

Healthcare-Associated Infections: Glossary (variables, metrics and measurement methods)

	Term	Definition	Metrics	Measurement method
Environmental variable	Air pressure difference between adjacent spaces (positive/negative pressure room)	Positive pressure room: a room supplied with enough air pressure to prevent air in corridors and adjacent areas from entering the room. Negative pressure room: a room where enough air has been evacuated to prevent air from flowing out of the room and into adjacent areas (Sehulster et al., 2004).	Yes/no (Gustafson et al., 1982)	Design manipulation/tracer gas studies - Air flow studies were conducted using pure sulfur hexafluoride (SF6) as a tracer gas. The gas was released at a steady rate in the positive-pressure room. The concentration of gas in the corridor and nearby rooms was measured using Wilkes-Miran single-beam infrared portable spectrophotometer connected to a Rikadenki recorder (Gustafson et al., 1982).
	Alcohol-based hand rub	A preparation containing alcohol that is designed to be applied to the hands for the purpose of reducing the number of viable microorganisms on the hands. In the United States, these preparations usually contain 60%--95% ethanol or isopropanol (Boyce & Pittet, 2002).	- Alcohol-based hand rub vs. water/soap sinks (Cohen et al., 2003) - Manually operated versus automatic dispensers (Larson et al., 2005) - Bed-to-sink/dispenser ratio	Design manipulation/site inspection - Comparison of units with different dispensers/sinks (Cohen et al., 2003; Larson et al., 2005)
	Antimicrobial-finished textile product	Textile products containing antimicrobial agents (e.g., silver, quaternary ammonium chloride, chitosan) which show antibacterial activity against a wide range of microorganisms (Takai et al., 2002).	- Various textile materials containing different antimicrobial agents, e.g., Ag. Zn. Ammonium Zeolite and chitosan (Takai et al., 2002)	Research manipulation - Testing of five textile materials containing Ag. Zn. Ammonium Zeolite and chitosan, to various extents, and an untreated control material (Takai et al., 2002)
	Computerized (automatic) reminder of hand hygiene	A computerized system providing prerecorded, audio/visual messages instructing healthcare personnel to wash their hands before exiting the room or within 10 seconds of exiting the room. The system monitors room entry/exit and handwashing device usage (Swoboda et al., 2004).	Yes/no (Swoboda et al., 2004).	Research manipulation - The installation of an automatic reminding device (Swoboda et al., 2004)
	Copper-silver ionization system	A system that reduces Legionella colonization of a hospital water supply by introducing positively charged copper and silver ions into the water system (Modol et al., 2007).	Presence/absence	Design manipulation The installation of a copper-silver ionization system (Modol et al., 2007).
	Hand hygiene devices, number of	The number of staff-accessible handwashing sinks (Kaplan et al., 1986).	Bed-to-sink/dispenser ratio (Kaplan et al., 1986)	Design manipulation/site inspection - Dividing the total number of beds in one unit by the number of sinks/dispensers in that unit (Kaplan et al., 1986)
	HEPA filters, location of	The locations of HEPA filters in anHVAC system (Crimi et al., 2006).	Central (inside main air ducts) versus peripheral (at the openings of ducts) (Crimi et al., 2006)	Site inspection - Hospital departments with central HEPA filters and departments with peripheral HEPA filters were identified and compared (Crimi et al., 2006)

Term	Definition	Metrics	Measurement method
High-efficiency particulate air (HEPA) filter	A high-efficiency air filter that removes at least 99.97% of airborne particles measuring 0.3 micrometers (µm) in diameter (Sehulster et al., 2004). Can be portable or installed in an HVAC system.	Yes/no (Barnes & Rogers, 1989; Hahn et al., 2002)	Design manipulation - Before/after installation of HEPA filter (Barnes & Rogers, 1989) Site inspection - One unit wing with HEPA filters (including some rooms with laminar air flow) vs. another wing without HEPA filters (Hahn et al., 2002).
Interior finish material	Material covering interior surfaces such as ceiling, floors, and walls (Noskin et al., 2000)	Carpet, vinyl, fabric, wood, rubber etc. (Noskin et al., 2000)	Research manipulation - Testing of different materials (Noskin et al., 2000)
Laminar air flow (LAF)	HEPA-filtered air blown into a room at a rate of 90 ± 10 feet/min in a unidirectional pattern with 100 ACH–400 ACH (Sehulster et al., 2004).	Yes/no (Barnes & Rogers, 1989)	Design manipulation - Before/after the installation of LAF (Barnes & Rogers, 1989)
Mobile air-treatment unit that uses nonthermal-plasma reactors	A portable device utilizing nonthermal-plasma reactors to destroy microorganisms and electrostatically capture particles and molecular residues for the purpose of reducing airborne bioburden in high-risk areas (Bergeron et al., 2007).	On versus off; presence/absence (Bergeron et al., 2007)	Research manipulation/Site inspection - In an operating room with volume of 118 m3, airborne concentration was measured when the air treatment was turned on versus off; in a hematology unit, airborne fungal level in one room with the unit was compared to the airborne fungal level in the control room (Bergeron et al., 2007)
