	0	0
Humidification type	Steam			8	0	0	0
MINIMIZATION OF MOLD GROWTH							
Duct insulation	None internal			8	0	0	0
Humidifier location	(d)			7	0	1	0
Humidifier drain pan (n=11)	Present			4	2	5	0
High limit humidistat (n=11)	Present			7	1	3	0
Duct takeoffs wrt humidifier (n=11)	(e)	5 to >16		0	0	11	0

- (a) Pre before air conditioning equipment, final after any fans or blowers
- (b) Only one project explicitly specified an OR pressure, which was +0.04in. wg.
- (c) We assumed this was met if humidification provided.
- (d) After filter or at least 15 feet before
- (e) Far enough to ensure complete absorption. Compliance could not be evaluated from the contract documents.

The AIA 2001 guidelines require ORs to be kept at +0.01 in. wg (+2.5 Pa) or more relative to the surrounding areas, but the previous version (AIA 1997) only required the direction of airflow to be out. Only one project included an explicit design pressure difference for the OR. All projects appeared to meet the 1997 requirement by providing more supply flow to the OR than return flow, however, other factors external to these rooms may not allow outward airflow across all surfaces.

None of the projects controlled OR supply or return flow based on space pressure in occupied mode. Three controlled return flow to provide a fixed flow difference between supply and return, while the rest relied on return balancing dampers or a motorized return damper with pre-set position to maintain a flow difference. Only two of the project specifications stated that the

OR was to be balanced for positive pressure; one of these and one other provided a permanently installed pressure monitoring device.

Design OR supply flow exceeded return flow by 100 cfm to 420 cfm (47 L/s to 198 L/s), with most projects providing a flow differential of 100 cfm or 200 cfm (47 L/s to 94 L/s). These designs could therefore tolerate an OR effective leakage area (ELA) of 39 in² to 164 in² (252 cm² to 1057 cm²) at the AIA 2001 recommended +0.01 in. wg (+ 2.5 Pa) room pressure. All of the ORs had monolithic ceilings, consistent with the AIA guidelines.

Six of the eight projects provided reduced OR airflow in unoccupied mode. The AIA guidelines require that positive pressure be maintained when flow is reduced, which would be more difficult to achieve with fixed balancing dampers. Two of the three projects with fixed return dampers did not reduce flow in unoccupied mode.

Several ORs failed to meet or could not be determined to meet one or more of the guidelines intended to limit potential for mold growth downstream of humidifiers.

Airborne Infection Isolation Rooms

All room designs, too, were generally consistent with most AIA 2001 guidelines. All but one of the projects met the guidelines for total air change rate and outdoor air change rate. Excluding the non-complying project, the rates varied among projects by about a factor of two. Six of the AII rooms had anterooms, and for two of these the anteroom air change rate appeared to fall slightly below the AIA guideline. All ten projects met the requirement to exhaust all air and the requirement for minimum distance from the AII room exhaust to any outdoor air intake. Two projects did not provide a separate toilet and tub or shower. One provided a toilet and sink only. For the other, the room reviewed was an AII exam room rather than a patient room, and had no toilet.

All but one project met the guideline for pre-filter and final filter efficiencies and filter placement.

Eight of the ten projects met the requirement to provide flow from clean areas to less clean areas. The AIA guidelines do not address supply outlet type. Several types were used, with the most common being ceiling outlets with horizontal discharge.

Seven projects met the requirement for a permanently installed device to monitor AII room pressure. Five projects stated a design room pressure, only three of which met the AIA 2001 guideline of -0.01 in. wg (-2.5 Pa). The 1997 *Guideline* (AIA 1997) had only required airflow in, although it referenced a publication by the Centers for Disease Control that recommended -0.001 in. wg (-0.25 Pa). All projects appeared to meet the 1997 requirement for airflow in by providing more exhaust from the AII room plus toilet room than supply, however, other factors external to these rooms may not allow inward airflow across all surfaces.

Four projects controlled AII room flow based on room pressure, two of which provided explicit design pressures and two of which did not. Five projects did not control flow on room pressure and did not address room pressure in their balancing specifications, but three of these did provide explicit design pressures and permanently installed monitoring. The tenth project did not specify how the exhaust air valve was controlled.

The design exhaust from the AII room plus toilet room exceeded the supply by 50 cfm to 370 cfm (24 L/s to 175 L/s) with a median of 95 cfm (45 L/s). Most provided a flow differential of 50 cfm to 200 cfm (24 L/s to 94 L/s). These designs could tolerate an AII room ELA of 20 in² to 144 in² (129 cm² to 929 cm²) at the AIA 2001 required -0.01 in. wg (-2.5 Pa) room pressure.

Table E-2. Comparison of airborne infection isolation room designs with AIA 2001 guidelines.

AII Rooms on Non-Critical Care Wards (n=10)	AIA Guideline	Range	Median	Gdl Met	Not met	Indeterminate	NA
DILUTION							
Patient rm tot air chg rate, h ⁻¹	≥ 12	8.5-21.9	14.6	9	1	0	0
Patient rm outdoor air chg rate, h ⁻¹	≥ 2	1.9-4.9	3.1	9	1	0	0
Anteroom air chg rate, h ⁻¹	≥ 10 (a)	9.6-15.6	12.2	4	2	0	4
Toilet rm air chg rate, h ⁻¹	≥ 10	8.5-21.9	14.6	8	0	0	2
All air exhausted	Yes (b)			10	0	0	0
Minimum distance from OA intake to any exhaust, ft (m)	≥ 25 (≥ 7.6)	25 to 85+ (7.6 to 25.5+)		10	0	0	0
Separate toilet & tub or shwr	Yes			8	2	0	0
FILTRATION							
Pre-filter efficiency, %	≥ 30	25-60	30	9	1	0	0
Final filter efficiency, %	≥ 90	85-99.97	95	9	1	0	0
Filter placement	(c)			9	1	0	0
AIR DISTRIBUTION							
Airflow direction	Clean to less clean			8	2	0	0
PRESSURE CONTROL							
DP monitoring	Permanently installed device			7	3	0	0
Pressure difference, in. wg (Pa)	≤ -0.01 (≥ -2.5)	-0.15 to -0.001 (-37.4 to -0.25)	-0.025 (-6.2)	3	2	5	0
Supply – return, cfm (L/s) (AII+TR)	Airflow in	-370 to -50 (-175 to -24)	-95 (-45)	10	0	0	0
Room envelope	Sealed tightly			5	0	5	0
MINIMIZATION OF MOLD GROWTH							
Humidifier location	(d)			5	0	2	3
Humidifier drain pan	Present			4	0	3	3
High limit humidistat	Present			5	0	2	3
Duct takeoffs wrt humidifier ft (m)	(e)	10+ to 75+ (3+ to 22.5+)		0	0	10	3
Internal duct insul wrt	≥ 15 (4.5)	Not used		10	0	0	0

humidifier, ft (m)							
(a)	Not clear whether this applies to all AII room anterooms or only those for patients requiring protective environments who also require airborne infection isolation.						
(b)	If not practical, return through HEPA filters to air handling system exclusively serving the isolation room.						
(c)	Pre before fan, final after any fans or blowers						
(d)	After filter or at least 15 feet (4.5 m) before						
(e)	Far enough to ensure complete absorption. Compliance could not be evaluated from the contract documents.						

Five projects included *prescriptive* requirements to seal the walls, but since we did not have complete architectural documentation, we were unable to determine whether the other five projects did or not. Four of the projects definitely had no *performance* requirement (e.g., maximum allowed ELA) for AII room airtightness and no test of airtightness, but no information is available for the other six. At least six AII rooms had ceilings consisting partly or entirely of lay-in tile, which can contribute to room leakage. For three of these the wall heights continued to the slab of the floor above.

The design of AII suites with anterooms varied considerably. Four suites were laid out in series so that the patient room could only be accessed through the anteroom, and two were laid out in parallel. Two anterooms had supply exceeding exhaust, two had balanced flows, and two had exhaust exceeding supply. Two suites monitored pressure in the patient room relative to the anteroom, one in the patient room relative to the corridor, and one in the anteroom relative to the corridor.

Seven of the AII rooms had humidification and, of these, several could not be determined to meet one or more of the guidelines intended to limit potential for mold growth downstream of humidifiers.

Overall Quality Control

The AIA 2001 guidelines state that “acceptance criteria for mechanical systems shall be specified,” that “[c]rucial ventilation specifications for air balance and filtration shall be verified before owner acceptance,” and that areas including surgical services, PE and AII rooms, among others, “shall be recognized as requiring mechanical systems that ensure infection control, and ventilation deficiencies shall not be accepted.” In an advisory appendix, they recommend commissioning by an entity independent from the installing contractor, identify building areas of particular concern including surgical services and isolation rooms, and note in particular that “air balancing, pressure relationships, and exhaust criteria ... must be... tested to create an environment of care that provides for infection control.”

For purposes of our review, we interpreted this to mean that the testing, adjusting and balancing (TAB) must be verified, at least for the critical spaces, and that some process must be included to identify and correct deficiencies prior to acceptance. Three of the projects’ TAB specifications included rechecks of a sample of data in the balancing report, witnessed by the owner or architect, and a fourth project included a general statement that the job would be accepted on the basis of tests and inspections. Only one of the four spelled out acceptance criteria and consequences of non-acceptance in detail. Two designers whose TAB specifications did not

include verification said that it was in fact included in the project. The four other projects apparently did not include it.

Two of the projects included formal third-party commissioning. All of the others included some level of system performance verification, performed by the TAB contractor, the controls contractor or both. The scopes of work were brief so that the level of effort could be open to interpretation. In most cases the required reporting was of deficiencies only. Five of these included some witnessed testing of control system performance or an option for witnessed testing. Whether these meet the AIA criterion that “crucial specifications... shall be verified” and “ventilation deficiencies shall not be accepted” probably depends in large part on how well they are enforced by the owner’s representative or architect and executed by the responsible contractor.

The AIA guidelines require that an Infection Control Risk Assessment (ICRA) be provided by the owner. Although the designer is required to incorporate the construction-related requirements of the ICRA into the contract documents, it is not possible from review of the documents themselves to determine whether an ICRA was done or which requirements were driven by the ICRA. Three of the designers who provided follow-up information reported that an ICRA had been performed.

Table E-3. Comparison of quality control practices with AIA 2001 guidelines.

	AIA Guideline	Guideline Met	Not Met	Indeterminate
TAB verification	Yes (a)	6	4	0
Commissioning	Yes, limited (a)	2	0	8
Infection Control Risk Assessment	Yes (b)	3	0	7

(a) This is our interpretation of the AIA guidelines. See text for details.

(b) Required only for remodels, additions and new hospitals adjacent to existing hospitals.

Discussion

Overall, the project design features and parameters showed reasonably good agreement with the AIA 2001 guidelines and with each other. The exceptions have possible implications both for infection control and for owning and operating costs. Contract documents most often fell short of AIA guidelines or did not provide enough information to determine whether they met the guidelines in the areas of room pressure control, minimization of mold growth downstream of humidifiers, TAB verification, and overall system performance verification or commissioning.

The lack of compliance with AIA guidelines for pressure control may be due in part to the fact that the AIA guidance changed in 2001 and was still relatively new when these designs were done. It may also reflect insufficient consideration of the physics of room air leakage. The types of terminal equipment, control strategies and balancing approaches used to achieve OR and AII room pressure control varied considerably. Anteroom layout, supply/return flow ratios and differential pressure measurement points also vary greatly. These variations may reflect equally valid designer/owner preferences or they may reflect insufficient guidance as to most effective approaches to achieve reliable pressure control and effective isolation.

Occupied and unoccupied mode total air change rates, outdoor air change rates and final filter efficiencies generally met AIA guidelines but also varied considerably, and variations in these

design parameters have a significant impact on first costs and operating costs. The owners' or designers' rationale for using higher design targets in these projects is unknown. Other design considerations (e.g., cooling loads), anticipation of future requirements, more exacting uses of the space (e.g., use of a general purpose OR for orthopedic surgeries) or consideration of other design guidance documents could all factor into these choices.

The AIA 2001 guidelines for commissioning and for the location of duct take-offs with respect to humidifiers were stated in such a way that we were unable to unambiguously assess compliance from the contract documents alone. This is true to a lesser extent of the requirements for TAB verification, filter fit, and room sealing. These guidelines are stated in performance terms but the performance descriptors appear open to some interpretation.

This plan and specification review was in general agreement with the survey by Hewett (Hewett and Hermans 2006) in that for most of the design parameters reviewed, there was little distinction between designers of fewer projects and more experienced designers. For example, no distinction could be seen for the design approach to room pressure control. Where general tendencies could be seen from the small sample size, experienced designers tended to specify higher ventilation rates and higher differential flow rates between supply and return/exhaust.

Objective

Ten recent hospital projects were reviewed to determine the design features and parameters used to control airborne infections and whether these are consistent with accepted standards for health care construction.

Background

Control of airborne infections in hospitals is critical both to effective health care and to the control of direct and indirect health care costs. In 1992, the U.S. Centers for Disease Control estimated that two million patients per year contract infections in hospitals, causing \$4.5 billion in excess health care costs (CDC 1992). The CDC still uses these estimates of the impact of health-care associated infections in hospitals, also estimating that they cause 90,000 deaths per year (CDC 2006). Because these figures include all forms of healthcare-associated infections (HAI) and because most of these are considered contact transmission, the impact of airborne infections is probably a small subset of the overall problem. Nevertheless, the indirect costs of hospital construction and the operation and maintenance costs for infection control are significant: per unit area, hospitals are among the most expensive buildings to build and are among the most costly to heat and cool.

A number of design features and strategies are used to control the spread of airborne infections. These include primarily:

- providing high total air change rates and outdoor air change rates,
- providing adequate separation between outdoor air intakes and exhaust outlets,
- providing very high efficiency filters that capture microbes or render them nonviable,
- maintaining proper space pressure relationships to control the direction of movement of infectious agents,
- providing anterooms to reduce air exchange due to door openings,
- locating room air outlets and inlets to minimize the flow of contaminated air over uninfected persons,
- maintaining space relative humidity within an optimal range,
- avoiding internally lined ductwork and minimizing the potential for mold growth in ductwork,
- using antimicrobial coatings on ductwork, and
- using ultra-violet light in ducts to kill microbes.

This plan and specification review is a part of a project which is assessing current design practice relative to all of these features and strategies, but it places particular emphasis on directional pressure differences for several reasons:

- (1) The impact of space pressure control on the spread of airborne infections has been researched less than most of the other design issues that affect airborne infection control.
- (2) The U. S. guidance on differential pressures for infection control has changed significantly in recent years. In 1997, Streifel and Marshall began recommending a

design pressure differential of about 0.01 in. wg (2.5 Pa) (Streifel and Marshall 1997, Streifel 1999, Streifel 2000). The American Institute of Architects' (AIA) 2001 edition of the *Guidelines for Design and Construction of Hospital and Health Care Facilities* incorporated this recommendation, requiring a differential pressure of +0.01 in. wg (-0.25 Pa) for operating rooms (ORs) and protective environment (PE) rooms and -0.01 in. wg (-2.5 Pa) for airborne infection isolation (AII) rooms, whereas the 1997 edition had required only airflow out for ORs and PE rooms and airflow in for AII rooms. The 1997 guidelines did suggest that reference be made to certain publications by the Centers for Disease Control (CDC). One of these (CDC 1994a) recommended a pressure of -0.001 in. wg (-0.25 Pa) for AII rooms and the other (CDC 1994b) recommended a 10 % to 20 % excess of supply air over exhaust air in new specialized care units for high risk patients (PE rooms), specifically in the context of interruption of transmission of *aspergillus* spores. The 2003 CDC guidelines, which compiled and updated CDC guidance from a number of previous CDC publications, followed the 2001 AIA guidelines in recommending that a ± 0.01 in. wg (2.5 Pa) pressure differential be maintained. They further stated that an ideal pressure differential would be more than +0.032 in. wg (+8 Pa) for PE rooms and less than -0.01 in. wg (-2.5 Pa) for AII rooms. The 1999 edition of the *ASHRAE Handbook of Heating, Ventilating and Air-Conditioning Applications* (ASHRAE 1999a) required only directional airflow, but the 2003 edition called for a -0.01 in. wg (-2.5 Pa) pressure differential for AII rooms and a +0.01 in. wg (+ 2.5 Pa) pressure differential for PE rooms and some types of ORs.

- (3) The pressure difference required has a significant impact on first costs due to equipment sizing and on operating costs due to the energy impact.

No systematic information is currently available regarding designers' awareness of the new guidance or the means by which it is being addressed in practice through design, construction, commissioning and operation. The first phase of this project was to survey a number of hospital design engineers to delineate the current state of the art in design of critical spaces for infection control. (Hewett and Hermans, 2006) The second phase, reported here, is to review plans and specifications for a subset of these designers to determine how the design concepts they use are translated into contract documents.

Methodology

Design and Selection of the Hospital Sample

The hospital designers interviewed in the first component of the project had been selected from two sample groups but were re-assigned *post hoc* to two different sample groups. Of the original sample groups, the first was intended to represent firms that do a large volume of hospital design, and was selected from the 2003 *Engineering News Record's* list of the top 25 firms in health care by 2002 design revenue (ENR 2003). The second was intended to represent firms that do occasional health care design, and was selected from those designing hospital projects placed on McGraw-Hill Construction's "Dodge Plans" (McGraw 2004) service in the period from May to September 2004. Since the survey results showed that these original sample groups were ineffective in separating frequent and occasional health care designers, the respondents were regrouped *post hoc* into a "many projects" group and a "few projects" group.

In selecting projects for plan and specification review we attempted to the extent possible to select those designed by firms that were either in both the “frequent designers” group and the “many projects” group or in both the “occasional designers” group and the “few projects” group. The purpose of this was to maximize the likelihood that the plan and specification review sample would include both designers who do a great deal of hospital design work and work for major healthcare design firms, and those who do fewer hospital projects and do not work for the largest players. Seven of the ten designers selected met these criteria (Table 1).

The group of designers whose plans and specifications were reviewed included five from the “many projects” group, who had designed 19 to 80 projects since January 1, 2001, four from the “few projects” group, who had designed 2 to 10 hospitals since January 1, 2001, and one who was in the survey sample but had not actually been interviewed.

Table 1. Distribution within the original and redefined survey samples of designers whose plans and specifications were reviewed.

↓ Original sample groups	Redefined sample groups			Total
	Many projects	Few projects	Not interviewed	
Frequent hospital designers	3 (2d, 1D)	0	NA	3
Occasional hospital designers	2 (2D)	4 (1d, 3D)	NA	6
Not interviewed	NA	NA	1 (1D)	1
Total	5	4	1	10

D = plans and specifications from DodgePlans, d = plans and specifications from designer.

Seven of the sets of plans and specifications reviewed were obtained from the Dodge Plans service and three were provided by the designer, the latter being selected from the survey respondents who said they would be willing to share plans and specifications for this phase of the project. When these designers were re-contacted, they were asked to provide a project that met the following criteria:

- schematic design started after January 1, 2001, but the construction documents complete,
- includes two or more of the space types under study (operating rooms, airborne infection isolation rooms, and protective environment rooms),
- is located in one of the geographic areas that was underrepresented in the sample from the Dodge Construction reports (In each case, we asked for a project in the Census Region where the designer’s office is located).

Selection of Rooms for Review

Our objective was to select rooms from each project that would be directly comparable in terms of the care objectives and environments and the applicable AIA design guidance. We accomplished this by selecting one general purpose operating room (OR) and one airborne infection isolation (AII) room in a non-critical-care nursing unit from each project, if the project included rooms of these types. A general purpose OR was selected rather than one for procedures such as orthopedic or organ surgery or for bronchoscopy, since these may have different and specialized requirements. An AII room in a non-critical care nursing unit was

selected rather than one in a critical care (intensive care or neonatal intensive care) unit or in an emergency department because the latter areas often have physical layouts required to support delivery of care that can make attainment of effective isolation more difficult. Rooms designed to be switched back and forth between airborne infection isolation and protective environment functions were also excluded from the primary group of rooms selected for design review.

All ten of the projects reviewed had AII rooms in non-critical-care nursing units, and eight of the ten had general purpose ORs. When a project had more than one such room, they were generally very similar and a typical example was chosen.

In addition to the primary group of rooms described above, we also reviewed special purpose ORs and AII rooms in other areas of the hospital when they were included in a project. This included three specialized ORs from two projects and three emergency department AII rooms and one bronchoscopy AII room from three different projects.

Scope of Review

The plan and specification review addressed the following issues:

- **Dilution of airborne infectious agents**
 - Total air change rate (occupied and unoccupied)
 - Outdoor air change rate
 - Recirculation vs. exhaust of air from contaminated spaces
 - Separation of outdoor air intakes from exhaust outlets
- **Filtration and air treatment to remove or kill airborne infectious agents**
 - Air handler pre-filter and final filter efficiency; zone level filter efficiency
 - Airtightness of filter housing
 - Filter location relative to air conditioning equipment and fans
 - Treatment of air with ultraviolet light
- **Air distribution design to minimize spread of airborne infectious agents**
 - Supply diffuser type and location
 - Return grill location
 - Direction of airflow through space
- **Differential pressure control to minimize spread of airborne infectious agents**
 - Design pressure difference
 - Method of pressure control
 - Method of pressure monitoring
 - Difference between supply and return/exhaust airflow
 - Control of supply and return/exhaust airflow
 - Ceiling construction
 - Prescriptive or performance requirements for air-sealing of room boundaries
 - Tests of room airtightness
- **Use of buffer zones to minimize spread of airborne infectious agents**
 - Presence of anterooms
 - Anteroom layout (series/parallel)
 - Anteroom pressurization
- **Control of relative humidity to minimize the spread of airborne infections**
 - Presence and type of humidifiers

- **Minimization of microbial growth in ductwork**
 - Duct insulation placement (internal/external)
 - Location of duct lining relative to humidifiers
 - Location of humidifiers relative to final filters
 - Provisions for water removal from ductwork with duct-mounted humidifiers
 - Provision of high limit humidistat downstream of humidifier
 - Distance from humidifier to nearest duct takeoff
- **General construction management and quality control**
 - Infection Control Risk Assessment (ICRA)
 - Verification of air balancing
 - Formal commissioning

These elements provide a broad overview of design for infection control but are not all-inclusive.

Data Collection

Most data were collected from the plans and specifications themselves. The plans and specifications placed on Dodge Plans for bid include some addenda and may not reflect the final design on all points due to addenda and change orders that may have occurred later in the process. Likewise the designers who provided plans and specifications may not have sent all addenda and change orders. However, the plans and specifications should include many of the features that are standard elements of the hospital designs.

After data were extracted from the plans and specifications, the information was sent to the designer (engineer of record) with a request to correct any errors and provide missing information. Four designers provided corrected or additional information, either verbally or in writing. The data tables in the Appendix distinguish between data from the original plan and specification review and data obtained subsequently from the designer.

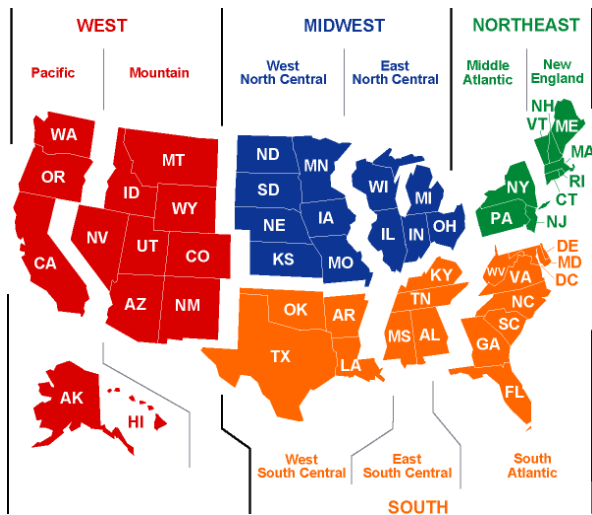
Results

Sample Characteristics

Eight of the ten projects, the seven from Dodge Plans and one other, have plans dated between May and September 2004, while two are somewhat older (September 2002 and May 2000 plan dates respectively). Nine of the projects are recent enough that the AIA guidelines released in March 2001 should have been available to the designer.

Table 2. Sample characteristics.

Project ID#	1	2	3	4	5	6	7	8	9	10
Date	Jul-04	Jul-04	May-04	Jun-04	Jul-04	Jun-04	Sep-04	May-00	Sep-02	Jun-04
New Bldg/Addition	New Bldg	Addition	New Bldg	New Bldg	Addition	Addition	New Bldg	Addition	Addition	New Bldg
Original survey sample group	freq hosp design	occ hosp design	occ hosp design	occ hosp design	occ hosp design	not interviewed	freq hosp design	freq hosp design	occ hosp design	occ hosp design
Redefined survey sample group	many projects	many projects	few projects	few projects	few projects	not interviewed	many projects	many projects	few projects	many projects
Plan/spec source	Dodge	Dodge	Dodge	Dodge	Dodge	Dodge	designer	designer	designer	Dodge
Census Region*	South	Midwest	South	South	Midwest	South	Midwest	Northeast	West	West



*Census Region key

Half the projects were new hospitals and half were additions to existing hospitals. Four were located in the South Census Region, three in the Midwest, two in the West, and one in the Northeast (Table 2).

Design of Operating Rooms

AIA Design Guidelines for ORs

The previously referenced survey had confirmed that AIA’s *Guidelines for Design and Construction of Hospital and Health Care Facilities* is a key design document for the industry. Designers were more familiar with this document than any of the others addressed by the survey, and more had been required to use it to establish design criteria for their most recent project, either alone or with other codes and standards, than any other document. Most had been required to use the 2001 edition. Currently, more than 40 states and the Joint Commission on Accreditation of Healthcare Organizations reference the AIA guidelines for licensure or accreditation of hospitals (AIA 2006).

Table 3 shows key AIA requirements for the design and construction of ORs. These requirements were the primary point of reference against which the project plans and specifications were compared.

Table 3. Key AIA 2001 guidelines for design and construction of operating rooms.

Item	AIA 2001 Guidelines
DILUTION	
TSA ACH	7.31.D1...For rooms listed in Table 7.2, where VAV systems are used, minimum total air change shall be within limits noted. Table 2. Minimum total air changes per hour: 15. [Note 4]: Number of air changes may be reduced when the room is unoccupied if provisions are made to ensure that the number of air changes indicated is reestablished any time the space is being utilized. Adjustments shall include provisions so that the direction of air movement shall remain the same when the number of air changes is reduced...Air quantity calculations must account for filter loading such that the indicated air change rates are provided up until the time of filter change-out. [Note 5]: Air change requirements indicated are minimum values. Higher values should be used when required to maintain indicated room conditions (temperature and humidity), based on the cooling load of the space...
Outdoor Air ACH	Table 2. Minimum air changes of outdoor air per hour: 3. [Note 3] ... Minimum outdoor air quantities shall remain constant while the system is in operation.
Distance from AHU OA intake to nearest exhaust	7.31.D3. Fresh air intakes shall be located at least 25 feet...from exhaust outlets of ventilating systems, combustion equipment stacks, medical-surgical vacuum systems, plumbing vents, or areas that may collect vehicular exhaust or other noxious fumes unless it can be demonstrated that adequate ventilation can be achieved. (Prevailing winds and/or proximity to other structures may require greater clearances.) Plumbing and vacuum vents that terminate at a level above the top of the air intake may be located as close as 10 feet...

Table 3, continued.

FILTRATION AND AIR TREATMENT	
AHU filter efficiency Pre/Final	7.31.D8. All central ventilation or air conditioning systems shall be equipped with filters with efficiencies equal to, or greater than, those specified in Table 3. Where two filter beds are required, filter bed no. 1 shall be located upstream of the air conditioning equipment and filter bed no. 2 shall be downstream of any fan or blowers. Filter efficiencies, tested in accordance with ASHRAE 52-92, shall be average... Table 3: All areas for inpatient care, treatment, and diagnosis... No. filter beds: 2. Filter bed no. 1 (%) 30; Filter bed no. 2 (%) 90.
Filter frame/installation	7.31.D8. ...Filter frames shall be durable and proportioned to provide an airtight fit with the enclosing duct work. All joints between filter segments and enclosing duct work shall have gaskets or seals to provide a positive seal against air leakage. A manometer shall be installed across each filter bed having a required efficiency of 75 percent or more, including hoods requiring HEPA filters. Provisions shall be made to allow access for field testing.
Zone level filter efficiency	[No requirement]
Ultraviolet treatment	[No requirement]
AIR DISTRIBUTION	
Supply diffuser type	[No requirement]
Supply and return diffuser type, location, number	7.31.D4. In new construction and major renovation work, air supply for operating and delivery rooms shall be from ceiling outlets near the center of the work area. Return air shall be near the floor level. Each operating and delivery room shall have at least two return air inlets located as remotely from each other as practical. (Design should consider turbulence and other factors of air movement to minimize fall of particulates onto sterile surfaces.)...
ROOM PRESSURIZATION	
Design pressure difference	Table 2. [Note 11]: Differential pressure shall be a minimum of 0.01" water gauge (2.5 Pa). If alarms are installed, allowances shall be made to prevent nuisance alarms of monitoring devices.
Use of terminal boxes	[No requirement]
Method of pressure control	[No requirement]
Method of room pressure monitoring	[No requirement]
Design difference in airflow (supply – return)	Table 2. Air movement relationship to adjacent area: Out
Minimum difference in airflow	Table 2. [Note 2] ...If any form of variable air volume or load shedding system is used for energy conservation, it must not compromise the corridor-to-room pressure balancing relationships or the minimum air changes required by the table.
Ceiling Type? All walls to structure? Sealing leaks, fire walls, other?	7.28.B5. In new construction or major renovation work, the floors and wall bases of all operating rooms...shall be monolithic and joint free... 7.28.B6. ... In operating rooms, delivery rooms for caesarean sections, isolation rooms, and sterile processing rooms, wall finishes shall be free of fissures, open joints, or crevices that may retain or permit passage of dirt particles. 7.28.B7. Floors and walls penetrated by pipes, ducts, and conduits shall be tightly sealed to minimize entry of rodents and insects. Joints of structural elements shall be similarly sealed. 7.28.B8. Ceiling finishes in restricted areas such as operating rooms shall be monolithic, scrubbable, and capable of withstanding chemicals. Cracks or perforations in these ceilings are not allowed.
Performance specification for room tightness?	[No requirement]
Test for room tightness?	[No requirement]
HUMIDIFICATION	
Relative humidity	Table 2: 30 % to 60 %.
Humidifier type	7.31.D9. Steam humidifiers shall be used. Reservoir type water spray or evaporative pan humidifiers shall not be used.

Table 3, continued.

MINIMIZATION OF MOLD GROWTH IN DUCTWORK	
Duct lining/insulation	7.31.B5. Duct linings exposed to air movement shall not be used in ducts serving operating rooms, deliver rooms, LDR rooms, nurseries, protective environment rooms, and critical care units. This requirement shall not apply to mixing boxes and acoustical traps that have special coverings over such lining. 7.31.B.7. Duct lining shall not be installed within 15 feet (4.57 meters) downstream of humidifiers.
Humidifier placement and control	7.31.D9. If duct humidifiers are located upstream of the final filters, they shall be located at least 15 feet (4.57 meters) upstream of the final filters. Ductwork with duct mounted humidifiers shall have a means of water removal. An adjustable high limit humidistat shall be located downstream of the humidifier to reduce the potential of condensation inside the duct. All duct takeoffs shall be sufficiently downstream of the humidifier to ensure complete moisture absorption.
Antimicrobial duct coating	[No requirement]

Dilution

High air change rates increase the frequency with which air in a space is passed through the air handler, where a high percentage of microbes will be removed or killed by the filters. All of the general purpose operating rooms reviewed had constant supply airflow when occupied. Total air changes per hour (total supply airflow/room volume) ranged from 16.1 h⁻¹ to 29.3 h⁻¹ with a median of 23.3 h⁻¹ (Figure 1). All of the plans and specifications reviewed meet the 2001 AIA requirement of 15 h⁻¹ for ORs. Only three of the eight meet the higher recommendation from the ASHRAE *Handbook of Heating, Ventilating and Air-Conditioning Applications* (ASHRAE 2003) of 25 h⁻¹. ASHRAE has recommended 25 h⁻¹ since 1968.

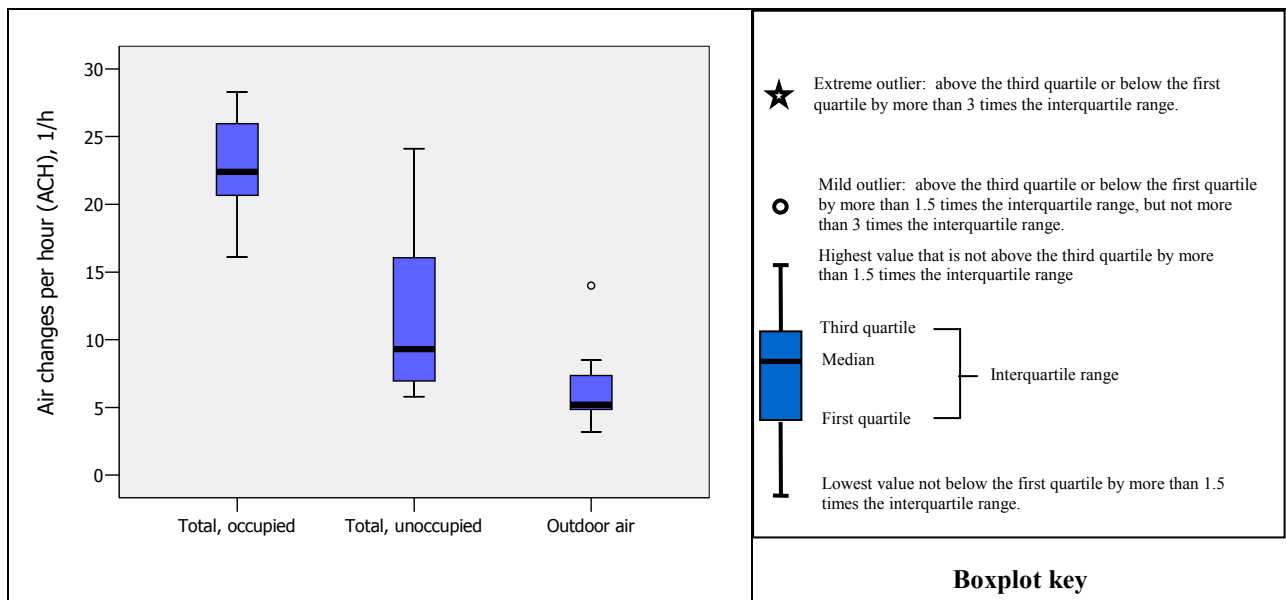


Figure 1. OR total air change rates when occupied and unoccupied and outdoor air change rate when occupied (n=8 for occupied total ACH, outdoor air ACH, n=7 for unoccupied total ACH, including two for which unoccupied flow was not reduced).

Reducing the supply airflow to ORs when unoccupied can significantly reduce fan energy consumption. Six of the ORs clearly had design provisions for reduced supply airflow when unoccupied. For the five where the unoccupied mode total supply airflows were given they ranged from 20 % to 56 % of the occupied flows, resulting in unoccupied mode air changes ranging from 5.8 h⁻¹ to 11.5 h⁻¹. The AIA guidelines do not require a specific unoccupied air change rate but do require that pressure relationships be maintained. This issue is discussed in a later section.

Outdoor air dilutes airborne infectious agents. All of the general purpose ORs are served by recirculating HVAC systems that use a mixture of outdoor air and return air. The outdoor air change rate was calculated by multiplying the minimum outdoor air percentage at the air handler by the constant OR supply airflow when occupied and dividing by the room volume. Outdoor airflow when occupied ranged from 3.2 h⁻¹ to 14.0 h⁻¹ with a median of 5.5 h⁻¹ (Figure 1). All of these meet the AIA guidelines' requirement for 3 h⁻¹ of outdoor air in ORs. Six of the eight meet the higher ASHRAE *Applications* handbook's recommendation of 5 h⁻¹ of outdoor air.

Outdoor air intakes must be located far enough from exhaust outlets to minimize the risk of reintroducing pathogens via the outdoor air. For the air handlers serving these rooms, distances to the nearest exhaust ranged from 20 ft to 53 ft (6.1 m to 16.2 m) with a median of 40 ft (12.2 m). The AIA guidelines require a minimum of 25 ft (7.6 m) and note that prevailing winds or proximity to other structures may require greater clearances. Two of the systems reviewed had minimum distances less than 25 ft (7.6 m). Except for these two, all designs met all of the AIA guidelines related to dilution (Figure 2).

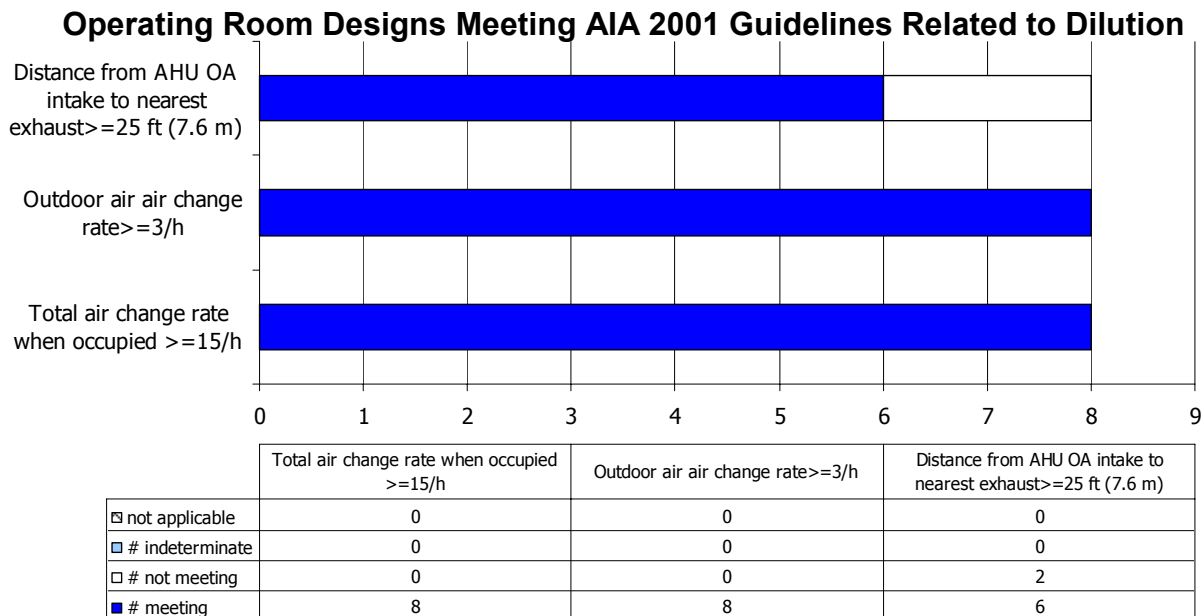


Figure 2. OR designs meeting AIA 2001 guidelines related to dilution (n=8).

Filtration and Air Treatment

High efficiency filters remove or kill a high percentage of airborne bacteria, viruses and molds (Kuehn et al. 1990; Margard and Logsdon 1985; Furuhashi, 1978; Darlow 1966; Decker et al. 1963; Foarde and Hanley 2001). Consistent with the AIA guidelines, all of the projects reviewed specified filters in terms of atmospheric dust spot efficiencies (ASHRAE 1992) rather than the newer minimum efficiency reporting value (MERV)(ASHRAE 1999b). Six of the general purpose ORs were served by air handlers having two filter beds, while two were served by air handlers having three filter beds. Efficiencies specified for bed no. 1 ranged from 25 % to 35 %, with a median and mode of 30 %. Efficiencies specified for the final filter ranged from 90 % to 99.97 % with a median of 97.5 % and a mode of 99.97 % (Figure 3). One OR with a 95 % efficient final filter at the air handler had a 99 % efficient zone level filter for the OR.

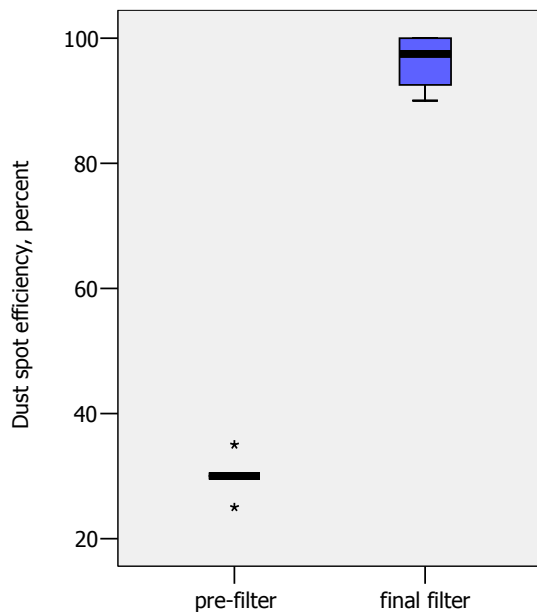


Figure 3. OR filter efficiencies (n=8).

The AIA guidelines do not give a specific requirement for filter efficiency in ORs. The general requirement for all areas for inpatient care, treatment and diagnosis is 30 % for filter bed no. 1 and 90 % for filter bed no. 2. All of the designs meet or exceed these criteria except the design with the 25 % efficient pre-filter. The 2003 ASHRAE *Handbook* recommends filter efficiencies in terms of MERV (ASHRAE 1999b), which is not directly comparable to dust spot efficiency. The 1999 ASHRAE *Handbook*, which still used dust spot efficiencies, recommended 25 % efficient pre-filters and 90 % efficient filters for general procedure ORs.

The AIA guidelines require that the filter frames “provide an airtight fit with the enclosing duct work” and that “all joints between filter segments and enclosing duct work shall have gaskets or seals to provide a positive seal against air leakage.” All eight

project specifications addressed filter leakage to some extent.

Two simply stated that the frames should prevent bypass, so could be considered to have barely met this requirement. Four required the frames to be sealed and gasketed, but provided no specifics as to how this should be accomplished. Two described the construction of the frame sealing in detail, including one that required the filters to be caulked in place.

The AIA guidelines state that the pre-filter must be upstream of the air conditioning equipment and the final filter downstream of any fans or blowers. All of the general purpose ORs reviewed were consistent with this requirement.