Patient room occupancy	The number of patients per patient room—one (single room, private room), two (double room), four (multi-bed open bays) (Ben-Abraham, et al., 2002).	Single versus double or multiple occupancy room (Ben-Abraham, et al., 2002) Proportion of beds in single rooms (Gardner et al., 1973)	Design manipulation - Conversion of an open bay unit to a single-room unit with separated sinks (Ben-Abraham, et al., 2002) Site inspection - The study wards were divided into two groups based on the percentage of beds in single rooms <40% versus >85% (Gardner et al., 1973)
Physical proximity	A risk factor of nosocomial infection. A patient is considered to be in physical proximity when he/she is a roommate or neighbor of a patient with an infectious disease, or when he/she stays in the room after the patient with the infectious disease has left (Chang & Nelson, 2000).	Yes/no, whether or not a patient was roommate or neighbor of a patient with diarrhea, or stayed in the room after the patient with diarrhea left (Chang & Nelson, 2000)	Mapping patient rooms - With medical records data, determine whether or not a patient was a roommate or neighbor of a patient with diarrhea, or stayed in the room after the patient with diarrhea left (Chang & Nelson, 2000)

	Term	Definition	Metrics	Measurement method
	Surface cleaning--cleaning, disinfection, sterilization	<p>Cleaning: removal of visible soil and organic contamination from a device or surface, using either the physical action of scrubbing with a surfactant or detergent and water, or an energy-based process such as ultrasonic cleaners with appropriate chemical agents; thorough cleaning is an important step before high-level disinfection and sterilization (Sehulster et al., 2004).</p> <p>Disinfection: compared to sterilization, a less lethal process of microbial inactivation that eliminates virtually all recognized pathogenic microorganisms but may not eliminate all microbial forms (e.g., bacterial spores) (Sehulster et al., 2004).</p> <p>Sterilization: use of a physical or chemical procedure to destroy all microbial life, including large numbers of highly-resistant bacterial endospores (Sehulster et al., 2004).</p>	Type of cleaning processes and products (Carling, et al, 2006)	<p>Research Manipulation</p> <p>- Before and after the intervention to improve environmental cleaning—a structured, multidisciplinary educational intervention was developed for the environmental services staff of participating hospitals. The role of the staff in infection prevention and safety improvement within the hospital was explained, and expectations with respect to cleaning HTOs were defined (Carling et al., 2006).</p>
	Ultraviolet germicidal irradiation	Use of ultraviolet radiation to kill or inactivate microorganisms (Sehulster et al., 2004).	On versus off (McDevitt et al., 2008)	<p>Research manipulation</p> <p>- Testing of the effectiveness of upper room UVGI in a simulated real world environment in an experimental chamber (McDevitt et al., 2008)</p>
	Ventilation grilles, location of	Arrangement of ventilation grilles on ceilings and walls (Beggs et al., 2008).	Ceiling versus wall ventilation; High versus low (Beggs et al., 2008)	<p>Research manipulation</p> <p>- Various ventilation regimes set up in computer simulation using Fluent 6.2 CFD software (ANSYS, Canonsburg, PA) with an unstructured tetrahedral grid containing approximately 540,000 cells. A standard k-e turbulence model with enhanced wall treatment was used, and a no-slip condition was applied at the walls (Beggs et al., 2008).</p>
	Ventilation rate	The rate at which air enters and leaves a building or a space/room (EPA, n.d.).	<ul style="list-style-type: none"> - Air changes per hour (ACH) - Cubic feet per minute (CFM) - Cubic meter per hour (absolute ventilation rate) (Escombe et al., 2007) 	<p>Tracer gas concentration decay technique</p> <p>- With all windows and doors closed, carbon dioxide (CO₂) was released and mixed well with room air using large fans to create a spatially uniform CO₂ concentration in the room. CO₂ concentrations were measured throughout the room at 1-minute intervals using a centrally located infrared gas analyzer. ACH were calculated as the gradient of the straight line through the natural logarithm of CO₂ concentration plotted against time in hours (Escombe et al., 2007; Menzies, et al., 2000)</p>

	Term	Definition	Metrics	Measurement method
	Ventilation, natural	Movement of outdoor air into a space through intentionally provided openings such as windows, doors, or non-powered ventilators) (Sehulster et al., 2004).	Natural versus mechanical ventilation (Escombe et al., 2007)	Site inspection - 70 naturally ventilated clinical rooms where infectious patients are likely to be encountered were compared with 12 mechanically ventilated, negative-pressure respiratory isolation rooms built post-2000 (Escombe et al., 2007)
Outcome	Bacterial growth	An increase in the amount of bacteria on surfaces (Lankford et al., 2006).	Confluent growth (CG, bacterial growth so heavy that individual colonies are not recognized for counting), no confluent growth (NCG, 1-388 cfus), no growth (NG) (Lankford et al., 2006).	Surface culture/biology analysis - The cultures for VRE and PSAE were performed using culture impression plates (Remel, Lenexa, KS) containing tryptic soy agar plus 5% sheep blood. For each surface tested, approximately 10 cm ² was touched 5 times with culture impression plates to ensure that the inoculated area was sampled. All plates were incubated at 35° C in ambient air and evaluated at 48 hours to determine the presence of VRE or PSAE. Bacterial growth on culture impression plates was quantified and organisms identified to the species level to confirm that the bacteria that were inoculated onto the surfaces were the bacteria recovered (Lankford et al., 2006).