Ultraviolet radiation is sometimes recommended as a method to remove pathogens not removed by filtration (First et al., 1999). From the information available, it appeared that none of these projects included ultraviolet sources to treat supply air for the ORs.

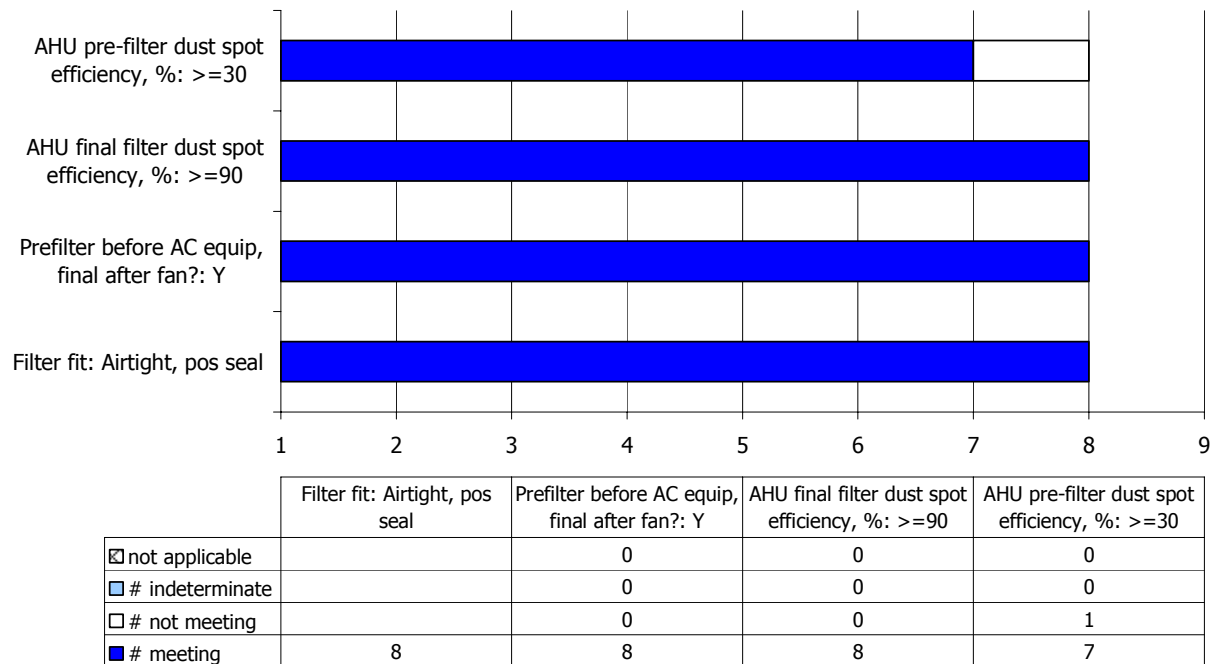


Figure 4. OR designs meeting AIA 2001 guidelines related to filter efficiency (n=8).

Air Distribution

Air distribution affects the spread of airborne infections in several ways. Proper placement of the supply outlets and return inlets directs airflow from clean toward less clean areas. Proper supply and return placement combined with proper selection of diffusers also provides sufficient mixing of the room air to allow pathogens to be swept from the space and returned to the air handler, where they can be removed or killed by the filters. In operating rooms, proper selection and placement of diffusers is important to minimize the fall of particulate contaminants onto the surgical site and sterile surfaces (Memarzadeh and Manning 2002).

The AIA guidelines state that in new construction and major renovations, “air supply for ..[ORs]... shall be from ceiling outlets near the center of the work area. Return air shall be near the floor level. Each...[OR] shall have at least two return air inlets located as remotely from each other as practical.” The guidelines do not specify the type of outlet or inlet. When supply outlets with vertical throws (Group E, ASHRAE 2005 p 33.7) are used, the layout required by AIA causes downward flow of clean air through the breathing and working zones to the floor level for removal.

All of the general purpose ORs reviewed had supply outlets mounted in the ceiling near the center of the room. Of the seven for which outlet types could be determined, five were Group E outlets with laminar flow (either explicitly stated in the contract documents or determined based on the models specified), one was Group E non-laminar, and one was adjustable from Group E to Group A air distribution. All of these ORs had returns in the sidewalls, but only four could be clearly determined from the mechanical plans to have these returns positioned low on the walls. All of the ORs had at least two returns, and all except one had these in opposite corners (Figure 5).

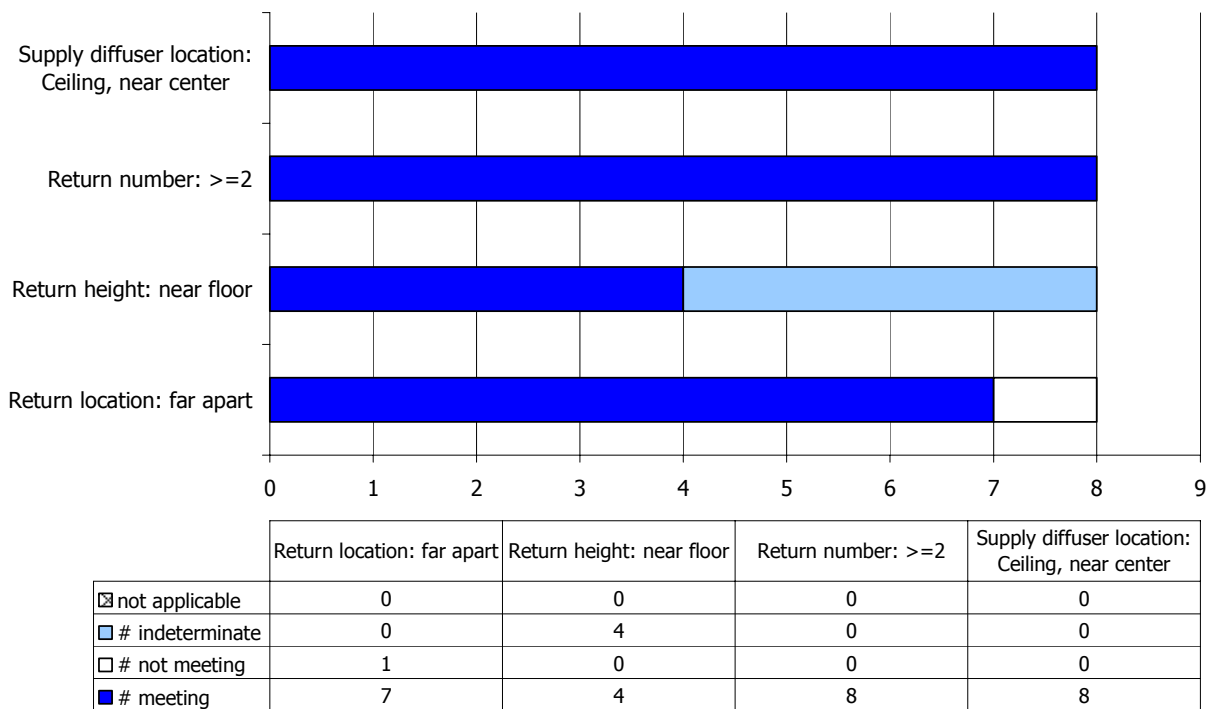


Figure 5. OR designs meeting AIA 2001 guidelines related to air distribution (n=8).

Differential Pressure Control

Keeping ORs at positive pressure relative to surrounding spaces reduces the potential for contaminated air to flow into the OR through gaps around doors or door frames and to pass-through openings, pipes, electrical outlets, light fixtures and other penetrations and joints between building components. Only one of the general purpose ORs reviewed explicitly specified an OR pressure, which was +0.04 in. wg (+ 10 Pa). This project and one other provided permanently installed electronic differential pressure (DP) sensors to monitor OR pressure. The 2001 AIA guidelines require a minimum DP of +0.01 in. wg (+ 2.5 Pa) for ORs. (Figure 8.)

As noted earlier, all of the general purpose ORs had constant supply air volume in occupied mode. None of the designs controlled return flows to maintain OR differential pressure in occupied mode. Three projects had terminal boxes on both the supply and return, with the box on the supply maintaining a flow setpoint and the box on the return maintaining a fixed difference between the supply and return/exhaust flow. Two projects had terminal boxes maintaining constant volume on the supply and provided motorized dampers on the return. In one case the motorized damper went to a preset position, and in the other case it went to its maximum position in occupied mode and was controlled by OR pressure in unoccupied mode. Two projects provided terminal boxes on the supply only, relying on static balancing to set a return flow lower than supply terminal box flow, and one used no terminal boxes, relying on static balancing on both supply and return to maintain return flow lower than supply flow.

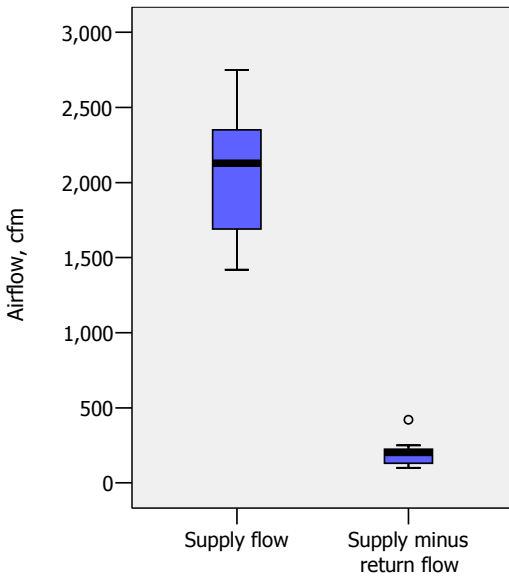


Figure 6. OR design supply air volume and design difference between supply and return volumes (n=8).

except at joints between building elements or at penetrations for piping, outlets, switches etc. We were able to determine from follow-up with the designers that one OR had a requirement for the perimeter to be sealed and one had sealed light fixtures. Because we did not have complete architectural and electrical specifications for most of the projects, we cannot say how many others included either a prescriptive or a performance requirement for the OR envelope to be sealed, or how many included a test for envelope tightness.

The actual OR pressure maintained depends on the excess of supply over return airflow and the leakiness of the OR boundaries. The eight general purpose ORs reviewed had differences between design supply and return/exhaust flow ranging from 100 cfm to 420 cfm (47 L/s to 198 L/s) with a median and mode of 200 cfm (94 L/s) (Figure 6). This is very similar to the findings from the survey, which were 100 cfm to 500 cfm with a median of 225 cfm (47 L/s to 236 L/s, with a median of 106 L/s). Most of the design flow differentials were in the range of 100 cfm to 200 cfm (47 L/s to 94 L/s) (Figure 7). Flow differentials ranged from 4 % to 19 % of total supply flow, with half the designs just under 10 % of total supply flow (Figure 7).

All of the general purpose ORs had gypsum board ceilings. We do not have information on the wall construction but in ORs it is generally tile or gypsum board. Thus the room surfaces should be leak-free

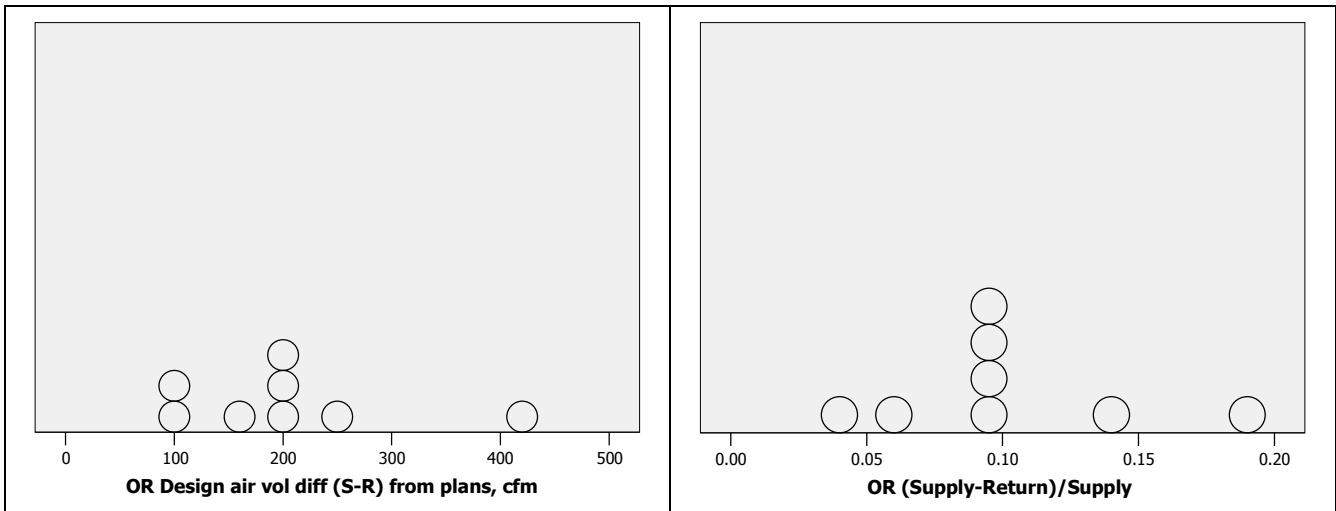


Figure 7. Individual values of the design difference between OR supply and return volumes and difference as a percentage of supply flow (n=8).

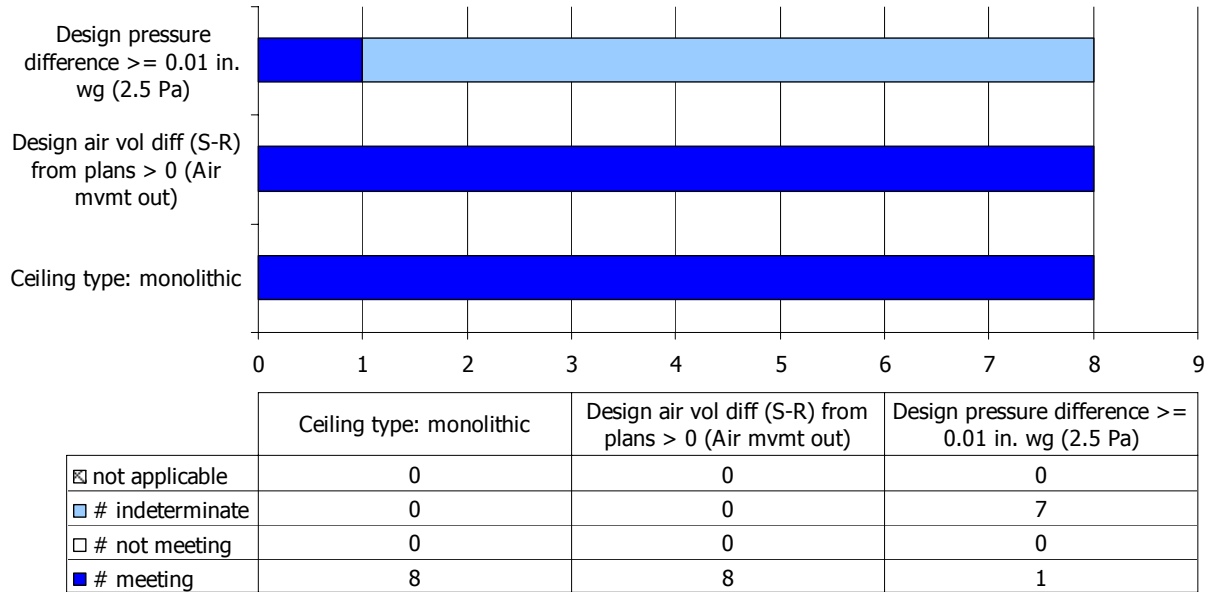


Figure 8. OR designs meeting AIA guidelines related to room pressurization (n=8).

An effective leakage area is implicit in the assumption that a given pressure difference can be maintained with a given airflow difference. The relationship is given by (ASHRAE 2001 p. 26.12):

$$A_L = C_5 Q_r \frac{\sqrt{\rho/2}}{C_D} \sqrt{\frac{1}{\Delta p_r}} \quad (1)$$

where:

A_L = effective leakage area, in²

C_5 = unit conversion factor = 0.186

Q_r = predicted (reference) airflow rate at reference pressure difference Δp_r , cfm

ρ = air density, lbm/ft³, assumed here to be the standard 0.0765 lbm/ft³

C_D = discharge coefficient, assumed to be 1.0 for effective leakage area as commonly calculated in the U.S.

Δp_r = reference pressure difference, inches of water, assumed here to be 0.016 in. wg, as commonly used in the U.S. This is equivalent to 4 Pa.

Since:

$$Q = C \Delta p^n \quad (2)$$

and n is typically assumed to be 0.65 for building leaks, Q_r in the above equation can be replaced by:

$$Q_r = \frac{Q_d}{\Delta p_d^{0.65}} \Delta p_r^{0.65} \quad (3)$$

where:

Q_d = design excess supply airflow reported by respondent, cfm (m^3/s)
 Δp_d = design room pressurization reported by respondent, inches of water (Pa)

With this substitution, the effective leakage area reduces to:

$$A_L = C_5 \frac{Q_d}{\Delta p_d^{0.65}} \frac{\sqrt{\rho/2}}{C_D} \Delta p_r^{0.65-0.5} = 0.019564 \frac{Q_d}{\Delta p_d^{0.65}} \quad (4)$$

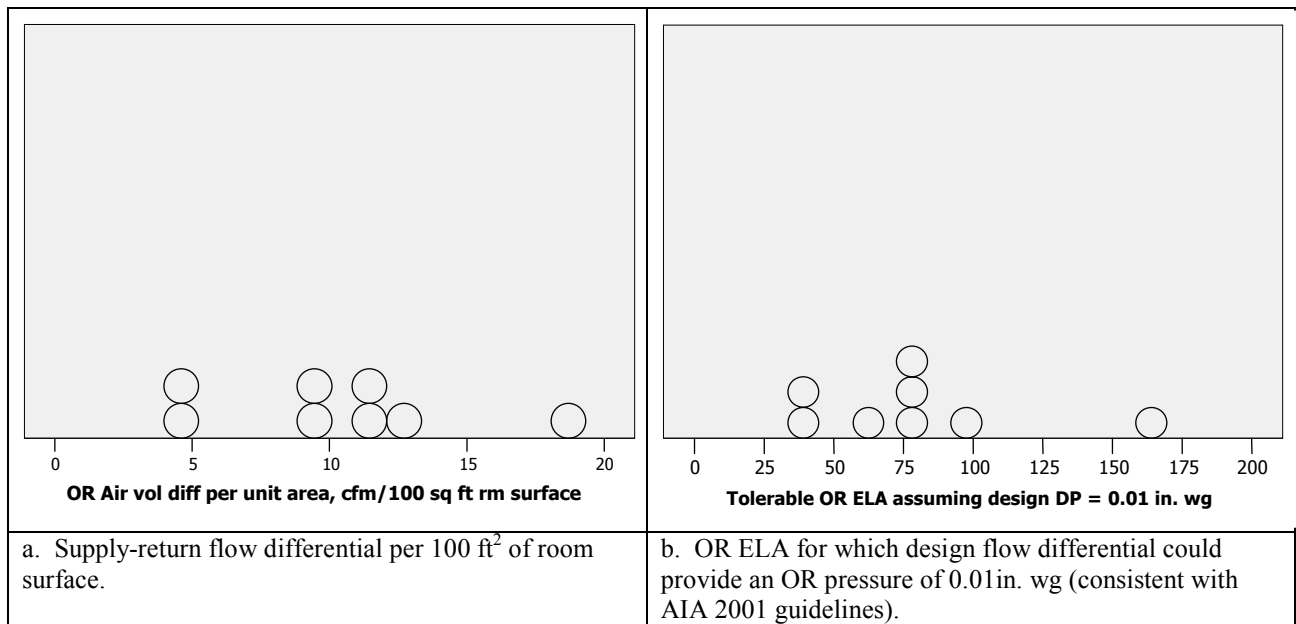


Figure 9. Measures of implicit OR leakage area (n=8).

For the one OR where a pressure difference was shown in the contract documents, the implicit effective leakage area calculated from the DP and the design excess supply airflow was 67 in² (432 cm²). (This OR had the highest flow differential, 420 cfm [198 L/s]).

The larger the difference between the supply and return flow, the greater the leakage (ELA) the design can tolerate while still providing a given space pressurization. For a desired OR pressure of +0.01 in. wg (+ 2.5 Pa) (meeting the 2001 AIA guidelines) the various ORs could tolerate ELAs of 39 in² to 164 in² (252 cm² to 1058 cm²) (Figure 9b). The OR that can tolerate the highest ELA and still provide a pressure of +0.01 in. wg (+ 2.5 Pa) is the one that was actually designed for a DP of

+0.04 in. wg (+10 Pa). Omitting this OR, the others could have leakage areas of 39 in² to 98 in² (252 cm² to 632 cm²) and meet the AIA guideline pressure of +0.01 in. wg (+ 2.5 Pa). Larger ELAs could be accommodated by reducing the return airflow (within limits imposed by constraints on mixed air conditions). Only three of the balancing specifications address the issue of balancing for room pressurization, however. The balancing specification for project #8 states that balancing “shall include verification of the pressure relationships in each Operating Room in both the occupied and unoccupied modes” and that the reference is the perimeter corridor. The specification for project #9 states that “room grill and register flows may be plus or minus 10 %, however, maintaining positive, neutral or negative pressures as shown...” and specifically identifies the OR as one of the room types that “must operate at positive pressure relative to their surroundings.” The specification for project #7 discusses procedures for space pressurization measurements and adjustments at some length, but states that the balancer is to “measure space pressure differential where pressure is used as the design criteria, and measure airflow differential where differential airflow is used as the design criteria for space pressurization.” For the OR the latter is the case, so the balancing process as specified would not assure any particular space pressure.