	Bioaerosol concentration	The amount of airborne particles that are biological in origin (Bergeron et al., 2003).	cfu (colony-forming unit)/m ³ (Bergeron et al., 2003).	Air sampling using biocollector and biology analysis - Concentrations of airborne biological particles were determined with biocollectors (MAS 100; Merck) from a height of 1 meter above the floor and operating at 100 L/min for 5 minutes. Petri dishes containing Sabouraud culture media were used for fungal analysis, and standard plate count agar dishes were used to evaluate the total mesophilic flora. Fungal cultures were incubated at 27° C and the number of colony-forming units was determined on days 3, 5, and 7 (Bergeron et al., 2003). Computational fluid dynamics [CFD] study - Fluent 6.2 CFD software (ANSYS, Canonsburg, PA) with an unstructured tetrahedral grid containing approximately 540,000 cells was used to estimate bioaerosol concentration in various simulated conditions (Beggs et al., 2008)
	Cleaning, thoroughness of terminal cleaning	The amount of high-risk objects that are cleaned after terminal cleanings (cleanings after discharge) (Carling et al., 2006)	- Percentage of objects cleaned after terminal cleanings (Carling et al., 2006)	Fluorescent marker - Objects marked with targeting solutions which fluoresces under black light (Carling et al., 2006)

	Term	Definition	Metrics	Measurement method
	Endotoxin concentration	The amount of toxins associated with certain bacteria (Menziez et al., 2003).	eu/m ³ , eu/coupon (Menziez, et al, 2003)	Air sampling - Airborne samples for endotoxin measurements were captured on an isopore polycarbonate membrane (Millipore, Bicester, MA, UK) backed by a glass fiber pad (Millipore) with a volumetric air pump (Menziez et al., 2003);
	Hand hygiene compliance	Adherence with recommendations/guidelines of hand hygiene in healthcare settings (Larson et al., 2005).	- Percentage of actual hand hygiene divided by hand hygiene opportunities (Swoboda et al., 2004); - Number of hand touches with new gloves/cleaned hands, used gloves, and no gloves/uncleaned hands per neonate per shift (Cohen et al., 2003) - Number of incidences of hand hygiene per patient per hour; - Number of incidences of hand hygiene before patient contact per hour.	Observation - Hand hygiene behavior of staff members whose activities could be directly observed was recorded. At regular intervals, an observer assumed a position that allowed direct observation of the maximum number of contacts between staff members and patients. On the basis of the 8 indications for hand hygiene listed in the recommendations of the CDC hand hygiene guideline, the observer noted when a hand hygiene episode was indicated and whether the staff member used soap or the alcohol sanitizer (Larson et al., 2005). Automatic electronic system - The system consisted of electronic beam breakers or motion detectors placed at the threshold of each room to monitor entry and exit of personnel, both staff and visitors. The toilets, sinks, soap, and waterless antiseptic dispensers were fitted with sensors and switches. When a sensor was activated either by the toilet being flushed, soap or foam being dispensed, or water flowing through the tap, a radio signal was sent to the computer indicating that the switch was opened or closed (Swoboda et al., 2004).
	Length of stay	Period of time during which a patient is confined to a hospital or other health facility (NLM MeSH).	Days (Ben-Abraham et al., 2002)	Medical charts - Review of medical records (Ben-Abraham et al., 2002)
	Mortality	The rate of death from any cause in hospitalized populations (NLM MeSH).	Percentage of deaths/total number of patients (McManus et al., 1992)	Actual: Medical charts; Expected: Estimated using an equation based on patient characteristics e.g. burn size, age (McManus et al., 1992)

	Term	Definition	Metrics	Measurement method
	Nosocomial infection	An infection that is acquired in a hospital as a result of medical care; also called hospital-acquired infection (Sehulster et al., 2004).	<ul style="list-style-type: none"> - Number of NIs per 100 admits/discharges (Modol et al., 2007); - Number of NIs per 1,000 patient days (Swoboda et al., 2004); - Number of hospital-acquired infections per patient (Ben-Abraham et al., 2002); - Risk of infection - Percentage of susceptible patients infected (Escombe et al., 2007) 	<p>Medical charts</p> <ul style="list-style-type: none"> - Infection data were prospectively collected and stored in a computerized database. All infections and antibiotic uses were reviewed by the facility's Infection Control Committee based on pre-existing criteria (McManus et al., 1992) - Physician evaluation according to CDC criteria based on test results of respiratory, serum, or urinary samples (Modol et al., 2007) <p>Model estimation</p> <ul style="list-style-type: none"> - Estimated by Wells-Riley model of airborne infection (Escombe et al., 2007)
	Particulate level	Amount of particles in the air (Bergeron et al., 2003).	Number of particles/m ³ (Bergeron et al., 2003).	<p>Air Sampling using particle counter</p> <ul style="list-style-type: none"> - Airborne particle counts were measured over a 1-minute interval with a 6-channel, light-scattering particle counter (CI-500; Climet), operating at a flow rate of 1.7 cubic meters per hour and placed 1.2 meters above floor level (Bergeron et al., 2003).
	Patient colonization	Isolation of a targeted pathogen (organism) from the patient (e.g., sputum, wound surface, urine, stool) (McManus et al., 1992).	Percentage of patients colonized; Postburn time delay in colonization (McManus et al., 1992)	<p>Microbiology surveillance</p> <ul style="list-style-type: none"> - Microbiology surveillance was performed for the first 30 days of hospitalization or longer if patients remained in the unit. The surveillance included weekly cultures of sputum, wound surface, urine, and stool. Colonization was defined as isolation of the organism from any site on the body (McManus et al., 1992)

	Term	Definition	Metrics	Measurement method
	Surface contamination	Presence of pathogens on inanimate surfaces (Anderson et al., 1982).	Number of microorganisms (cfu) per square inch (Anderson et al., 1982); Bacterial community composition (Harris et al., 2010)	Swab sampling/biology analysis - Surface swab samples were collected from each flooring type using a surface swab kit (SKC, Eighty Four, PA, USA). DNA from the swab washes was extracted with an Ultraclean Microbial DNA Kit (Mo-Bio, Carlsbad, CA, USA) (Harris et al., 2010). Generic analysis - denaturing gradient gel electrophoresis (DGGE) - The DGGE technique is based on the separation of PCR fragments of the same length in a linearly increasing gradient of chemical denaturants. The different fragments melt and, consequently, stop at particular positions in the gel, a transition from helical to partially melted molecule that depends on the base composition of their sequences. The resulting banding pattern represents a profile of the community, and the relative intensity of each band represents the relative abundance of a particular member of the community. Consequently, microbial communities can be quickly analyzed and compared, permitting temporal and spatial analysis within and between communities (Harris et al., 2010)
	Tuberculin conversion & reactivity	TB conversion: indurations of 10 mm or greater with an increase of at least 6 mm more than 1 year after a negative result (<10 mm). TB reactivity: indurations of 10 mm or greater (Menzies et al., 2000).	- Ratio (percentage) of healthcare workers with Tuberculin conversion (Menzies et al., 2000); - Ratio (percentage) of patients/visitors w/ Tuberculin reactivity (Hutton et al., 1990).	TB skin test - Tuberculin conversion is indicated by induration of 10 mm or greater with an increase of at least 6 mm more than 1 year after a negative result (<10 mm) (Menzies et al., 2000)

Healthcare-Associated Infections: Article analysis

Reference	Environmental feature		Outcome		Study design	Results	Setting	Sample
	Variable	Metric	Variable	Metric				
Anderson, R. L., Mackel, D. C., Stoler, B. S., & Mallison, G. F. (1982). Carpeting in hospitals: An epidemiological evaluation. <i>Journal of Clinical Microbiology</i> , 15 (3), 408-415.	Flooring material	Carpet vs. vinyl tile flooring	Microorganism contamination on floor surface; Patient colonization; Nosocomial infection rate	# of microorganisms per square inch; Type of microorganisms found in patients and flooring; # of patients with community-acquired and hospital-acquired infections	Experiment	The level of microorganism contamination was higher on carpeted floor than on bare vinyl-tile floor. The same types of organisms initially recovered from the carpet in patient rooms were found on patients. No difference in infection rate was found between carpeted and non-carpeted rooms.	Two patient rooms (one had new carpet installed) in a pediatric hospital	18 carpet samples and 6 vinyl floor samples in each sampling period (total 58 periods); 23 patients in carpeted rooms and 36 in non-carpeted rooms.