As a point of comparison to the ELA range above, the half-inch undercut of a four foot wide door for an emergency care isolation room was found through tests to have an ELA of 23 in² (148 cm²) (Bohac, 2006). A typical OR door would be wider than this and could have gaps along the side and top as well as the bottom. For swinging OR doors, these gaps could be substantial. ELAs for other penetrations and joints in hospital environments are not readily available.

Since the actual design pressure difference was not available for most of the ORs, we also calculated the airflow difference per hundred square feet of OR surface (ceiling, walls and floor) as an alternative metric. This ranged by a factor of four from 4.4 cfm to 18.7 cfm per 100 ft² (0.22 L/s.m² to 0.95 L/s.m²) with a median of 10.3 cfm/100 ft² (0.52 L/s.m²) (Figure 9a).

Humidification

The AIA guidelines require that the humidity in ORs be maintained between 30 % and 60 % and that any humidifier use steam rather than spray or low temperature evaporation. The use of steam minimizes the risk of the humidification itself serving as a source of microorganisms (Parat et al. 1996). All of the general purpose OR designs included steam humidification, either at the air handler (3 projects), in the OR duct (2 projects) or both (3 projects), and thus met the AIA guidelines (Figure 10).

Operating Room Designs Meeting AIA 2001 Guidelines Related to Humidity

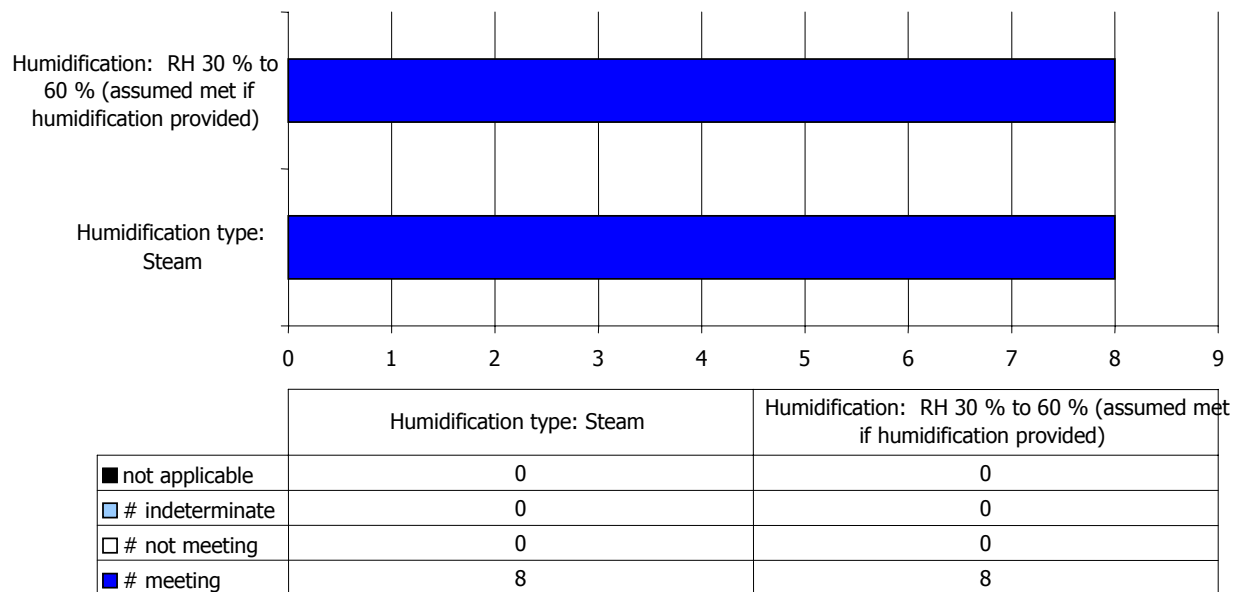


Figure 10. OR designs meeting AIA 2001 guidelines related to humidification (n=8).

Minimization of Mold Growth in Ductwork

The AIA guidelines state that “duct linings exposed to air movement shall not be used in ducts serving operating rooms...” None of the projects had internal duct insulation on the supplies. In two cases there was or may have been internal insulation on the returns, but we did not consider this to be in violation of the AIA guidelines since any duct lining particles would be removed by the filters.

The AIA guidelines include several requirements to minimize the risk of mold growth in the duct work downstream of humidifiers:

- If the humidifier is upstream of the final filters, it must be located at least 15 ft (4.6 m) upstream,
- A means of water removal must be provided,
- An adjustable high limit humidistat must be provided downstream of the humidifier,
- All duct takeoffs must be far enough downstream to ensure complete moisture absorption, and
- Duct lining must not be installed within 15 ft (4.6 m) downstream of the humidifier.

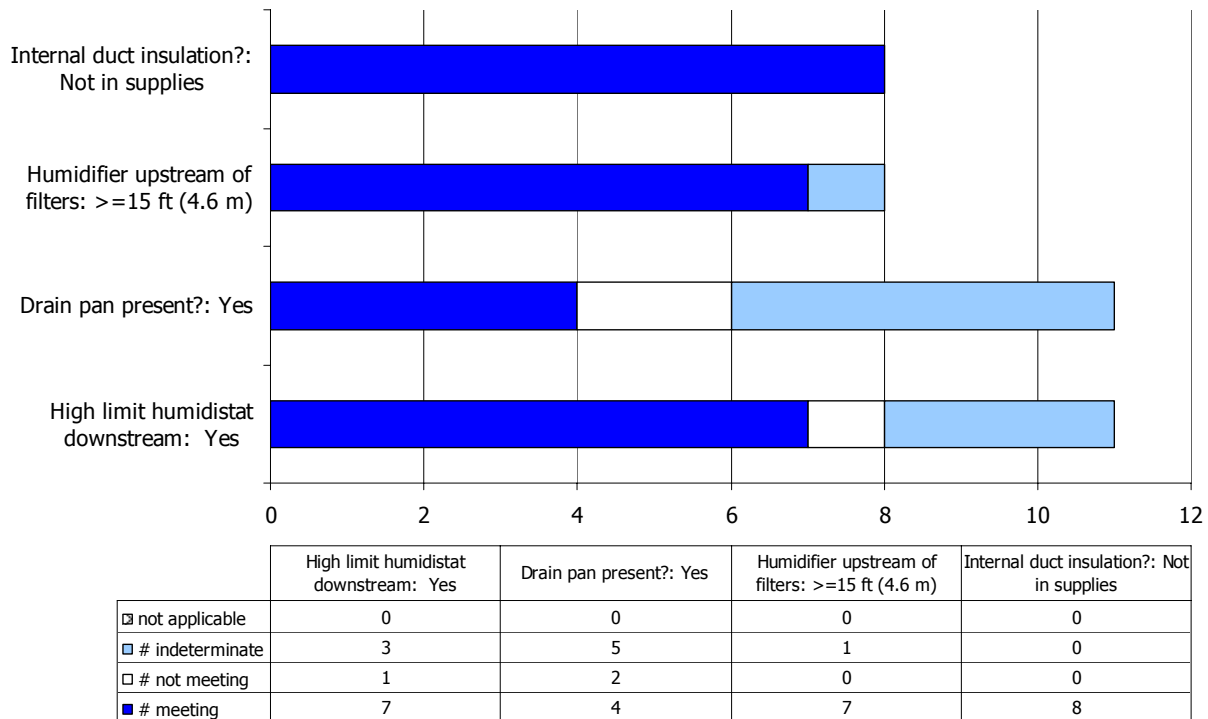


Figure 11. OR designs meeting AIA 2001 guidelines related to minimization of mold growth in ductwork. For duct insulation and humidifier location, n=8 projects. For drain pans and humidistats, n= 11 humidifiers, 6 at the air handler and 5 in the duct serving the OR (3 projects had both).

Six ORs had humidification at the air handler, and we were able to determine the location relative to the final filter for five of these. Three were downstream of the filter, one was 30 ft (9.1 m) upstream of it, and one was 15 ft (4.6 m) upstream. Two projects had humidification only in the OR duct. Thus seven met the AIA criterion that the humidification be either downstream of the filter or at least 15 ft (4.6 m) upstream of it, and the eighth was indeterminate.

We were able to confirm the presence of drain pans for removal of condensate for three of the six humidifiers located in AHUs and for one of the five humidifiers located in the OR duct. We were able to confirm the presence of high limit humidistats downstream of seven of the eleven humidifiers.

For seven of the eleven humidifiers, the first duct takeoff was 16 ft (4.9 m) or more downstream of the unit, but in three cases the distance was 5 ft to 7 ft (1.5 m to 2.1 m) and in the case of one duct humidifier, the location was not shown.

Since none of the hospitals had internal insulation on the supply ducts, all were consistent with the AIA requirement that duct lining not be installed within 15 ft (4.6 m) downstream of humidifiers.

Special Purpose ORs

Two of the projects (#8 and #10) had special purpose ORs. Project 8 had a clean OR and a switchable OR, and project 10 had two high volume ORs. These differed from the general purpose

ORs primarily in terms of total air change rates, outdoor air change rates, design difference between supply and exhaust flow, and filtration.

The clean OR provided approximately 39 h⁻¹ of total supply air and 12 h⁻¹ of outdoor air. The design supply flow was 620 cfm (293 L/s) higher than the return flow, but the design room pressure was not specified. At the AIA recommended OR pressure of + 0.01 in. wg (+2.5 Pa), the design flow difference could accommodate an effective leakage area of 242 in² (1561 cm²); at + 0.03 in. wg (~7.5 Pa), it could accommodate an ELA of 119 in² (768 cm²). This OR had zone level filtration with a dust spot efficiency of 99.97 %, in addition to 30 %, 95 % and 99.97 % efficient filter beds in the air handler.

The two high volume ORs provided approximately 42 h⁻¹ of total supply air and 10 h⁻¹ of outdoor air. They had design flows 200 cfm (94 L/s) higher than the return flow, in line with the flow differentials for the general purpose ORs. The switchable OR provided approximately 33 h⁻¹ of total supply air and 9 h⁻¹ of outdoor air. It had a design supply flow 245 cfm (116 L/s) *less* than the return flow.

Design of Airborne Infection Isolation Rooms

AIA Design Guidelines for All Rooms

Table 4 shows key AIA 2001 requirements for the design and construction of airborne infection isolation (AII) rooms. As with the ORs, these requirements were the primary point of reference against which the project plans and specifications were compared. One of the projects (#2) with an AII room only (no ORs) was a Veterans Affairs (VA) hospital addition, so some of the VA design criteria are also presented.

Table 4. Key AIA 2001 guidelines for design and construction of airborne infection isolation rooms.

Item	AIA 2001 Guidelines
ANTEROOMS	
Is there an anteroom?	[Not required for general AII room.] Table 2 [Note 16] If the facility determines that airborne infection isolation is necessary for protective environment patients, an anteroom should be provided.
Series or parallel layout?	[No requirement]

Table 4, continued.

DILUTION	
Total ACH, Patient Room	7.31.D1...For rooms listed in Table 7.2, where VAV systems are used, minimum total air change shall be within limits noted. Table 2. Minimum total air changes per hour: 12. [Note 4]: Number of air changes may be reduced when the room is unoccupied if provisions are made to ensure that the number of air changes indicated is reestablished any time the space is being utilized. Adjustments shall include provisions so that the direction of air movement shall remain the same when the number of air changes is reduced...Air quantity calculations must account for filter loading such that the indicated air change rates are provided up until the time of filter change-out. [Note 5]: Air change requirements indicated are minimum values. Higher values should be used when required to maintain indicated room conditions (temperature and humidity), based on the cooling load of the space... [Note 17]: Supplemental recirculating devices may be used in the patient room, to increase the equivalent room air exchanges; however, such recirculating devices do not provide the outdoor air requirements. Air may be recirculated within individual isolation rooms if HEPA filters are used. Table 2: All air exhausted directly to outdoors: Yes. [Note 18]: If it is not practical to exhaust the air from the airborne infection isolation room to the outdoors, the air may be returned to the air-handling system through HEPA filters.
Total ACH, Toilet Room	7.31.D1...For rooms listed in Table 7.2, where VAV systems are used, minimum total air change shall be within limits noted. Table 2: 10
Total ACH, Anteroom	7.31.D1...For rooms listed in Table 7.2, where VAV systems are used, minimum total air change shall be within limits noted. Table 2: 10
Outdoor Air ACH, Patient Room	Table 2. Minimum air changes of outdoor air per hour: 2. [Note 3] ... Minimum outdoor air quantities shall remain constant while the system is in operation.
All rm all air exhausted directly to outdoors?	Table 2: Yes. [Note 15] If it is not practical to exhaust the air from the airborne infection isolation room to the outdoors, the air may be returned through HEPA filters to the air-handling system exclusively serving the isolation room.
Distance from All room exhaust to nearest OA intake	[See text under ORs]
FILTRATION AND AIR TREATMENT	
AHU filter efficiency Pre/Final	[See text under ORs]
Filter frame/installation	[See text under ORs]
Zone level filter efficiency	[No requirement]
Ultraviolet treatment	[No requirement]
AIR DISTRIBUTION	
Supply diffuser type	[No requirement]
Supply diffuser location	[No requirement]
Return grill location	[No requirement]
Airflow direction	7.31.D1...To maintain asepsis control, airflow supply and exhaust should generally be controlled to ensure movement of air from "clean" to "less clean" areas.

Table 4, continued.

ROOM PRESSURIZATION	
Design pressure difference	Table 2. [Note 11]: Differential pressure shall be a minimum of 0.01" water gauge (2.5 Pa). If alarms are installed, allowances shall be made to prevent nuisance alarms of monitoring devices.
Use of terminal boxes	[No requirement]
Method of room pressure control	[No requirement]
Method of room pressure monitoring	7.2.C7. Rooms shall have a permanently installed visual mechanism to constantly monitor the pressure status of the room when occupied by patients with an airborne infectious disease. The mechanism shall continuously monitor the direction of airflow.
Design difference in airflow (supply – return), patient rm	Table 2. Air movement relationship to adjacent area: In.
Design difference in airflow (supply – return), toilet rm	Table 2. Air movement relationship to adjacent area: In.
Design difference in airflow (supply – return), anteroom	Table 2: Air movement relationship to adjacent area: In/Out.
Ceiling Type? All walls to structure? Sealing leaks, fire walls, other?	7.2.C3. Airborne infection isolation room perimeter walls, ceiling, and floors, including penetrations, shall be sealed tightly so that air does not infiltrate the environment from the outdoor or from other spaces. (See Glossary.) Glossary. Sealed (tight) room: A room that meets specific ventilation requirements and must have a minimum air leakage to achieve a particular designed air quality, airflow direction, and pressure differential. 7.28.B6. ... In operating rooms, delivery rooms for caesarean sections, isolation rooms, and sterile processing rooms, wall finishes shall be free of fissures, open joints, or crevices that may retain or permit passage of dirt particles. 7.28.B7. Floors and walls penetrated by pipes, ducts, and conduits shall be tightly sealed to minimize entry of rodents and insects. Joints of structural elements shall be similarly sealed.
Perf. spec for room tightness?	[No requirement]
Test for room tightness?	[No requirement]
HUMIDIFICATION	
Relative humidity	[No requirement]
Humidifier type	[See text under ORs]
MINIMIZATION OF MOLD GROWTH IN DUCTWORK	
Duct lining/insulation	7.31.B.7. Duct lining shall not be installed within 15 feet (4.6 meters) downstream of humidifiers.
Humidifier placement and control	[See text under ORs]
Antimicrobial duct coating	[No requirement]

Anterooms

Anterooms for AII rooms are not required by the AIA guidelines, and the guidelines do not address the subject of anteroom layout. Six of the ten AII rooms reviewed had anterooms. Four suites were laid out in series so that the patient room could be accessed only through the anteroom, while two were laid out in parallel so that both the anteroom and the patient room could be accessed from the corridor, and the patient room could also be accessed through the anteroom (Figure 12).

Two of the six anterooms were designed for net outflow of air (supply flow greater than exhaust flow), two for zero net flow, and two for net inflow of air. The AIA guidelines do not address anteroom pressures or net anteroom airflows. The CDC guidelines (2003) include illustrations by Streifel indicating that an anteroom that is at a negative pressure relative to the corridor but positive pressure relative to the patient room (and has its own supply and exhaust) is recommended for a patient with an airborne infectious disease, while an anteroom that is neutral to the corridor and positive to the patient room (supply only) or that is negative relative to both the corridor and the

patient room (exhaust only) is recommended for a patient with an airborne infection who is also immune-compromised (Figure 13).

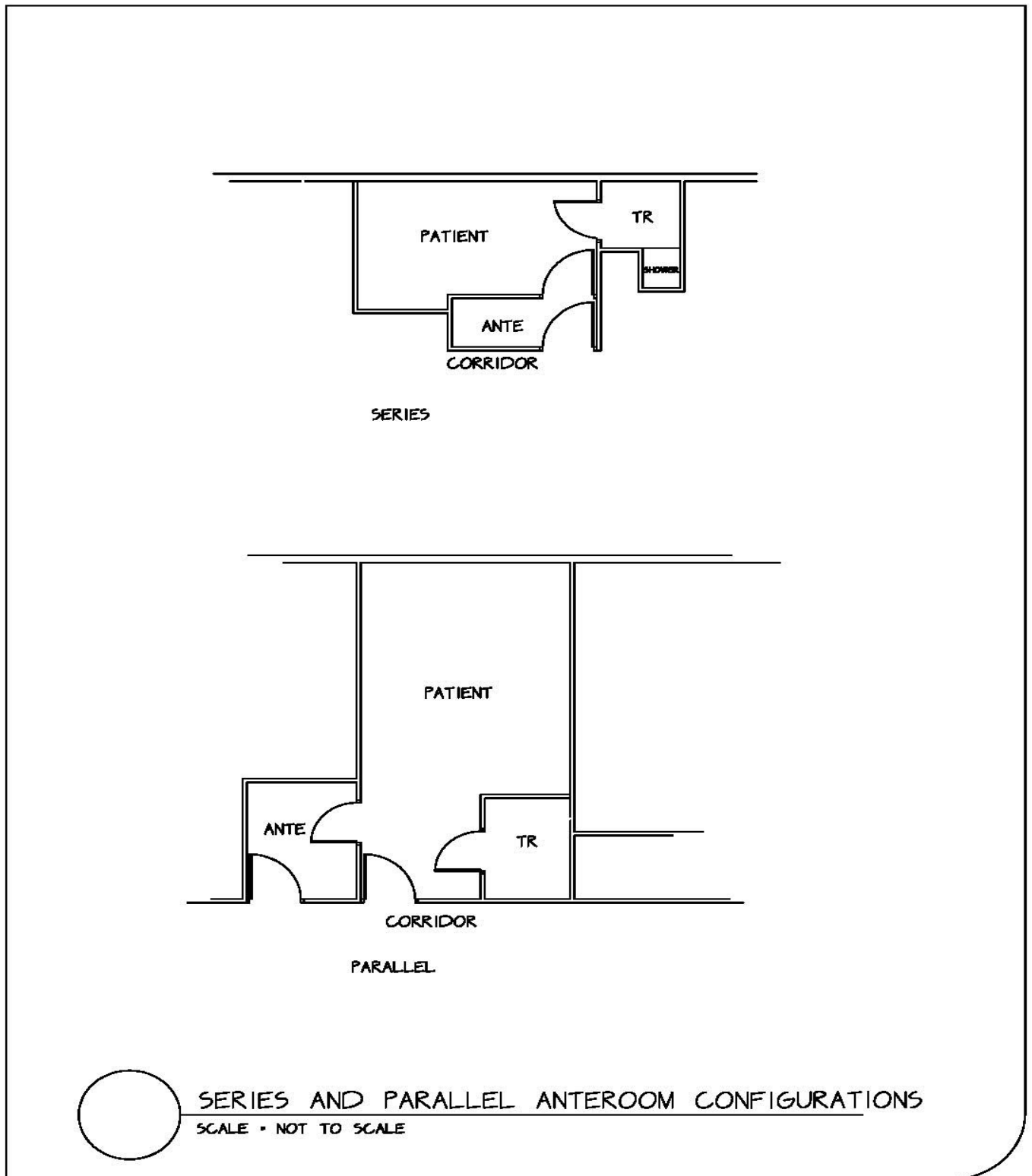


Figure 12. Series (top) and parallel (bottom) anteroom layouts.

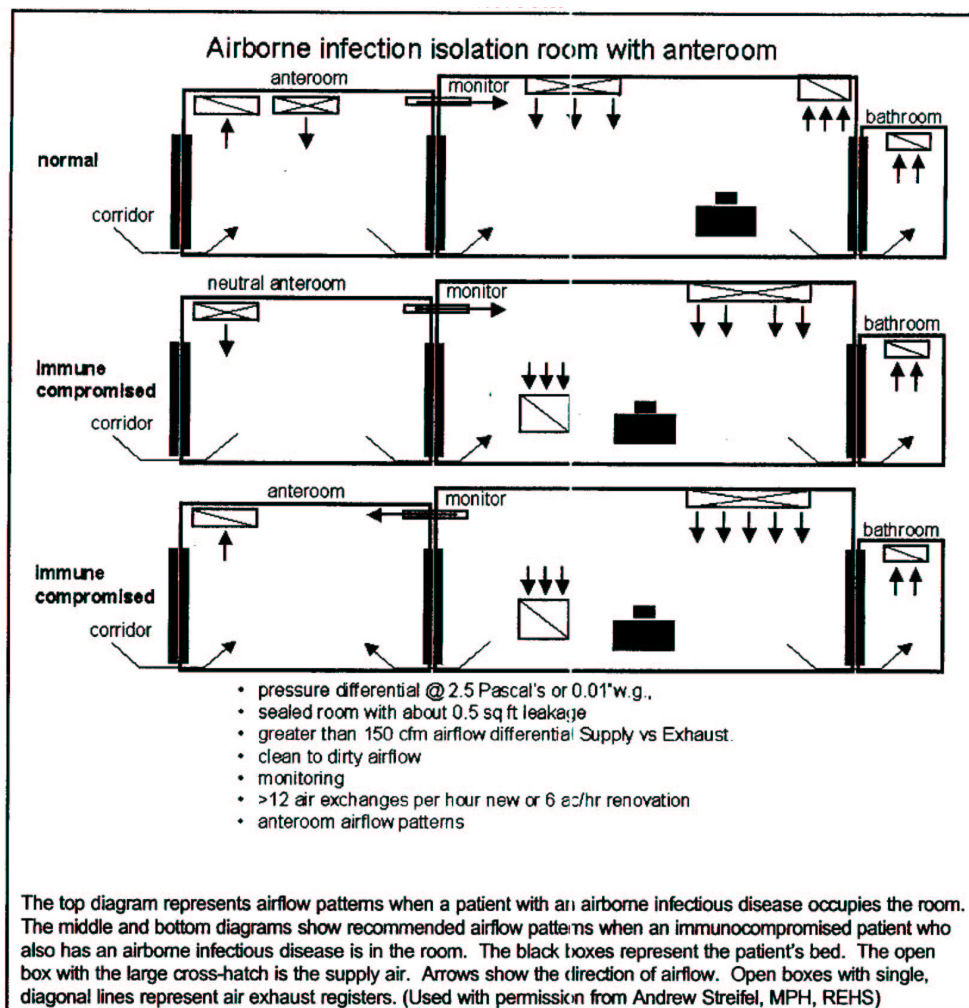


Figure 13. Alternative pressure relationships for AII room, anteroom and corridor (CDC 2003, after Streifel – used with permission of Andrew Streifel).

Dilution

There was no return flow from the AII room itself, the toilet room, or the anteroom (if there was one) for any of the AII rooms reviewed. This is consistent with the AIA guidelines which require all AII room air to be exhausted directly to outdoors or, if this is not practical, to be returned through HEPA filters to an air handling system exclusively serving the isolation room.

Total air changes per hour for the AII room itself were calculated as the total AII room exhaust divided by the AII room volume. Total AII room exhaust included both the exhaust from the patient room itself and the net exhaust (supply minus exhaust) from the adjoining toilet room:¹

¹ If patient room supply flow was constant and exhaust flow controlled based on room differential pressure, the supply flow was treated as the minimum possible exhaust flow and used in place of exhaust flow in the calculation. In two cases the anterooms had net exhaust, but this was not included in the patient room total air changes because the fraction drawn from the patient room as opposed to the corridor is unknown.

$$ACH_{AII, total} = Q_{E,AII} + \min(0, Q_{S, toilet room} - Q_{E, toilet room})$$

Total AII room air changes ranged from 8.5 h⁻¹ to 21.9 h⁻¹ with a median of 14.6 h⁻¹ (Figure 14). Nine of the ten projects met the 2001 AIA guidelines' requirement for 12 h⁻¹ in AII rooms (Figure 15), which is also the air change rate required by the VA (2000) and recommended by the ASHRAE 2003 *Applications* handbook. (ASHRAE 2003)

To calculate the outdoor air change rate requires consideration of the type of supply airflow control. Eight of the ten AII rooms had constant supply airflow. For these, the outdoor airflow rate was determined by multiplying the AII room supply flow rate by the minimum outdoor air percentage at the air handler. Two of the AII rooms had variable supply airflow, one based on space temperature and one on space pressure. The former was on an air handler for which the minimum outdoor air quantity was dynamically reset by continuous recalculation using the multiple space equation from ASHRAE Standard 62-2001 (a version of these calculations that has since been revised in the 2004 version of the standard). This control strategy assures that the design outdoor airflow is supplied to each room at all times, so the design outdoor air volume was used. The latter was on an air handler for which the OA dampers modulated to maintain a constant (adjustable) outdoor airflow volume. This control strategy provides an approximately constant outdoor airflow volume to each room served provided that the rooms' supply airflow changes little (which is probably true for this room, where VAV box flow varies to maintain space pressure) or that they all require approximately the same percentage of outdoor air.² It was assumed that this AII room would receive a reasonably consistent volume of unvitiated outdoor air, although this may be an overestimate. The AII room outdoor air change rate ranged from 1.9 h⁻¹ to 4.9 h⁻¹ with a median of 3.1 h⁻¹ (Figure 14). Nine of the ten are consistent with the AIA guidelines' requirement (and VA 2000 requirement) of 2.0 h⁻¹, and the tenth is only slightly below this (Figure 15).

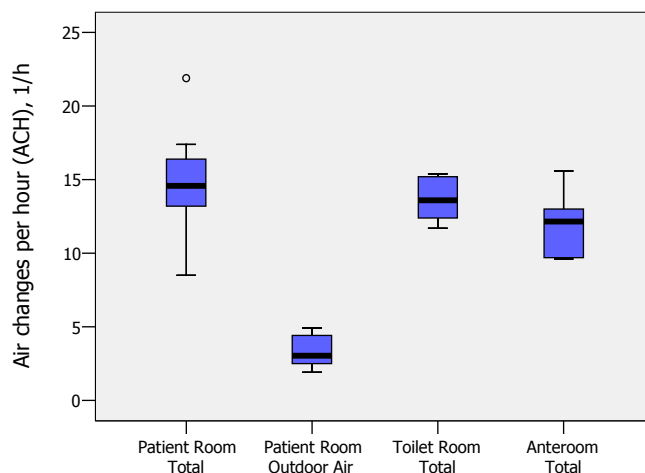


Figure 14. AII room total air changes and outside air changes, toilet room total air changes, anteroom total air changes.

For the six AII rooms with anterooms, anteroom air changes were calculated by dividing the greater of anteroom supply flow or anteroom exhaust flow by anteroom volume, and ranged from 9.6 h⁻¹ to 15.6 h⁻¹ with a median of 12.2 h⁻¹ (Figure 14). The AIA guidelines require 10 h⁻¹ for anterooms but it is not entirely clear whether this refers to all anterooms or only anterooms for protective environment rooms housing patients who also require airborne infection isolation. Two of the AII rooms reviewed have air changes slightly below this level (Figure 15).

² This may well not be true since the air handler serves about half patient rooms and the rest a mixture of nurses' work rooms, equipment rooms, lounges, offices, and other spaces.

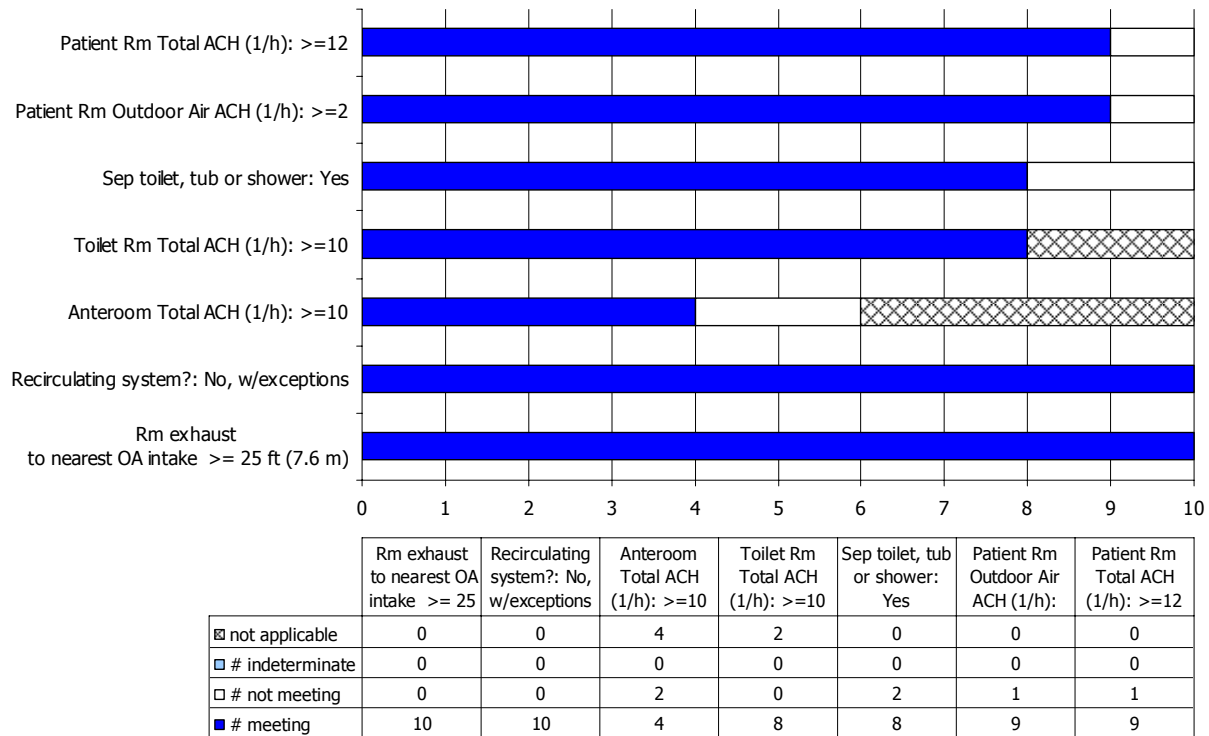


Figure 15. AII room designs meeting AIA 2001 guidelines related to dilution (n=10).

Nine of the ten AII rooms included toilet facilities. For project #9, the toilet and sink were within the patient room, separated only by a curtain, and there was no tub or shower. For project #2, the AII room reviewed was an AII exam room rather than a patient room, and there were common toilet facilities for multiple rooms. The AIA guidelines state that “Separate toilet, bathtub (or shower), and handwashing stations shall be required for each airborne infection isolation room” (7.2.C5), so only eight projects met these criteria. The AII guidelines require 10 h^{-1} for toilet rooms. For the eight AII rooms with separate toilet rooms, toilet room exhaust ranged from 11.7 h^{-1} to 15.4 h^{-1} with a median of 13.6 h^{-1} (Figure 14).

Filtration and Air Treatment

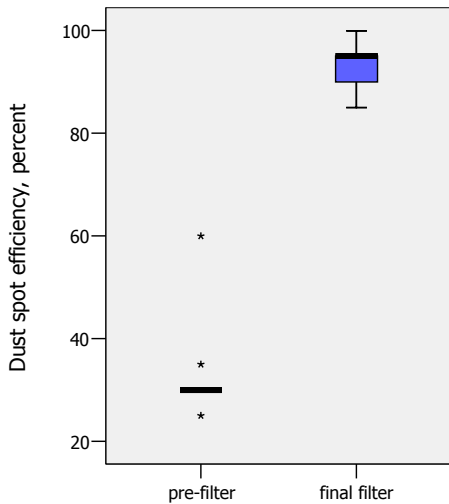


Figure 16. AII room first and final filter efficiencies.

Nine of the AII rooms were served by air handlers having two filter beds, while one was served by an air handler having three filter beds. Dust spot efficiencies specified for filter bed no. 1 ranged from 25 % to 60 %, with a median and mode of 30 % efficiency. Final filter efficiencies specified ranged from 85 % to 99.97 % with a median and mode of 95 % (Figure 16).

The AIA guidelines do not give a specific requirement for filter efficiency in AII rooms. As noted earlier, their general requirement for inpatient care, treatment and diagnosis areas is 30 % for filter bed no. 1 and 90 % for filter bed no. 2. Two of the AII rooms reviewed do not meet these criteria (Figure 17). One has a 25 % efficient pre-filter (consistent with the 1999 ASHRAE *Handbook*) and one, the VA project, has an 85 % efficient final filter. The VA 2000 requirement for filter efficiency in patient exam rooms and bedrooms is 85 %.

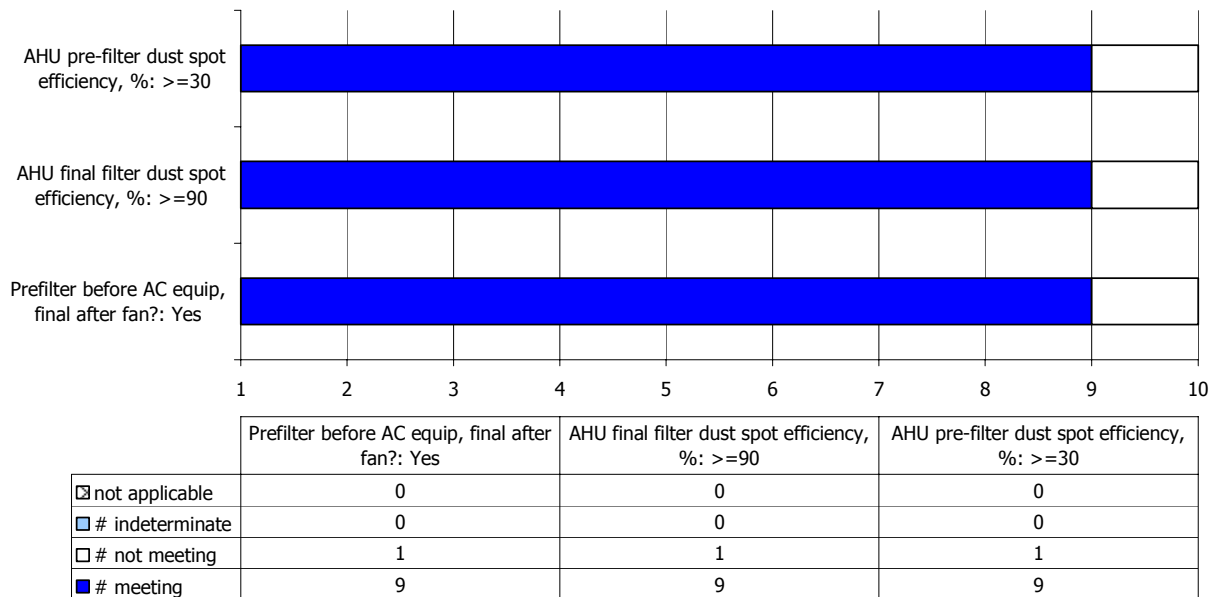


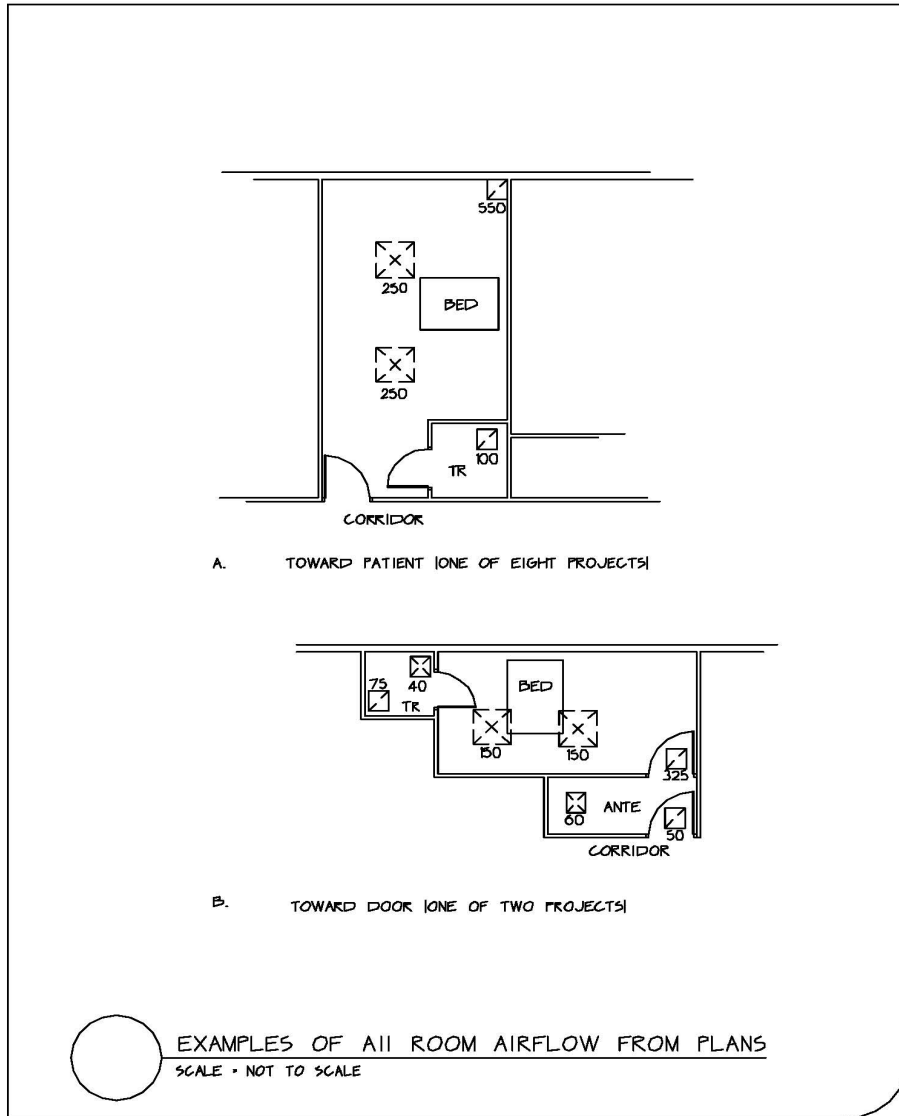
Figure 17. AII room designs meeting AIA 2001 guidelines related to filtration (n=10).

Nine of the air handlers had the pre-filter upstream of the air conditioning equipment and the final filter downstream of any fans or blowers, which is consistent with the AIA guidelines (Figure 17). The tenth, the VA project, had both sets of filters upstream of the coils and fans. The VA only requires the final filter to be downstream of the supply air fans for “critical functions, such as...surgical suite, recovery rooms, and intensive care units.” None of the AII rooms reviewed had

zone level filters. From the information available, it also appeared that none of these projects included ultraviolet sources to treat supply air for the AII rooms.

Air Distribution

The layout of the AII room supply outlets and exhaust inlets determines the direction of airflow in the room. In eight of the rooms, supply air flowed toward the patient to an exhaust away from the door (Figure 18, top).



This flow pattern helps to capture and exhaust airborne contaminants. Two of the rooms had airflow toward the door (Figure 18, bottom). It is believed that this flow pattern can increase the likelihood that airborne contaminants will enter the breathing zone of staff or visitors or will be released from the room due to door openings.

All ten of the AII rooms had ceiling supply diffusers. Seven had Group A outlets, that is, outlets that discharge air horizontally (ASHRAE 2005, p 33.7). One had both Group A outlets and Group E outlets (which project primary air vertically) and two had outlets that could be adjusted to provide either A or E flow patterns. Seven of the AII rooms had ceiling exhaust grilles, and three had low sidewall grilles. Memarzadeh and Jiang (2000) concluded from isolation room modeling

that “high level exhaust is more effective than low level exhausts in removing particles through ventilation” for the particle release points they considered.

The AIA guidelines do not include requirements for outlet or inlet types or locations in AII rooms. They do state in a more general context that “airflow supply and exhaust should generally be controlled to ensure movement of air from ‘clean’ to ‘less clean’ areas.”

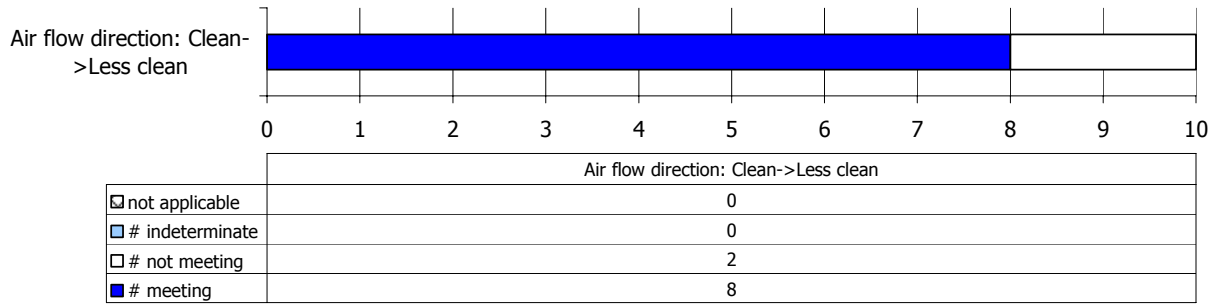


Figure 19. AII room designs meeting AIA 2001 guidelines related to air distribution. AII rooms with flow from the door toward the patient were considered to meet the guidelines.