Barnes, R. A., & Rogers, T. R. (1989). Control of an outbreak of nosocomial aspergillosis by laminar airflow isolation. <i>Journal of Hospital Infection</i> , 14 (2), 89-94.	Construction work; High-efficiency particulate air (HEPA) filters; Laminar air flow (LAF)	Bone marrow transplant (BMT) unit near the construction site vs. a control unit and outdoor; Installation of a LAF system with HEPA filters vs. natural ventilation	Airborne fungal concentration Invasive pulmonary aspergillosis (IPA) infection	cfu/m3, ratio of concentration indoor/outdoor (microbiology analysis of air samples); Number of IPA cases	Before-after study	During construction, aspergillus spore concentration in the BMT unit (133cfu/m3) far exceeded (a ratio of 11:1) those measured in outdoor while the spore counts in other units were consistent lower than outdoor. Installation of LAF w/HEPA virtually eliminated aspergillus spore. Six of 19 children in BMT unit during construction work died of IPA. No cases of IPA were documented after the installation LAF/HEPA.	A bone marrow transplantation unit	38 children undergoing bone marrow transplant (19 before and 19 after LAF/HEPA installation)
Beggs, C. B., Kerr, K. G., Noakes, C. J., Hathway, E. A., & Sleight, P. A. (2008). The ventilation of multiple-bed hospital wards: Review and analysis. <i>American Journal of Infection Control</i> , 36 (4), 250-259.	Ventilation strategy (location of ventilation grilles)	Ceiling vs. wall (low-high, and high low)	Bioaerosol concentration (volume average)	cfu/m3 (Computational fluid dynamics [CFD] study)	Experiment using simulation software	Bioaerosol concentration was lower in ceiling ventilation (2467 cfu/m3) than wall ventilation (12487 and 10601 cfu/m3)	An empty 32-m3 room	NA
Ben-Abraham, R., Keller, N., Szold, O., Vardi, A., Weinberg, M., Barzilay, Z., & Paret, G. (2002). Do isolation rooms reduce the rate of nosocomial infections in the pediatric intensive care unit? <i>Journal of Critical Care</i> , 17 (3), 176-180.	Single rooms with separated sinks	Conversion of a open bay unit to single room unit with separated sinks	Nosocomial infection rate; Patient length of stay	# of hospital-acquired infections per patient (infection surveillance); # of days (medical records)	Before-after	Both hospital -acquired infections and the patient length of stay were significantly reduced when the unit was converted from open bay to single rooms with separate sinks.	A six-bed pediatric intensive care unit in Israel	About 200 patients hospitalized for more than 48 hours
Bergeron, V., Reboux, G., Poirot, J.L., & Laudinet, N. (2007). Decreasing airborne contamination levels in high-risk hospital areas using a novel mobile air-treatment unit. <i>Infection Control and Hospital Epidemiology</i> , 28 (10), 1181-1186.	Mobile air-treatment unit that uses nonthermal-plasma reactors	Air treatment unit on vs. off; Patient room w/ the air treatment unit vs. patient room w/o the unit	Particulate level (all particles >0.5 um); Bioaerosol concentration (fungal flora, mesophilic flora)	Particles/m3 (air Sampling using particle counter); cfu/m3 (air sampling using biocollector and biology analysis)	Quasi-experiment	The air-treatment unit significantly reduced the time (from 12 minutes to 2 minutes) to lower airborne particles by 90% and reduced airborne fungus levels (75%- 80%).	Two hospitals in France	An operating room and two Hematology patient rooms
Carling, P. C., Briggs, J. L., Perkins, J., & Highlander, D. (2006). Improved cleaning of patient rooms using a new targeting method. <i>Clinical Infectious Diseases</i> , 42 (3), 385-388.	A new method of identifying high touched objects (HTOs) that are poorly cleaned; Multidisciplinary educational intervention	Before and after the intervention	Cleaning of HTOs	Percentage of HTOs cleaned after 2-3 terminal cleanings (HTOs marked with targeting solutions which fluoresces under black light)	Before-after	Sinks, toilet tops, and tray tables had high rates of cleaning (85%-92%); bedpan cleaning equipment, toilet handholds, door knobs were least cleaned (12%-17%). After the educational program, the rates of cleaning improved.	Three hospitals	1404 HTOs in 157 rooms before the intervention, 744 HTOs in 98 rooms after the intervention
Carling, P. C., Parry, M. F. & Von Beheren, S. M. (2008). Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. <i>Infection control and hospital epidemiology</i> , 29 (1), 1-7.	Environmental surface type	High-risk object categories (e.g. sink, door knob, toilet seat)	Thoroughness of terminal cleaning	Percentage of objects cleaned after terminal cleanings (objects marked with targeting solutions which fluoresces under black light)	Observational	Overall, 49% of evaluated surfaces were cleaned after terminal cleanings. Some objects (e.g. sink, toilet seat, tray table) tended to better cleaned than other objects (e.g. toilet handhold, bedpan cleaner, light switch, door knob)	23 hospitals	13,369 high-risk objects in 1119 patient rooms/bathrooms
Chang, V. T., & Nelson, K. (2000). The role of physical proximity in nosocomial diarrhea. <i>Clinical Infectious Diseases</i> , 31 (3), 717-722.	Physical proximity	Whether or not a patient was roommate or neighbor of another patient with diarrhea, or stayed in room after the patient with diarrhea left (mapping of patient rooms)	Nosocomial acquisition of <i>Clostridium difficile</i> associated diarrhea (CDAD) and antibiotic-associated diarrhea (AAD)	Whether a patient had nosocomial CDAD and AAD (clinical records)	Observational, regression analysis	Physical proximity is an independent risk factor for acquisition of nosocomial CDAD and AAD.	A 305-bed community hospital	2859 patients who stayed > 2 days

Reference	Environmental feature		Outcome		Study design	Results	Setting	Sample
	Variable	Metric	Variable	Metric				
Cohen, B., Saiman, L., Cimiotti, J., & Larson, E. (2003). Factors associated with hand hygiene practices in two neonatal intensive care units. <i>Pediatric Infectious Disease Journal</i> , 22 (6), 494-499.	Hand hygiene device	Alcohol-based hand rub dispenser vs. antimicrobial soap and sink	Hand hygiene compliance	# of hand touches with new gloves/cleaned hands, used gloves, and no gloves/uncleaned hands per neonate per shift	Quasi-experiment, comparison of two units using different hand hygiene devices	Staff members in the NICU using alcohol-based hand rub dispenser were more likely to use new gloves/cleaned hands to directly touch neonates than staff in the NICU using antimicrobial soap and sinks.	Two NICU's (44 and 50 beds) in New York City	1,472 hand touches by staff members
Crimi, P., Argellati, F., Macrina, G., Tinteri, C., Copello, L., Rebor, D., . . . Rizzetto, R. (2006). Microbiological surveillance of hospital ventilation systems in departments at high risk of nosocomial infections. <i>Journal of Preventive Medicine and Hygiene</i> , 47 (3), 105-109.	Location of HEPA filters in the HVAC system; Ventilation type	Central (inside main air ducts) vs. peripheral (at the openings of ducts); Natural ventilation vs. mechanical ventilation	Air contamination of bacteria, Aspergillus	Percentage of positive samples; cfu/m3 (air sampling, incubation)	Observational	Hospital departments with central HEPA filters had higher level of air contamination than the departments with peripheral HEPA filters. Lower levels of air contamination were recorded in spaces with mechanical ventilation.	Seven departments in an Italian hospital	About 310 air samples
Escombe, A. R., Oeser, C. C., Gilman, R. H., Navincopa, M., Ticona, E., Pan, W., et al. (2007). Natural ventilation for the prevention of airborne contagion. <i>PLoS Medicine</i> , 4 (2), e68.	Ventilation type; Environmental factors influencing natural ventilation	Natural ventilation vs. mechanical ventilation; Area of windows/doors open (m2) Placement of windows/doors on opposite walls Ceiling height (m) Floor area (m2) Wind speed (km/h)	Ventilation rate; Estimated risk of airborne Tuberculosis (TB) infection	Air changes per hour (ACH, measured by tracer gas concentration decay technique) Absolute ventilation rate (m3/h) Percentage of susceptible patients infected, estimated by Wells-Riley model of airborne infection	Experiment	Natural ventilation by opening windows/doors provided a median of 28 ACH, compared to 12 ACH designed for (< 6 ACH actually delivered by) mechanically ventilated isolation rooms. Older rooms with higher ceilings and bigger windows had higher ventilation rates (40 ACH). The risk of TB infection was lower in naturally ventilated rooms.	Eight hospitals in Lima, Peru	70 clinical rooms with natural ventilation, 12 isolation rooms with mechanical ventilation
Gardner, P. S., Court, S. D., Brocklebank, J. T., Downham, M. A., & Weightman, D. (1973). Virus cross-infection in paediatric wards. <i>British Medical Journal</i> , 2 (5866), 571-575.	Single room	Single room unit vs. open unit (percentage of beds in single rooms <40% vs. >85%)	Rate of virus cross-infection for respiratory syncytial infection, influenza A, parainfluenza	Cross-infection per million susceptible days per infective day	Quasi-experiment, comparison of four single room units and four open units	Cross infection rates were significantly lower in single room units than in open units.	8 pediatric units in UK	8 pediatric units
Gustafson, T. L., Lavelly, G. B., Brawner, E. R., Jr., Hutcheson, R. H., Jr., Wright, P. F., & Schaffner, W. (1982). An outbreak of airborne nosocomial varicella. <i>Pediatrics</i> , 70 (4), 550-556.	Air flow pattern	Air flowing from the positive-pressure isolation room where a patient with varicella stayed (air flow pattern identified using tracer gas study)	Concentration of viral particles in corridors; Rate of Varicella transmission	Relative concentration compared to the level in index patient room (% estimated by tracer gas study) Percentage (# patients who contracted varicella/total patients)	Observational	Air flowed from the positive-pressure isolation room to corridor. The tracer gas released in the room achieved significant concentration in corridor. Patients who were closer to the isolation room had significantly higher risk of varicella transmission. Patients who entered corridor zone with higher concentration of viral particles (estimated by tracer gas study) were more likely to contract varicella.	A pediatric unit	70 patients potentially susceptible to varicella
Hahn, T., Cummings, K. M., Michalek, A. M., Lipman, B. J., Segal, B. H., & McCarthy, P. L., Jr. (2002). Efficacy of high-efficiency particulate air filtration in preventing aspergillosis in immunocompromised patients with hematologic malignancies. <i>Infection Control and Hospital Epidemiology</i> , 23 (9), 525-531.	High-efficiency particulate air (HEPA) filters; Laminar air flow (LAF)	One unit wing w/ HEPA filters (including some rooms w/ LAF) vs. another wing w/o HEPA/LAF; Before and after the installation of HEPA filters in the later wing	Aspergillus concentration Aspergillosis infection	cfu/m3 (air samples) Number of Aspergillosis cases	Before-after study	Higher Aspergillus conidia count (>150 cfu/m ³) in the wing w/o HEPA/LAF than the wing w/ HEPA and LAF(<4 cfu/m ³). There were fewer infections of invasive aspergillosis in the wing with HEPA/LAF. The infection rate in the wing without HEPA/LAF was reduced after the installation of HEPA and other infection control measures.	A hematologic oncology unit	91 immunocompromised patients who stayed more than 4 days