Differential Pressure Control

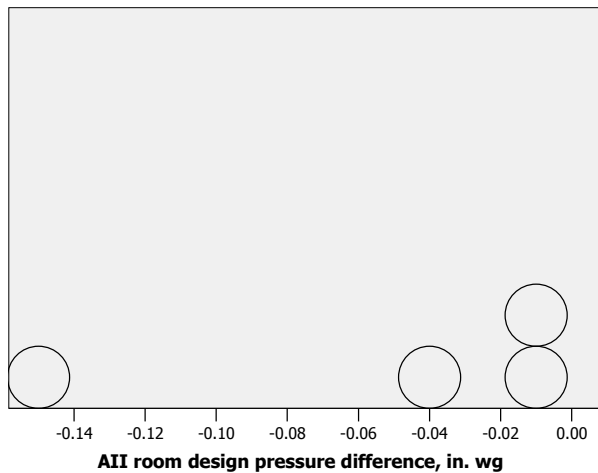


Figure 20. AII room design pressures.

The AIA guidelines require a permanently installed visual mechanism to constantly monitor the pressure status of AII rooms. Seven of the AII rooms had a permanently installed electronic DP sensor (Figure 21). Three had no permanently installed monitoring device, perhaps relying on use of flutter strips or chemical smoke pencils by the medical staff to check flow direction.

The three AII rooms *without* anterooms that had permanently installed monitoring equipment measured AII room pressure relative to the corridor. Among the four AII rooms *with* anterooms that had permanently installed monitoring equipment, one measured the

pressure difference between the patient room and the corridor, two measured the pressure difference between the patient room and the anteroom, and one measured the pressure difference between the anteroom and the corridor. The AIA guidelines are somewhat ambiguous about the point of reference for the pressure measurement.³ The CDC guidelines, on the other hand, clearly state a

³ The column in Table 7.2 that deals with this is labeled “air movement relationship to adjacent area.” Note 2 states that “any form of variable air volume or load shedding system... must not compromise the corridor-to-room pressure balancing relationships...” This is the only explicit mention of the corridor.

requirement to “Maintain continuous negative air pressure... in relation to the air pressure in the corridor,” although they only call for monitoring “periodically... at the door.”

Only four of the plans/specifications indicated a specific differential pressure; these were: -0.001 in. wg, -0.01 in. wg, -0.04 in. wg and -0.15 in. wg (-0.25 Pa, -2.5 Pa, -10 Pa and -37.4 Pa). A fifth, the VA project, indicated a range of -0.003 in. wg to -0.03 in. wg (-0.75 Pa to -7.5 Pa). This designer noted that he designs to a percent difference in airflow rather than a differential pressure *per se*; the VA 2000 requirements read, “for the space to be maintained under negative pressure, exhaust 15 % more air than the supply.” For the five other AII rooms, the design DP is not explicitly stated in the contract documents. The 2001 AIA guidelines require that a pressure difference of -0.01 in. wg (-2.5 Pa) be maintained; this is an increase from the requirement of -0.001 in. wg (-0.25 Pa) in the 1997 guidelines. Only three projects are definitely in compliance with this requirement (Figure 21).

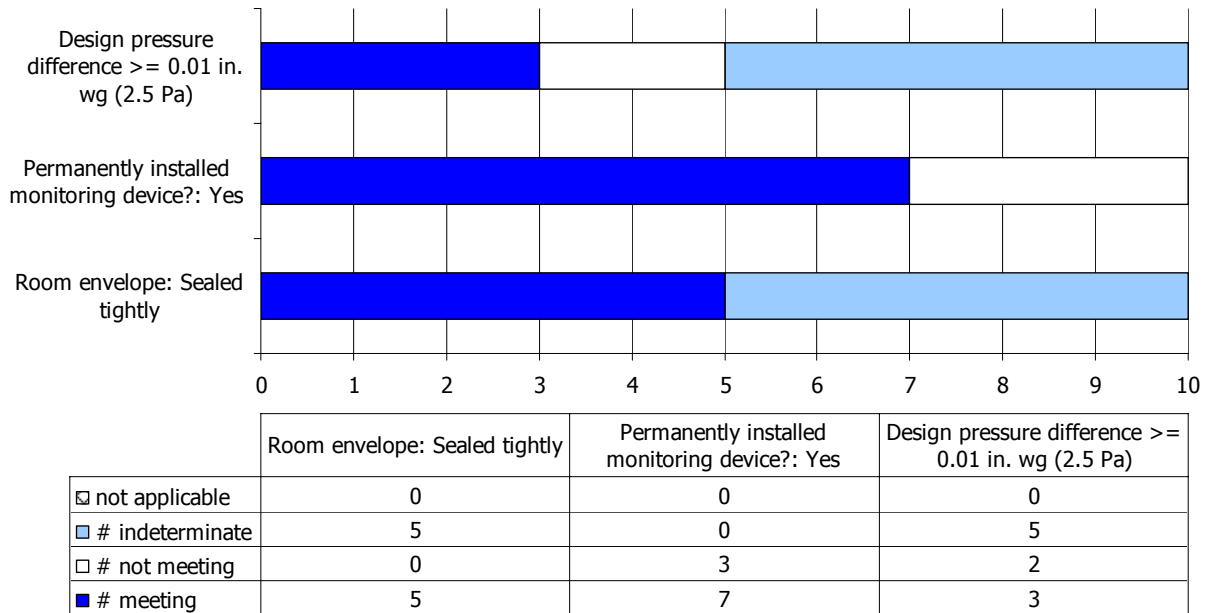


Figure 21. AII room designs meeting AIA 2001 guidelines related to room pressurization.

Four of the designs controlled terminal equipment based on room pressure. These included the project with a design AII room pressure range of -0.003 in. wg to -0.03 in. wg (-0.75 Pa to -7.5 Pa), the project with a design pressure of -0.15 in. wg (-37.4 Pa) and two projects where no design pressure was specified. One of these projects had terminal boxes on both the supply and exhaust, with the supply airflow controlled to constant volume and the exhaust airflow controlled to provide a constant room DP. A second had a terminal box on the supply and motorized dampers on the exhaust, again with the supply controlled to a constant volume and the return to a constant room DP. The other two had terminal boxes on the supply only and controlled supply flow to maintain a constant room DP.

Another design had a terminal box on the supply and an air valve on the exhaust. The supply was controlled to a constant volume but it was not clear from the documents available how the exhaust was controlled.

Three other designs had terminal boxes on the supplies only that were controlled to provide a constant flow. Another had a terminal box on the supply only that varied flow for room temperature control (conventional VAV). One design had no terminal boxes on either supply or return. None of these five addressed room pressure in the balancing specifications.

Only three projects did address room pressures in their balancing specifications, projects #7 and #8, which controlled AII room flow on room pressure, and project #9, for which the method of exhaust control was not specified. The specification for project #7 requires balancing for “space pressure differential where pressure is used as the design criteria,” but no design AII room pressure was provided. The specification for project #8 states that balancing “shall include verification of the pressure relationships in each Isolation Room...” and a design pressure *was* provided. The specification for project #9 states that “room grill and register flows may be plus or minus 10 %, however, maintaining positive, neutral or negative pressures as shown...” but did not state a design AII room pressure.

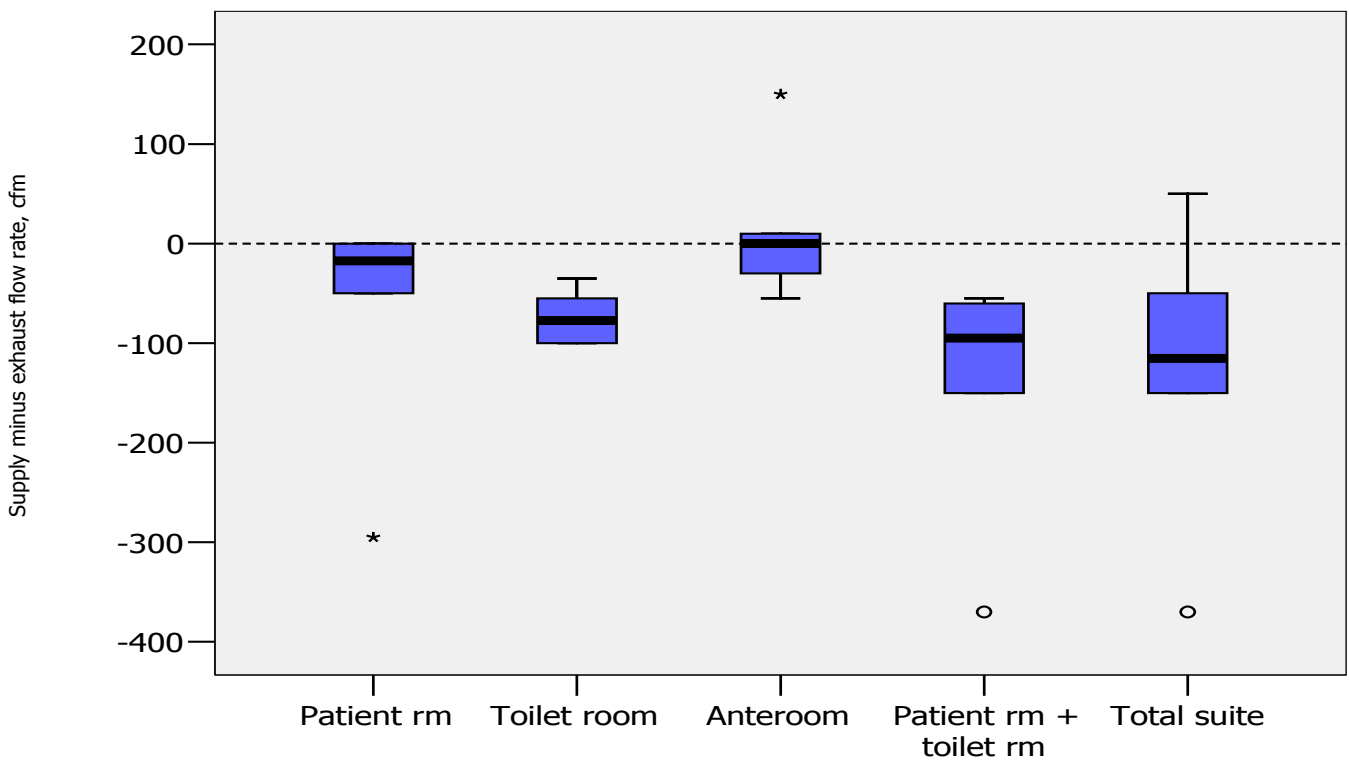


Figure 22. Flow differences (supply minus return) for AII rooms.

The actual pressure difference maintained depends on the difference between supply and exhaust airflows and the leakiness of the room boundaries. Supply minus exhaust flow was calculated separately for the patient room, the toilet room (if any), and the anteroom (if any). A subtotal for the patient room plus toilet room and a total for the suite including the anteroom were also

calculated.⁴ For the patient room plus toilet room, the net flow ranged from -50 cfm to -370 cfm (-24 L/s to -175 L/s) with a median of -95 cfm (-45 L/s). With the anteroom included, the design net flow for the suite ranged from +50 cfm to -370 cfm (= 24 L/s to -175 L/s) with a median of -115 cfm (-54 L/s) (Figure 22).

Only three of the AII rooms on non-critical care nursing wards had ceilings entirely of gypsum board. Four had lay-in tile ceilings. Two had a combination of gypsum and tile; in one case the ceiling was primarily gypsum with lay-in tile in the center of the room, and in the other case gypsum was used over the toilet room and an internal corridor and lay-in tile over the patient room itself. For the tenth room, we were unable to determine the ceiling type. Air can flow across a lay-in tile ceiling in response to pressure differences, so air flows up through the AII room ceiling and down through a lay-in ceiling in an adjacent room, for example, is a potential path for movement of infectious agents. If the AII room walls go to structure, the space above the ceiling will be connected to adjacent rooms only by penetrations in the walls, reducing the potential leakage. We were able to determine that the walls went to structure for three of the six AII rooms with all tile or partial tile ceilings. For the other three the wall height could not be determined from the mechanical drawings.

Four of the AII rooms reviewed included *prescriptive* requirements in the contract documents to seal the walls. For a fifth project the designer indicated verbally in follow-up that the walls were sealed. Because we did not have complete architectural documentation, we cannot say whether the other five projects did or did not have prescriptive requirements for sealing of the AII room boundaries. For four of the projects we were able to determine that there was no *performance* requirement for AII room envelope tightness and no test for envelope tightness. Again, we cannot say definitively that the others did or did not have such requirements.

⁴ In some cases there is a range of potential flows, either because the patient room uses variable supply air volumes for temperature or pressure control, or because different flow values were found in different places in the contract documents, or because follow-up information from the designers differed from information in the contract documents. In calculating implicit effective leakage areas we used the flows on the plans for VAV systems, rather than the flows on the VAV box schedules. (In one case the supply flow on the plans was equal to the maximum box flow. In the other case it was slightly less than the maximum box flow. Using supply flows at or near the maximum results in a lower room flow differential). We used the flow in the balancing instructions rather than the flow on the plans in the one case where the two were different. We used the flow difference from the designer in the two cases where it differed from that in the contract documents.

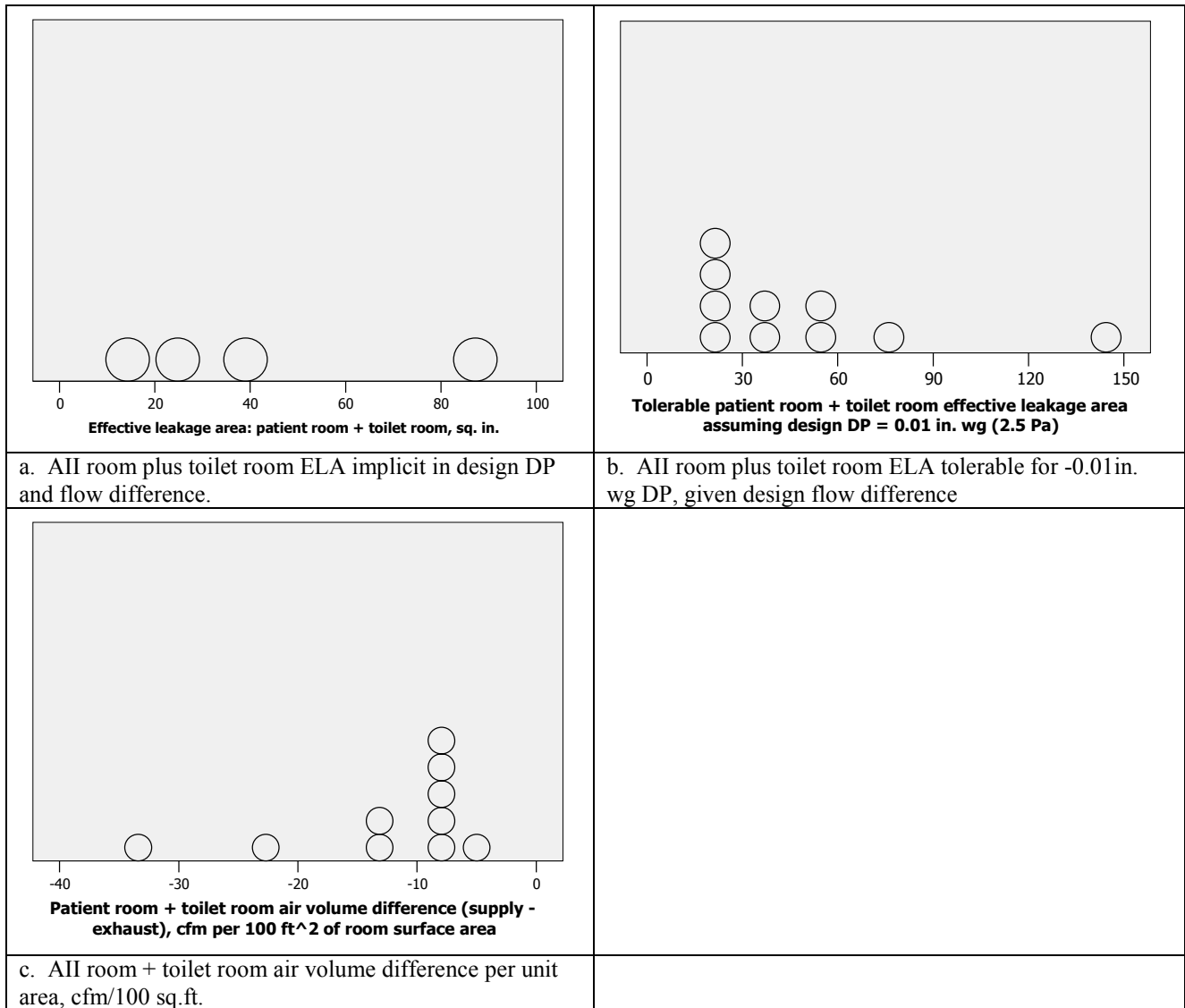


Figure 23. Measures of implicit AII room leakiness.

For the five cases where we had both a design flow differential and a design pressure differential, we calculated the implicit effective leakage area. All of the toilet rooms had net negative flows, as would be expected, and many of these were larger than the net negative flow for the patient room. We assumed that the designers intended the toilet rooms to be at a more negative pressure than the patient room and to help create a negative pressure in the patient room. The implicit leakage area for the patient room plus toilet room taken together ranged from 11 to 87 in² (71 cm² to 561 cm²). (Figure 23a).

The larger the difference between the supply and return flow, the greater the leakage (ELA) the design can tolerate while still providing a given space pressurization. For a desired AII room

pressure of -0.01 in. wg (-2.5 Pa) (meeting the 2001 AIA guidelines) the various combined AII room/toilet room areas could tolerate ELAs of 20 in² to 144 in² (129 cm² to 929 cm²) (Figure 23b). As a point of comparison, Bohac (2006) measured an ELA of 63 in² (406 cm²) for an isolation room in a Minnesota hospital. The room was 10 ft by 12 ft (3.0 m by 3.7 m) and had a T-bar lay-in tile ceiling with lay-in light fixtures, sprinkler heads and other penetrations, and a four foot wide hinged door with a 0.5 in (1.3 cm) undercut and weatherstripping around the sides and top. It had been designed for a pressure difference of -0.001 in. wg (-0.25 Pa). Since we did not have design DPs from which to calculate ELAs for all of the AII rooms, we calculated the airflow difference (supply-return) per unit of room surface area, which varied by a factor of seven from -5 cfm/100 ft² to -33 cfm/100 ft² (-0.25 L/s.m² to -1.68 L/s.m²) with a median of -9 cfm/100 ft² (-0.46 L/s.m²). Most were between -5 cfm/100 ft² and -13 cfm/100 ft² (-0.25 L/s.m² to -0.66 L/s.m²). (Figure 23c).

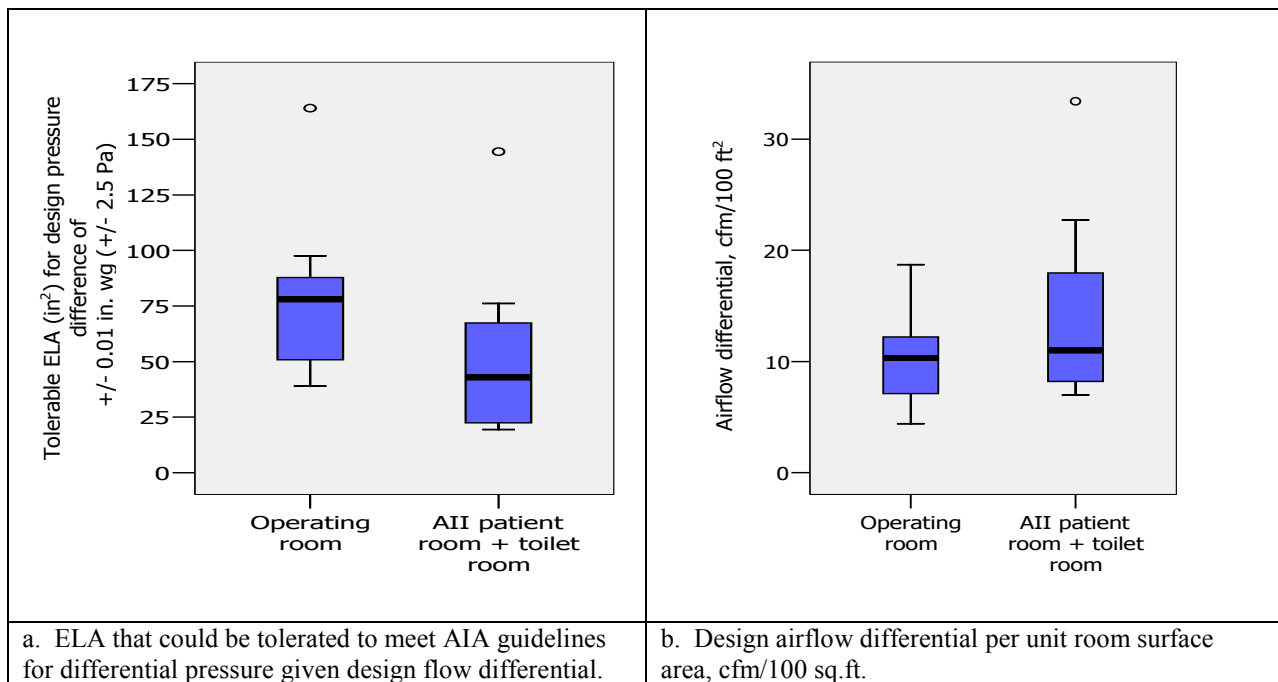


Figure 24. Comparison of leakage metrics for ORs and AII rooms.

The differential airflows (absolute value of supply minus return) per unit room surface were similar for ORs and AII rooms (Figure 24b). This may or may not be realistic. Two thirds of the AII rooms had at least some lay-in ceiling tile, which could be expected to be leakier than the gypsum board ceilings that were present in all of the ORs. On the other hand, ORs can have more penetrations for electrical connections and medical gas lines.

Humidification

Seven of the AII rooms were served by air handlers that had humidification, although the AIA guidelines do not require humidification for AII rooms. All were steam-based humidifiers, as required by AIA.

Minimization of Mold Growth in Ductwork

For five of the projects with humidification of AII rooms, the humidifier was either downstream of the final filter or more than 15 ft (4.6 m) upstream of it, consistent with AIA requirements, but for the other two the location relative to the filters could not be determined. Drain pans were clearly present, as required by AIA, for four of the seven humidifiers, and high limit humidistats, also required, were clearly present for five. AIA requires that duct takeoffs be far enough downstream to ensure complete moisture absorption. The distance could be determined for six of the seven, and ranged from over 10 ft (3 m) to over 75 ft (23 m). As discussed earlier, none of the projects used internal duct insulation on the supplies, although one or two used it on returns.

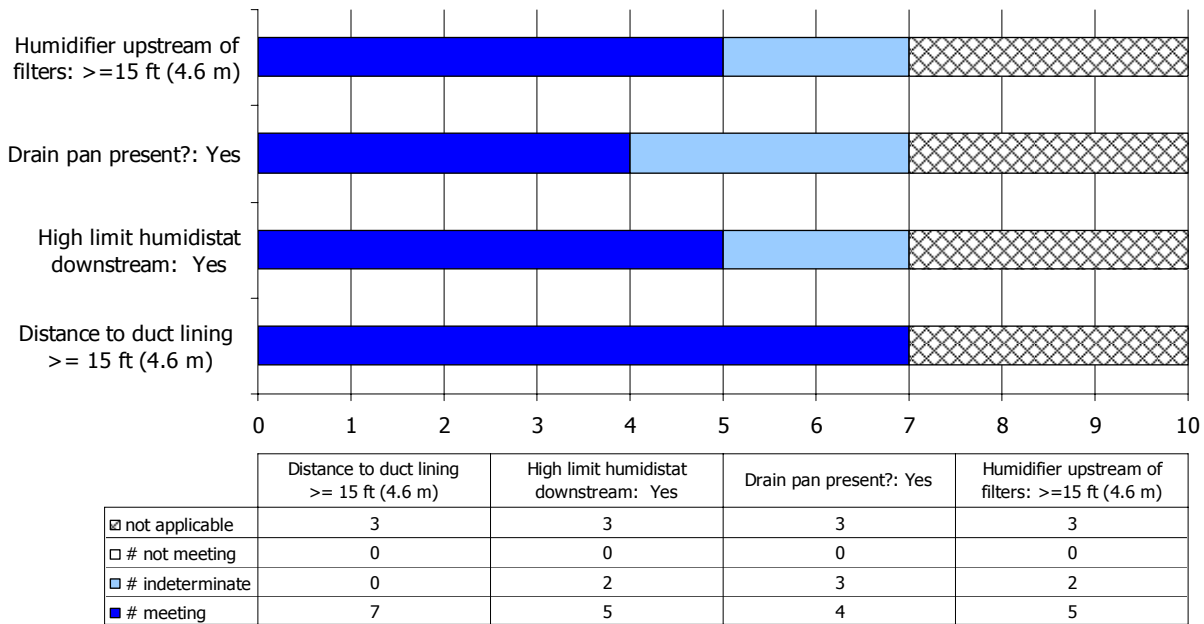


Figure 25. AII room designs meeting AIA guidelines related to mold growth in ductwork (n=10).

Special Purpose All Rooms

Four of the projects had special purpose AII rooms in addition to the AII rooms on non-critical care nursing units. Projects #7 and #8 had emergency department AII rooms and project #10 had both an emergency department AII room that could be switched to a normal patient room and a room for bronchoscopic procedures. For the most part, the designs did not differ markedly in features or design parameters from those for the AII rooms on non-critical care nursing wards. An exception was that the switchable AII room had controls to shut the exhaust fan off and change the position of a two-way damper from exhaust to return when it was not in use as an AII room. The anteroom and toilet room flow differences, which were 0 cfm and -75 cfm (0 L/s and 35 L/s) respectively, stayed the same in both control modes, but the patient room flow difference (supply – return) was -75 cfm (-35 L/s) in AII room mode and 0 cfm (0 L/s) in normal patient room mode.

Overall Quality Control

The AIA guidelines require that “Crucial ventilation specifications for air balance... shall be verified before owner acceptance...” (Table 5). Three project TAB specifications clearly stated that a sample of data recorded in the balancing report would be re-checked, as selected and witnessed by the Owner or Architect. Only one of these specified the amount of testing, failure criteria for individual measurements and the overall test, and consequences of a failed test (requirements for a second inspection if the first one failed, and completion of the final balance by a different firm if both the first and second inspections failed, with costs deducted from the original balancing firm’s payments). A fourth TAB specification included a general statement that the “job will be accepted on basis of tests and inspections.” Two other designers indicated verbally that their projects included TAB verification, although it was not in the available balancing specification. All six of these were treated as meeting the AIA guidelines (Figure 26), but this may be a generous assessment. The other four projects did not appear to include TAB verification.

The AIA guidelines state that “[a]cceptance criteria for mechanical systems shall be specified,” that “[c]rucial ventilation specifications for air balance and filtration shall be verified before owner acceptance,” and that areas including surgical services, PE and AII rooms, among others, “shall be recognized as requiring mechanical systems that ensure infection control, and ventilation deficiencies shall not be accepted.” In an advisory appendix, they recommend commissioning by an entity independent from the installing contractor, identify building areas of particular concern including surgical services and isolation rooms, and note in particular that “air balancing, pressure relationships, and exhaust criteria ... must be... tested to create an environment of care that provides for infection control.” Only two of the projects included formal commissioning with a third-party commissioning agent hired by the Owner. The other eight projects each included some kind of system performance verification, performed by the balancing contractor, the controls contractor, or both. These typically included requirements like the following:

Examine system and equipment installations to verify that they are complete...

Examine systems for functional deficiencies...

Examine equipment for installation and for properly operating safety interlocks and controls...

Examine automatic temperature system components to verify the following:

1. Dampers, valves, and other controlled devices operate by the intended controller.
2. Dampers and valves are in the position indicated by the controller.
3. Integrity of valves and dampers for free and full operation and for tightness of fully closed and fully open positions. This includes dampers in variable-air-volume terminals.
4. Automatic modulating and shutoff valves, including 2-way valves and 3-way mixing and diverting valves, are properly connected.
5. Thermostats are located to avoid adverse effects of sunlight, drafts, and cold walls.
6. Sensors are located to sense only the intended conditions.
7. Sequence of operation for control modes is according to the Contract Documents.
8. Controller set points are set at design values. Observe and record system reactions to changes in conditions. Record default set points if different from design values.
9. Interlocked systems are operating.
10. Changeover from heating to cooling mode occurs according to design values.

In most cases the required reporting from these tests was of deficiencies only. Four of the projects without formal commissioning did include witnessed testing of control system performance, and a fifth provided an option for witnessed testing. Descriptions of the testing were typically brief,

(Example 1) Acceptance shall consist of a full operational test in which the Building Control System is demonstrated to be functioning properly in accordance with all requirements of this specification.

(Example 2) Prove the operation of the mechanical systems and of each individual item in the systems. At least 10 days' notice shall be given the Architect of such tests. Should any item... fail to perform in an approved manner, this test shall be repeated until the operating test is approved by the Architect. During this test, balance circulation of ...all...fluids... to provide proper quantities... Adjust and set all balancing cocks, valves, dampers and similar items... Following the successful completion of the first operating tests by the Contractor, the Owner and Architect shall have the privilege of making such tests as they may desire during a period of three weeks... [after corrections]... an operating test shall then be performed by the Contractor to the satisfaction of the Architect for a period of three days. Should any element of the systems not perform properly, the Contractor shall make all required corrections, and the test shall be repeated until successfully performed... Make the following measurements at two hour intervals... during the 3-day operating test... [Includes only motor amps and volts, static P in and out of filters, coils, fans and dampers, air temperatures in conditioned space, at the entrance and exit of each coil and downstream of mixing dampers, RH at each humidity sensor, water pressures and temperatures at pump, converter and coil inlets and outlets, domestic hot water temperature at closest and furthest fixtures, static pressure of cold water line at building service connection.]

Whether the projects without formal commissioning define and verify acceptance criteria to a level consistent with the AIA guidelines probably depends in large part on how well they are enforced by the owner's representative or architect.

The AIA guidelines require that an Infection Control Risk Assessment (ICRA) be provided by the owner. Although the designer is required to incorporate the construction-related requirements of the ICRA into the contract documents, it is not possible from review of the documents themselves to determine whether an ICRA was done or which requirements were driven by the ICRA. Three of the designers who provided follow-up information reported that an ICRA had been performed. We were not able to draw a firm conclusion about the other projects.

Table 5. Key AIA 2001 guidelines for quality control.

Item	AIA 2001 Guidelines
Test and balance verification?	[See text under "formal commissioning process"]
Formal commissioning process?	<p>5.3. Commissioning. Acceptance criteria for mechanical systems shall be specified. Crucial ventilation specifications for air balance and filtration shall be verified before owner acceptance. Areas requiring special ventilation include surgical services, protective environments, airborne infection isolation rooms, laboratories, and local exhaust systems for hazardous agents. These areas shall be recognized as requiring mechanical systems that ensure infection control, and ventilation deficiencies shall not be accepted. Acceptance criteria for local exhaust systems dealing with hazardous agents shall be specified and verified.</p> <p>A.5.3. Commissioning. Commissioning is a quality process used to achieve, validate, and document that facilities and component infrastructure systems are planned, constructed, installed, tested, and are capable of being operated and maintained in conformity with the design intent or</p>

	<p>performance expectations. This process extends through all phases of a new or renovation project from conceptual design to occupancy and operations. Checks at each stage of the process should be made to ensure validation of performance to meet the owner's design requirements. Commissioning should be performed by an entity that is independent from the installing contractor... Facility acceptance criteria should be based on the commissioning requirements specified in the contract documents. These criteria specify the tests, training, and reporting requirements necessary for the owner to validate that each system complies with the performance standards of the basis of design and for final acceptance of the facility. Key systems and components that need to be tested and validated, as a minimum, during the TBC [total building commissioning] process include the design and operation of the HVAC, plumbing, electrical, emergency power, fire protection/suppression, telecommunications, nurse call, intrusion and other alarm devices, and medical gas systems, as well as specialty equipment. Air balancing, pressure relationships, and exhaust criteria for mechanical systems must be clearly described and tested to create an environment of care that provides for infection control... While all areas of the health care facility are included in the commissioning process, the following areas are of particular concern: critical and intensive care areas; surgical services; isolation rooms, including those used for airborne infection/pathogens; pharmacies, and other areas potentially containing hazardous substances..."</p>
Infection control risk assessment?	<p>5.1. ... During the programming phase of a construction project, the owner shall provide an Infection Control Risk Assessment (ICRA)... The panel shall provide updated documentation of the risk assessment throughout planning, design, and construction... The design professional shall incorporate the specific construction-related requirements of the ICRA in the contract documents. The contract documents shall require the constructor to implement these specific requirements during construction. The ICRA is initiated in design and planning and continues through construction and renovation... the ICRA shall address... (c) Placement of effective barriers to protect susceptible patients for airborne contaminants such as Aspergillus sp. (d) Air handling and ventilation needs in surgical services, airborne infection isolation and protective environment rooms,....</p>

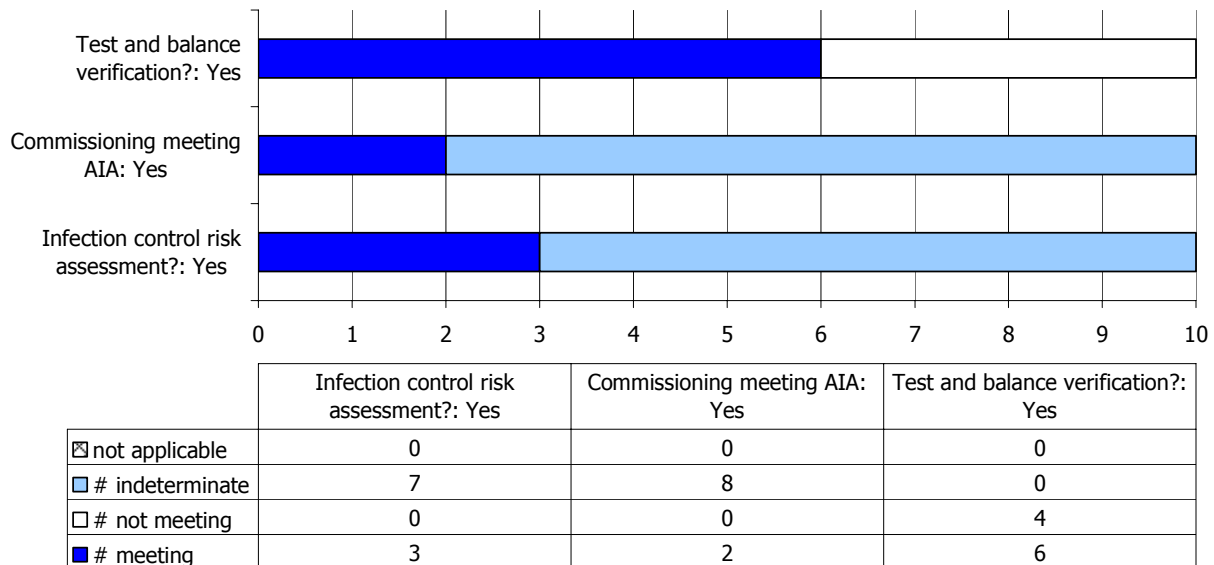


Figure 26. Projects meeting AIA 2001 guidelines related to quality control (n=10).

Discussion

The goal in standardizing the design and construction of health care facilities is first to provide a consistent quality of environments for delivery of care; convalescence of patients; and protection against hospital-acquired infections, and second to offer some control over both the first cost and

the operating cost of these facilities. This report of strategies to reduce the spread of airborne infection in hospitals sought to determine how effectively the process of standardization is accomplishing these two goals.

The previous report on the survey of designers (Hewett and Hermans 2006) found that the predominant standard the engineers interviewed use to guide their designs is the AIA guidelines. One project was designed to comply with the Veterans Administration requirements. The interviews, which focused on pressure relationships and quality control practices, showed little distinction in compliance with the AIA guidelines between designers who perform many projects and those who do occasional projects but considerable variation of compliance within these groups. Among the tentative conclusions drawn in that report are that:

- A significant minority of designers are not following the current AIA guidelines with regard to pressure differentials,
- There may be a need for engineers to gain a greater understanding of and give more explicit consideration to the effective leakage area of room boundaries,
- There may be a need to provide greater guidance on room airtightness,
- Designers see problems with construction and coordination between trades as the most significant challenge in achieving proper space pressure relationships, underscoring the need to enhance quality control through increased use of airtightness testing (used in a small minority of respondents' most recent projects) TAB verification (used by about half of projects) and commissioning (used in about a quarter of projects).

The detailed review of plans and specifications from a subset of survey respondents, reported here, found that project design features and parameters were largely in agreement with the AIA 2001 guidelines and with each other. The exceptions have possible implications both for infection control and for owning and operating costs.

Contract documents most often fell short of AIA guidelines or did not provide enough information to determine whether they met the guidelines in the areas of room pressure control, minimization of mold growth downstream of humidifiers, TAB verification, and overall system performance verification or commissioning. This is consistent with the findings from the survey, strongly suggesting that the engineers of record are applying the design concepts and criteria reported in the survey to their drawings and specifications. The findings related to pressure control in particular suggests that designers may not be changing their design intent as fast as changes occur in the guidelines.

The shortcomings in design for pressure control may be due in part to the fact that the AIA guidance changed in 2001 and was still relatively new when these designs were done. It may also reflect insufficient consideration of the physics of room air leakage. The types of terminal equipment, control strategies and balancing approaches used to achieve OR and AII room pressure control vary considerably. Anteroom layout, supply/return flow ratios and differential pressure measurement points also vary greatly. These variations may reflect equally valid designer/owner preferences, or they may reflect insufficient guidance as to most effective approaches to achieve reliable pressure control and effective isolation.

Occupied and unoccupied mode total air change rates, outdoor air change rates and final filter efficiencies generally met AIA guidelines but also varied considerably, and variations in these design parameters have a significant impact on first costs and operating costs. The owners' or designers' rationale for using higher design targets in these projects is unknown. Other design considerations (e.g., cooling loads), anticipation of future, more exacting uses of the space (e.g., use of a general purpose OR for orthopedic surgeries) or consideration of other design guidance documents could all factor into these choices.

The AIA 2001 guidelines for commissioning and for the location of duct take-offs with respect to humidifiers were stated in such a way that we were unable to assess compliance from the Contract Documents alone. This is true to a lesser extent of the requirements for TAB verification, flow from clean to less clean areas, filter fit, and room sealing. These guidelines are stated in performance terms but the performance descriptors are open to some interpretation. This makes compliance verification difficult in commissioning.

For many of the design parameters reviewed in this report there was general agreement with the previous survey (Hewett and Hermans 2006) in that there was little distinction in the design approach between designers who perform many projects and those who do occasional projects. One of the original operating theories of this work was that experienced designers learn over many projects to revise their designs to correct past design issues that become problematic in operation. The corrections may exceed the requirements of the AIA guidelines or they may be less if the local jurisdiction allows and there is an advantage to the hospital such as a reduction in the cost of operation. Because our sample size is so small it is impossible to make any hard conclusions based on a statistical test of significance. However, a few noteworthy tendencies appear in even this small sample.

In operating rooms:

- Experienced designers may tend to allow lower unoccupied total air flows;
- Experienced designers may tend to specify a higher supply airflow rate;
- Experienced designers may tend to specify a higher air volume difference;
- Experienced designers may tend to realize a higher tolerable effective leakage area assuming a differential pressure of 0.01 in. wg (2.5 Pa).

In AII rooms:

- Experienced designers may tend to supply more air to anterooms;
- Experienced designers may tend to specify a higher toilet room air volume difference;
- Experienced designers do not allow the general air pattern to move from the patient to the door whereas two of the four less experienced designers did.

One surprise in the analysis is the complete lack of correlation between experience and the AII room pressure control designs. There was no correlation for the design pressure difference, the location of the volume control damper(s), the air volume control method, the pressure monitoring device type and location, and the patient room air volume difference.

The implications of these findings are that even when the design guidance is generally familiar, design engineers use widely varying methods of compliance that may have varying degrees of

success, and when that guidance changes significantly, designers do not necessarily follow, nor may they be aware of, the change.

This issue speaks to the apparent need for a structured continuing education and perhaps even certification of health care ventilation design professionals.

Acknowledgements

This work was funded by the National Institute of Standards and Technology as part of a larger project under Order Number SB1341-04-W-0751. We greatly appreciate the willingness of the design engineers to share their plans and specifications for use in this project.

References

AIA 2006. *Call for revisions to 2001 edition of AIA health care facility design document*. News release, July 17, 2002. New York, NY: American Institute of Architects/Facility Guidelines Institute. Retrieved February 14, 2006 from www.aia.org/release_020717.

AIA 2001. *2001 Guidelines for Design and Construction of Hospital and Health Care Facilities: 2001 Edition*. New York, NY: American Institute of Architects/Facility Guidelines Institute.

AIA 1997. *1997 Guidelines for Design and Construction of Hospital and Health Care Facilities: 2001 Edition*. New York, NY: American Institute of Architects/Facility Guidelines Institute.

ASHRAE 2005. *2005 ASHRAE Handbook: Fundamentals*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 2003. *2003 ASHRAE Handbook: Heating, Ventilating and Air-Conditioning Applications*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 2001. *2001 ASHRAE Handbook: Fundamentals*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 1999a. *1999 ASHRAE Handbook: Heating, Ventilating and Air-Conditioning Applications*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 1999b. ANSI/ASHRAE Standard 52.2-1999 -- *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 1992. ANSI/ASHRAE Standard 52.1-1992 -- *Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bohac, 2006. Personal communication from David L. Bohac, P.E., Center for Energy and Environment. Measurements were taken in conjunction with this project.

CDC 2006. Healthcare-Associated Infections (HAIs). Retrieved February 3, 2006 from <http://www.cdc.gov/ncidod/dhqp/healthDis.html>.

CDC 2003. *Guidelines for Environmental Infection Control in Health-Care Facilities: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC)*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention (CDC).

CDC 1994a. Guidelines for preventing the transmission of mycobacterium tuberculosis in health care facilities. *Morbidity and Mortality Weekly Report*. October 28, 1994, Vol. 43 (No. RR-13).