Harris, D., Pacheco, A., & Lindner, A. S. (2010). Detecting potential pathogens on hospital surfaces: An assessment of carpet tile flooring in the hospital patient environment. <i>Indoor and Built Environment</i> , 19 (2), 239-249.	Flooring material	Types of flooring material (tiled and non-tiled carpet, vinyl)	Surface contamination	Bacterial community composition (bacteria types identified by swab sampling and generic analysis - denaturing gradient gel electrophoresis)	Observational	Bacterial diversity (number of genera identified) was higher in the edges of tiled carpets than the surface and backing. Vinyl floor samples exhibited a lower number of genera but higher numbers of bacterial genus/species associated with genera of pathogenic bacteria. Various surfaces (e.g. shoe sole, medical monitor, laundry cart) carried unique bacterial species and might potentially transmit disease.	Medical units in a Midwest community hospital	Swab samples in 12 locations (9 samples for each of the 6 tiled carpet locations) in each of 5 sampling visits

Reference	Environmental feature		Outcome		Study design	Results	Setting	Sample
	Variable	Metric	Variable	Metric				
Hutton, M. D., Stead, W. W., Cauthen, G. M., Bloch, A. B., & Ewing, W. M. (1990). Nosocomial transmission of tuberculosis associated with a draining abscess. <i>Journal of Infectious Diseases</i> , 161 (2), 286-295.	Air flow pattern; Exposure to the patient	Air flowing from the positive-pressure isolation room where a patient with a large tuberculous abscess stayed to other areas (air flow pattern identified using a aerosol dispersion study); Exposure to patient recalled by healthcare workers	Tuberculin conversion in healthcare workers; Tuberculin reactivity in visitors and patients (for whom the previous reactivity status was unknown)	# of healthcare workers w/ vs. w/o Tuberculin conversion (skin test, induration of 10 mm or greater with an increase of at least 6mm more than 1 year after a negative result (<10 mm); A reactor was a person whose current tuberculin test was >=10mm.	Observational	Exposure to the patient with Tuberculous infection was associated with increased risk of Tuberculin conversion and reactivity. Air flow from the positive pressure room where a patient with a large tuberculous abscess stayed was a strong factor contributing to high risk of Tuberculosis transmission. Patients and visitors closer to the positive pressure room had higher risk of Tuberculin reactivity.	A 250-bed hospital in rural Arkansas	442 employees and 50 students
Jiang, S. P., Huang, L. W., Chen, X. L., Wang, J. F., Wu, W., Yin, S. M., . . . Huang, Z. (2003). Ventilation of wards and nosocomial outbreak of severe acute respiratory syndrome among healthcare workers. <i>Chinese Medical Journal</i> , 116 (9), 1293-1297.	Natural ventilation window size	Ventilation window area/room volume (m2/m3)	Severe acute respiratory syndrome (SARS) infection rate	Percentage of healthcare workers infected with SARS	Observational	The percentage of healthcare workers infected with SRAS appeared to be negatively associated with the ratio of ventilation window area to room volume.	SARS wards in a Chinese hospital	About 430 healthcare workers in four wards
Kaplan, L. M., & McGuckin, M. (1986). Increasing handwashing compliance with more accessible sinks. <i>Infection Control</i> , 7 (8), 408-410.	Number of accessible handwashing sinks	Bed-to-sink ratio (1:1 vs. 4:1)	Hand-washing compliance rate	Percentage of direct contacts with patients and their support equipment followed by handwashing (observation)	Quasi-experimental	Nurses in the unit with lower bed-to-sink ratio had significantly higher handwashing compliance (76%) rate than those in the unit with fewer sinks (51%).	A open medical ICU (bed: sink = 1:1) and a open surgical unit (bed: sink = 4:1)	30 nurses, 8 physicians, and 4 technicians
Lankford, M. G., Collins, S., Youngberg, L., Rooney, D. M., Warren, J. R., & Noskin, G. A. (2006). Assessment of materials commonly utilized in health care: Implications for bacterial survival and transmission. <i>American Journal of Infection Control</i> , 34 (5), 258-263.	Interior finish materials; Surface decontamination	Upholstery (4), flooring (6), wall finishes (4); Before and after decontamination according to manufacturer recommendations	Bacterial growth (vancomycin-resistant enterococci [VRE] and Pseudomonas aeruginosa [PSAE])	Confluent growth (CG, bacterial growth so heavy that individual colonies are not recognized for counting), no confluent growth (NCG, 1-388 cfu's), no growth (NG)	Experiment	Vinyl composition tile, microvented perforated vinyl wall covering, and paper-backed wall covering had higher VRE growth than other materials including synthetic or vinyl-backed carpet. .	Hospital	14 interior materials
Larson, E. L., Albrecht, S., & O'Keefe, M. (2005). Hand hygiene behavior in a pediatric emergency department and a pediatric intensive care unit: Comparison of use of 2 dispenser systems. <i>American Journal of Critical Care</i> , 14 (4), 304-311.	Alcohol-based hand rub dispenser type	Manual operated dispenser vs. battery-operated, touch-free dispenser	Dispenser use frequency; Hand hygiene frequency	# of uses per dispenser per day (electronic counter); # of incidences of hand hygiene per patient per hour (observation); # of incidences of hand hygiene before patient contact per hour (observation)	Quasi-experiment, crossover design	The touch-free dispenser was used significantly more frequently than the manual dispenser.	ED and PICU at a large pediatric hospital	About 300 hours of observation in 4 months
Lutz, B. D. J., Rinaldi, J., Wickes, M. G., Huycke, B.L., Mark M. (2003). Outbreak of invasive Aspergillus infection in surgical patients, associated with a contaminated air-handling system. <i>Clinical Infectious Diseases</i> , 37 (6), 786-793.	HVAC system moisture and contamination; HVAC system maintenance (removing insulating materials and coating surfaces contaminated with fungicide)	Environmental inspection; Implementation of the maintenance	Air contamination; Invasive Aspergillus infection	# of particles > 3 u m (particle counter); # of invasive Aspergillus infection cases (hospital medical records)	Before-after; observational	Dampness and contamination of Aspergillus found in HVAC ductwork. 3-1000-fold increase in particle concentrations in operating rooms and hallways than in ductwork immediately downstream of air-handling system. After HVAC renovation, airborne particles reduced and no new invasive Aspergillus case was identified.	One operating room and related HVAC system	6 cases of Invasive Aspergillus, air samples, air duct material specimen
MacKenzie, F. M., Bruce, J., Struelens, M. J., Goossens, H., Mollison, J., & Gould, I. M. (2007). Antimicrobial drug use and infection control practices associated with the prevalence of methicillin-resistant Staphylococcus aureus in European hospitals. <i>Clinical Microbiology and Infection</i> , 13 (3), 269-276.	Environmental infection control measures: -Single room isolation -Hand hygiene device(alcohol-based hand solutions)	Yes/No response to postal and online questionnaire questions	MRSA prevalence rate (hospital level)	Percentage of clinical S. aureus isolates that were methicillin-resistant, collected by questionnaire	Observational, retrospective, cross-sectional study	Data strongly indicted that certain environmental control measures, alcohol-based solutions for hand hygiene and single rooms of isolating infected patients, were associated with lower MRSA prevalence rates.	Hospitals across various Europe regions	173 European hospitals

Reference	Environmental feature		Outcome		Study design	Results	Setting	Sample
	Variable	Metric	Variable	Metric				
McDevitt, J. J., Milton, D. K., Rudnick, S. N., & First, M. W. (2008). Inactivation of poxviruses by upper-room UVC light in a simulated hospital room environment. <i>PLoS ONE</i> , 3 (9), e3186.	Upper-room air ultraviolet germicidal irradiation (UVGI); Environmental factors influencing UVGI effectiveness	Upper-room UVGI on/off; Mechanical air mixing (ceiling fan); Convection (heat box); Relative humidity (%)	Equivalent air changes per hour due to UVGI	The amount of virus-free dilution air that would be needed to provide the same reduction of virus concentration that was actually measured (ptu/m3)	Experiment	Upper room UVGI produced decreases in airborne virus concentration equivalent to 18 and more air changes per hour. UVGI was more effective (i.e. more equivalent ACH) at low relative humidity in room with efficient air mixing.	A simulated hospital room	NA
McManus, A. T., Mason, A. D., Jr., McManus, W. F., & Pruitt, B. A., Jr. (1992). Control of pseudomonas aeruginosa infections in burned patients. <i>Surgical Research Communications</i> , 12, 61-67.	Single room	Single room unit vs. open unit	Frequency of colonization; Time delay in colonization; Expected mortality	Percentage of patients colonized; Postburn day of colonization; Estimated using an equation based on burn size and age	Before-after; retrospective;	The single room unit had a more delayed postburn day of colonization of Pseudomonas aeruginosa (PA). The single room unit had a lower frequency and a more delayed postburn day of colonization of Pseudomonas bacteremia, pneumonia, and invasive burn-wound infection.	An Army burn center	2,316 burn patients admitted in the open ward (1980-1983) or the single-room unit (1984-1990)
Menzies, D., Fanning, A., Yuan, & Fitzgerald, M. (2000). Hospital ventilation of risk for tuberculosis infection in Canadian health care works. <i>Annals of Internal Medicine</i> , 133 (10), 779-789.	Ventilation rate	Air changes per hour (tracer gas technique)	Tuberculin conversion in healthcare workers	# of healthcare workers w/ vs. w/o Tuberculin conversion (skin test, induration of 10 mm or greater with an increase of at least 6mm more than 1 year after a negative result (<10 mm)	Observational	Higher air changes per hour was associated with fewer healthcare workers with Tuberculin conversion.	17 Canadian acute-care hospitals	About 1300 healthcare workers who had two skin tests more than 1 year apart at the same hospital and was Tuberculin negative at the first test