CDC 1994b. Guidelines for prevention of nosocomial pneumonia, 1994. *Am J Infect Control* (22:247-292).

CDC 1992. Public health focus: surveillance, prevention, and control of nosocomial infections. *Morbidity and Mortality Weekly Report*. October 23, 1992, Vol. 41(42);783-787.

Darlow, H.M., 1966. Filtration of biological particles from air. *Filtration and Separation*. July/August, p. 303.

Decker, H.M., L.M. Buchanan, L.B. Hall, and K. Goddard, 1963. Air filtration of microbial particles. *American Journal of Public Health*, December, p. 1982.

ENR, 2003. The Top 500 Design Firms Sourcebook 2003. *Engineering News-Record*. McGraw Hill Construction. June 2003.

First, M.W., E.A. Nardell, W. Chaisson, and R. Riley, 1999, Guidelines for the application of upper-room ultraviolet germicidal irradiation for preventing transmission of airborne contagion – part 1 basic principals. *ASHRAE Transactions* 105(1) p. 869.

Foarde, KK and J.T. Hanley, 2001. Determining the efficacy of antimicrobial treatments of fibrous air filters. *ASHRAE Transactions* 107(1).

Furuhashi, M. 1978. Efficiency of bacterial filtration in various commercial air filters for hospital air conditioning. *Bulletin of Tokyo Medical and Dental University*. Vol. 25, p. 147.

Hewett, M.J. and R.D. Hermans 2006. Strategies to Reduce the Spread of Airborne Infections in Hospitals: Survey of Design Practice NIST GCR 05-883. Gaithersburg, MD: National Institute of Standards and Technology.

Kuehn, T.H., D.Y.H. Pui, D. Vesley, C.D. Berg and M. Peloquin 1990. *Matching Filtration to Health Requirements*. Final report of ASHRAE research project 625-RP. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Margard, W.L. and R.F. Logsdon 1985. An evaluation of the bacterial efficacy of air filters in the removal and destruction of airborne bacteria. *ASHRAE Journal*, May, p. 49.

McGraw-Hill Construction. 2004. *Dodge Plans Electronic Services*. Plans accessed from <http://dodge.construction.com/Plans/> between May and September 2004.

Memarzadeh, F. and A.P. Manning 2002. Comparison of operating room ventilation systems in the protection of the surgical site. *ASHRAE Transactions* 108(2).

Memarzadeh, F. and J. Jiang 2000. Methodology for minimizing risk of airborne organisms in hospital isolation rooms. *ASHRAE Transactions* 106(2).

Parat, S., H. Fricker-Hidalgo, A. Perdrix, D. Bemer, N. Pelissier, R. Grillot 1996. Airborne fungal contamination in air-conditioning systems: effect of filtering and humidifying devices. *American Industrial Hygiene Association Journal* 57: 996-1001.

Streifel, AH, 2000. "Health-care IAQ: guidance for infection control." *HPAC Heating/Piping/Air Conditioning Engineering* V. 72, No. 10. October 2000. p. 28-30, 33, 34, 36.

Streifel, A.J. 1999. Design and maintenance of hospital ventilation systems and the prevention of airborne nosocomial infections [Chapter 80]. In: Mayhall, CG, ed. *Hospital Epidemiology and Infection Control*. 2nd ed. Philadelphia, PA: Lippincott Williams and Wilkins, 1999.

Streifel, A.J., and J.W. Marshall. 1997. Parameters for ventilation controlled environments in hospitals. *Proceedings of Healthy Buildings/IAQ'97*, Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Vol. 1. September 27-October 2, 1997, p. 433-437. Also published in Moschandreas DJ, editor. *Design, Construction and Operation of Healthy Buildings. Solutions to Global and Regional Concerns*. Atlanta: ASHRAE Press; 1998. p. 305-9.

U.S. Department of Veterans Affairs 2000. *HVAC Design Manual for Hospital Projects*. Washington, D.C.

Abbreviations (as used in this report)

ACH	Air Changes per Hour (h^{-1})
AHU	Air handling unit
AIA	American Institute of Architects
AII	Airborne Infection Isolation
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
CDC	Centers for Disease Control
CFM	Cubic feet per minute
DP	Differential pressure
ELA	Effective leakage area
HAI	Healthcare-associated infection
HVAC	Heating, ventilating, and air-conditioning
ICRA	Infection control risk assessment
in. wg	Inches of water gauge
IQR	Inter quartile range
MERV	Minimum efficiency reporting value
OA	Outside air
OR	Operating room
Pa	Pascals
PE	Protective environment
PR	Patient room
Q	Quartile
TAB	Testing and Balancing
TR	Toilet room
TSA	Total supply air
VA	Veterans Administration
VAV	Variable air volume

Appendix A. Data Tables

OPERATING ROOMS

Project ID -->	1	2	3	4	5	6	7	8	9	10	median	2001 AIA Gdl
Date	Jul-04	Jul-04	May-04	Jun-04	Jul-04	Jun-04	Sep-04	May-00	Sep-02	Jun-04		
New Bldg/Addition	New Bldg	Addition	New Bldg	New Bldg	Addition	Addition	New Bldg	Addition	Addition	New Bldg		
Census Region	South	Midwest	South	South	Midwest	South	Midwest	Northeast	West	West		
Original survey sample group	freq hosp des	occ hosp des	occ hosp des	occ hosp des	occ hosp des	not interviewed	freq hosp des	freq hosp des	occ hosp des	occ hosp des		
Redefined survey sample group	many projects	many projects	few projects	few projects	few projects	not interviewed	many projects	many projects	few projects	many projects		
Plan and spec source	Dodge	Dodge	Dodge	Dodge	Dodge	Dodge	designer	designer	designer	Dodge		
DILUTION												
Total ACH when occupied (1/h)			16.1	29.3	24.1	20.7	27.8	28.3	20.6	22.4	23.3	>=15
			[8]							[1]		
Unocc/occ air flow ratio			0.45	not available	1.00	0.56	0.33	0.20	1.00	0.30	0.5	no req
Total ACH when unoccupied (1/h)			7.2	not available	24.1	11.5	9.3	5.8	20.6	6.7	9.3	maintain DP
Outside Air ACH (1/h)			3.2	5.85	4.52	6.2	5.2	8.5	14	5.2	5.5	>=3
			[2]				[3]	[4]				
Recirculating system?			Y	Y	Y	Y	Y	Y	Y	Y		recirc ok
Distance from AHU OA intake to nearest exhaust, ft			50	20	40	40	53	21	50	40	40	>=25
				[5]				[5]				
FILTRATION AND AIR TREATMENT												
AHU pre-filter dust spot efficiency, %			30	30	30	35	30	30	25	30	30	>=30
AHU int. filter dust spot efficiency, %			-	-	-	65	-	95	-	-	-	no req
AHU final filter dust spot efficiency, %			99.97	99.97	90	99.97	95	99.97	90	95	97	>=90
Zone level filter dust spot efficiency, %			-	-	-	-	99	-	-	-	-	no req
Prefilter before fan, final after coils?			Y	Y	Y	Y	Y	Y	Y	Y		Y
Is ultraviolet treatment used?				N				N	N			no req
AIR DISTRIBUTION												
Supply diffuser type [6]			E, non-laminar	E, laminar	E, laminar	E, laminar	E, laminar	E, laminar	A/E adjustable			no req
Supply diffuser location			Ceiling, over center	Ceiling, over center	Ceiling, over center	Ceiling, over center	Ceiling, over center	Ceiling, over center	Ceiling, over center	Ceiling, surrounds center		Ceiling, near center
Return number, type, location			2, sidewall, opp. corners	2, sidewall, opp. corners	2, sidewall, adj. corners	2, low sidewall, opp. corners	2, low sidewall, opp. corners	3, sidewall, corners	2, low sidewall, corner & opp mid wall	2, low sidewall, opp corners		>=2, near floor, far apart
ROOM PRESSURIZATION CONTROL												
Design pressure difference, "wc						0.04						>=0.01
Terminal box or air valve location			Supply	Both	Neither	Supply. Motorized damper on RA.	Both	Both	Supply	Supply. Motorized damper on RA		no req
Supply air flow control			Const with occ, unocc setpoints	Const with occ, unocc setpoints	None (static balance)	Const with occ, unocc setpoints	Const with occ, unocc setpoints	Const with occ, unocc setpoints	Const	Const with occ, unocc setpoints		no req
Return air flow control			None	Const flow difference (S-R)	None	Damper goes to preset position to maintain positive DP	Const flow difference (S-R)	Const flow difference (S-R)	None	Occ: damper at max; Unocc: controlled by room DP		no req
Permanently installed monitoring device?			N	N	N	Electronic DP	N	N	Electronic DP	N		no req
Design supply air volume from plans, cfm			1700	2750	1680	2160	2100	2500	1420	2200	2130	no req
Design air vol diff (S-R) from plans, cfm			100	100	160	420	200	250	200	200	200	Air mvmt out
Percent difference			6%	4%	10%	19%	10%	10%	14%	9%	10%	no req
Effective leakage area (ELA), sq. in.						66.6						
Tolerable ELA assuming 0.01"wg DP			39.0	39.0	62.5	163.9	78.1	98 in	78.1	78.1		
Air vol diff per unit area, cfm/100 sq ft rm surface			4.4	4.8	9.5	18.7	11.1	12.6	11.8	9.4	10.3	no req
Ceiling type			gypsum	gypsum	gypsum	gypsum	gypsum	gypsum	gypsum	gypsum		monolithic
All walls to structure?			Y	N	Y	Y		Y [7]		N		no req
Requirement to seal leaks? All walls fire walls? Other?				Sealed light fixtures				Sealed perimeter [7]				
Performance spec for room tightness?				N				N				no req
Test of room tightness?				N				N				no req

11/2/2006 8:14 AM

HUMIDIFICATION												
Humidification in AHU? In OR duct?			Y/Y	N/Y	N/Y	Y/Y	Y/Y	Y/N	Y/N	Y/N		RH in range
Humidification type			Steam	Steam	Steam	Steam	Steam	Steam	Steam	Steam		Steam
MINIMIZATION OF MOLD GROWTH IN DUCTWORK												
Internal duct insulation?			N	N	None indicated. Spec limits to returns if used.	N	N	N	<i>in returns and some exhaust</i>	N		Not in supplies
Humidifier location wrt filters			after	NA - in OR duct	NA - in OR duct	after		30 ft before final	15 ft before final	after		If before, >=15 ft
Drain pan present?				Y		in AHU	in AHU	Y				Y
High limit humidistat downstream?			N/Y	Y		Y/Y	Y/Y			Y		Y for each
Distance to first duct takeoff, ft			7 at AHU, 6 in OR duct	Location not indicated	5	25 at AHU, 17 in OR duct	> 50 at AHU, 16 in OR duct	> 30	> 30	30		ensure complete moisture absorption

GENERAL NOTE: Information in red italics is based on follow-up with designer, undocumented except as indicated.

NUMBERED NOTES:

[1] Schedule indicates that occupied ACH should be 25 and unoccupied ACH should be 4.

[2] Minimum OA control dynamically calculated by BAS according to ASHRAE standard 62 eq. 6-1.

[3] OA dampers modulate to maintain a constant adjustable minimum outside air flow (cfm)

[4] OA is set to 30% of total supply

[5] Exhaust on roof, OA intake on side of building. Actual distance along flow path may be longer than shown

[6] Group A --> Outlets mounted in or near the ceiling that discharge air horizontally. Group E --> Outlets mounted in or near the ceiling that project primary air vertically.

[7] In additional drawing provided by designer.

[8] Assumes 10 ft ceiling.

All ROOMS

Project ID -->	1	2	3	4	5	6	7	8	9	10	median	2001 AIA Gdl
Date	Jul-04	Jul-04	May-04	Jun-04	Jul-04	Jun-04	Sep-04	May-00	Sep-02	Jun-04		
New Bldg/Addition	New Bldg	Addition	New Bldg	New Bldg	Addition	Addition	New Bldg	Addition	Addition	New Bldg		
Census Region	South	Midwest	South	South	Midwest	South	Midwest	Northeast	West	West		
Original survey sample group	freq hosp des	occ hosp des	occ hosp des	occ hosp des	occ hosp des	not interviewed	freq hosp des	freq hosp des	occ hosp des	occ hosp des		
Redefined survey sample group	many projects	many projects	few projects	few projects	few projects	not interviewed	many projects	many projects	few projects	many projects		
Plan and spec source	Dodge	Dodge	Dodge	Dodge	Dodge	Dodge	designer	designer	designer	Dodge		
ANTEROOMS												
Is there an anteroom?	Y	N	Y	N	Y	Y	N	Y	N	Y		no rec
Anteroom in series or parallel?	Parallel	N/A	Series	N/A	Series	Series	N/A	Series	N/A	parallel		no rec
DILUTION												
Patient Room Total ACH (1/h)	15.2	8.5	13.4	15.2	16.4	17.4	21.9	14.0	12.1	13.2	14.6	>=12
Patient Room Outside Air ACH (1/h)	3.1	1.9	3.0	2.5	2.5	3.6	2.9	4.6	4.9	4.4	3.1	>=2
			[7]				[8]					
Have sep toilet, tub or shower	Y	N	Y	Y	Y	Y	Y	Y	Y, in PR, no tub/shower	Y		Y
Toilet Room Total ACH (1/h)	15.2	N/A	14.7	11.7	12.5	12.3	15.4	12.5	N/A	15.2	13.6	>=10
Anteroom Total ACH (1/h)	13.0	N/A	9.7	N/A	9.6	15.6	N/A	12.2	N/A	12.1	12.2	>=10
Recirculating system?	N	N	N	N	N	N	N	N	N	N		N w/except
Distance from All rm exhaust to nearest OA intake, ft	Over 60 ft on roof	over 25', facing opposite from intake	Over 70 ft, on roof	Over 85 ft, on roof to OA on side of bldg	Over 70 ft, on roof	Over 45 ft on roof	~70 ft, facing opposite on roof	Over 40 ft, Exh on roof to side of bldg	Over 65 ft, on roof	Over 45 ft, Exh on side of bldg to roof		>=25
Distance from AHU OA intake to nearest exhaust, ft	28	25 <i>[over 25]</i>	67	20	40	27	36	67	50	40	38.0	>=25
FILTRATION AND AIR TREATMENT												
AHU pre-filter dust spot efficiency, %	30	30	30	60	30	35	30	30	25	30	30.0	>=30
AHU int. filter dust spot efficiency, %						65						
AHU final filter dust spot efficiency, %	95	85	95	99.97	90	95	95	95	90	95	95.0	>=90
Zone level filter dust spot efficiency, %	-	-	-	-	-	-	-	-	-	-		no req
Prefilter before fan, final after coils?	Y	N (both before coils/fan)	Y	Y	Y	Y	Y	Y	Y	Y		Y
Is ultraviolet treatment used?		N		N				N	N			no req
AIR DISTRIBUTION												
Supply diffuser type [1]	A	A	A	A	A	A	A/E, adjustable	A	A/E adjustable	A & E		no req
Supply diffuser location	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling		no req
Return grill location	Low sidewall	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling	Low sidewall	Low sidewall		no req
Air flow direction	Toward patient	Toward patient	Toward door	Toward door	Toward patient	Toward patient	Toward patient	Toward patient	Toward patient	Toward patient		Clean->Less clean
ROOM PRESSURIZATION CONTROL												
Design pressure difference, "wc	-0.01	-0.03 to -0.003		-0.001		-0.04		-0.15				>=0.01
		[3]										
Terminal box or air valve location	Supply	Supply Room DP (H W Anemom)	Supply	Supply	Neither	Supply	Supply	Both	Supply; Air Valve on EA	Supply, Motorized damper on EA		no req
Supply air flow control	Const		VAV-space T	Const	None	Const	Room DP	Const	Const	Const		no req
Return air flow control	None	None	None	None	None	None	None	Room DP	Not specified	Room DP		no req
Permanently installed monitoring device?	Electronic DP	None	None	Electronic DP	None	Electronic DP	Electronic DP	Electronic DP	Electronic DP	Electronic DP		Yes
Monitoring location	In corr, to PR			In corr, to PR		In AR, to PR	In corr, to PR	In corr, to AR	In corr, to PR	In corr, sensor AR to PR		No req (?)
Patient rm air vol diff (S-R) from plans, cfm	0	-55	-25	-25	0	-10	-95	-295	-130	-50	-25.0	No req
	[9]			50 in plans				-60 in plans				
Toilet room air vol diff from plans, cfm	-100	N/A	-35	-25	-55	-80	-100	-75	N/A	-100	-75.0	No req

Anteroom air volume diff from plans, cfm	150	N/A	10	N/A	-55	-30	N/A	0	N/A	0	0.0	No req
Patient + toilet rm air vol diff, cfm	-100	-55	-60	-50	-55	-90	-195	-370	-130	-150	-95.0	No req
Total suite air vol diff, cfm	50	-55	-50	-50	-110	-120	-195	-370	-130	-150	-115.0	No req
Min total suite air vol diff	0 [9]	-	-30 [11]	-	-	-	-195 [12]	0 [13]	-	0 [13]		Maintain DP
Max total suite air vol diff	50 [9]	-	-150 [11]	-	-	-	-425 [12]	-370 [13]	-	-150 [13]		
Effective leakage area PR+TR, sq. in.	39.0	10.51 to 46.96		87.2		14.3		24.8				No req
Tolerable ELA assuming 0.01"wg DP	39.0	21.5	23.4	19.5	21.5	35.1	76.1	144.4	50.7	58.6		
Air vol diff per 100 sq ft room surface	-8.3	-5.0	-7.0	-7.7	-8.7	-13.1	-22.7	-33.4	-8.9	-13.2	-8.8	No req
Ceiling type	Lay-in tile	Gypsum	0	Lay-in tile	Lay-in tile	Lay-in tile	Gypsum & tile	<i>Gypsum</i>	Gypsum & tile	Gypsum		No req
All walls to structure?	Y	Y		Y	Y			<i>Y [2]</i>		Y		No req
Requirement to seal leaks? All walls fire walls? Other?	Walls to deck, sealed airtight	<i>Walls to structure, sealed penetrations</i>		Caulk and seal all walls, 2 fire rated walls				<i>Sealed perimeter [2]</i>		Walls sealed both sides, all penetrations sealed		Sealed tightly
Performance spec for room tightness?	N	<i>N</i>		<i>N</i>				<i>N</i>				No req
Test of room tightness?	N	<i>N</i>		<i>N</i>				<i>N</i>				No req
HUMIDIFICATION												
Humidification in AHU?	N	N	Y	Y	N	Y	Y	Y	Y	Y	Y	No req
Humidification type	-	-	Steam	Steam	-	Steam	Steam	Steam	Steam	Steam	Steam	Steam
MINIMIZATION OF MOLD GROWTH IN DUCTWORK												
Internal duct insulation?	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	See ORs	
Humidifier location wrt filters	-	-	After	Location not indicated	-	After		30 ft before final	20 ft before final	After		If before, >=15 ft
Drain pan present?	-	-		Y	-	Y	Y	Y				Y
High limit humidistat downstream?	-	-	Y	Y	-	Y	Y			Y		Y
Distance to first duct takeoff, ft	-	-	>10		-	15	>10	>50	>75	>30		ensure complete moisture absorption

GENERAL NOTE: Information in red italics is based on follow-up with designer, undocumented except as indicated.

NUMBERED NOTES:

[1] Group A --> Outlets mounted in or near the ceiling that discharge air horizontally. Group E --> Outlets mounted in or near the ceiling that project primary air vertically.

[2] In additional drawing provided by designer.

[3] Per designer, they do not design to a pressure, but to a 15% minimum increase in air flow (supply to exhaust) for All rooms

[4] Because exhaust box is variable, used supply flow to calculate possible minimum ACH. At design flows, ACH would be 23.4 using PR exhaust flow plus TR net exhaust (S-E)

[5] Documents state that a minimum of 12 ACH is to be maintained. If exhaust were to drop to equal supply flow in the PR, ACH would drop to 9.8

[6] Because exhaust flow is variable, used supply flow to calculate possible minimum ACH. At design flows, ACH would be 17.5 using PR exhaust flow plus net TR exhaust (S-E)

[7] Minimum OA control dynamically calculated by BAS according to ASHRAE standard 62 eq. 6-1.

[8] OA dampers modulate to maintain a constant adjustable minimum outside air flow (cfm)

[9] Plans show exhaust grill 550 cfm and supply 500, but note to balance exhaust to 500 cfm. EF can tolerate 550 exhaust from grill.

[10] Supply constant, exhaust variable to maintain room DP at setpoint.

[11] Based on max and min VAV box flows from schedule

[12] Based on max and min VAV box flows from schedule

[13] With control on DP, lowest air vol diff cannot go below 0; actual minimum undeterminable.

Project ID -->	1	2	3	4	5	6	7	8	9	10	median	2001 AIA Gdl
CONSTRUCTION MANAGEMENT AND QUALITY CONTROL												
Test and balance verification?	N	Y	Y	Y	N	N	Y	(Y)	N	Y		Y
Commissioning or performance verification?	by TAB	by CC	by TAB	Y	by TAB	by CC	by TAB & CC	by TAB & CC	Y	by CC		Y
Infection control risk assessment?		Y		Y				Y				Y