Menzies, D., Popa, J., Hanley, J.A., Rand, T., & Milton, D. K. (2003). Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and well-being: Double-blind, multiple crossover trial. <i>Lancet</i> , 362 (9398), 1785-1790.	Ultraviolet germicidal irradiation (UVGI) in ventilation system	UVGI (on vs. off)	Work-related symptom (systemic, mucosal, respiratory, musculo-skeletal) Thermal condition Chemical concentration Viable microbial concentration Endotoxin concentration	Questionnaire surveys; Mean temperature (C), relative humidity (%), air velocity (m/sec), HVAC recirculation (%); CO2 (ppm), TVOCs (mcg/m3), formaldehyde (ppm), ozone (ppb), nitrogen oxides (ucg/m3); Fungi (cfu/m3), bacteria (cfu/m3); Endotoxin (eu/m3, eu/coupon)	Quasi-experiment, repeated measurement	UVGI was associated with significant reduction of microbial and endotoxin concentrations on irradiated surfaces in the ventilation system. The use of UVGI resulted in fewer work-related symptoms.	Three office buildings in Canada, with sealed windows and mechanical ventilation	771 office workers
Modol, J., Sabria, M., Reynaga, E., Pedro-Botet, M. L., Sopena, N., Tudela, P., . . . Rey-Joly, C. (2007). Hospital-acquired legionnaires disease in a university hospital: impact of the copper-silver ionization system. <i>Clinical Infectious Diseases</i> , 44 (2), 263-265.	Water disinfection system: copper-silver ionization system; Cooper/silver levels	The installation of the copper-silver ionization system; Colorimetric analysis (optimal level 0.2-0.5mg/L), atomic adsorption (0.02-0.05 mg/L)	Environmental colonization of <i>Legionella</i> ; Rate of hospital-acquired legionnaires diseases (HALD) (physician evaluation according to CDC criteria,	# of samples tested positive for <i>L. pneumophila</i> , colony-forming unit (CFU)/L (water samples seeded in selective modified Wadowsky Yee-buffered charcoal yeast extract- α agar); # of cases per 1000 patient discharges (physician evaluation according to CDC criteria based on test results of respiratory, serum, or urinary samples)	Longitudinal study (repeated measurements) Period 1 (Jan 1998 - Sept. 199) Period 2 (Oct 1999 - Dec. 2004)	The installation of the copper-silver ionization system significantly reduced colonization of in water samples, and reduced infection rate of HALD, from 2.45 to 0.18 cases per 1000 patient discharge.	A 630-bed hospital in Spain	About 410 water samples, 82 HALD cases in period 1 and 20 in period 2
Noskin, G. A., Bednarz, P., Suriano, T., Reiner, S., & Peterson, L. (2000). Persistent contamination of fabric-covered furniture by Vancomycin-resistant Enterococci: Implication for upholstery selection in hospitals. <i>American Journal of Infection Control</i> , 28 (4), 311-313.	Furniture cover materials	Fabric vs. vinyl	Contamination of vancomycin-resistant <i>Enterococci</i> (VRE); Disinfection of VRE	Presence or absence of VRE (after inoculation, and after cleaning with a quaternary ammonium germicide in simulated inoculation studies)	Simulated experiment	VRE was found at 72 hours and seven days after inoculation on fabric and vinyl upholstered chairs. Routine disinfection was successful in removing VRE from vinyl surfaces but not from fabric surfaces.	A 688-bed hospital in Chicago	10 seat cushions in five randomly chosen hospital rooms; five simulated samples
Swoboda, S. M., Earsing, K., Strauss, K., Lane, S., & Lipsett, P. A. (2004). Electronic monitoring and voice prompts improve hand hygiene and decrease nosocomial infections in an intermediate care unit. <i>Critical Care Medicine</i> , 32 (2), 358-363.	Automatic computerized reminders for failure to perform hand hygiene on room exit.	Electronic system including electronic beam breakers or motion detectors placed at the threshold of each room to monitor entry and exit of personnel; A computerized reminding system that gave prerecorded audio/visual messages instructing personnel to wash their hands if they had not done so before exiting the room or within	Hand hygiene compliance Nosocomial infection rate	Electronic monitoring of entry and exit of personnel and the use of hand hygiene devices (percentage - actual hand hygiene divided by hand hygiene opportunities); Observation; # of NI's per 100 admits, # of NI's per 1000 patient days (clinical records, assessed by a review committee of physicians and nurse)	Quasi-experiment, repeated measurements	The hand hygiene compliance improved and the nosocomial infection rate decreased after the installation of automatic reminding device. Electronic monitoring underestimated hand hygiene compliance.	A 14-bed intermediate care unit in a university hospital	1875 patients admitted to the unit, 283,488 electronically monitored entries into a patient room

Reference	Environmental feature		Outcome		Study design	Results	Setting	Sample
	Variable	Metric	Variable	Metric				
Takai, K., Ohtsuka, T., Senda, Y., Nakao, M., Yamamoto, K., Matsuoka, J., & Hirai, Y. (2002). Antibacterial properties of antimicrobial-finished textile products. <i>Microbiology and immunology</i> , 46 (2), 75-81.	Antimicrobial-finished textile product (AFTPs)	Five AFTPs treated with antibacterial agents and one control product that is untreated	Bacteria contamination	Viable cell ratio (%)	Experiment	Textile materials containing Ag, Zn, Ammonium Zeolite and chitosan, to various extent, limited the growth of some bacterial species and strains. Organic matter and water content could affect the antibacterial effectiveness in clinical setting.	A lab	Samples of 5 AFTPs and one control material
Williams, H. N., Singh, R., & Romberg, E. (2003). Surface contamination in the dental operatory: A comparison over two decades. <i>Journal of the American Dental Association</i> , 134 (3), 325-330.	Environmental improvements: -reduce the number of surface areas -mobile countertops -central sterilization facility -autoclavable handpieces -foot-pedal controlled sinks	Before and after the environmental improvements	Surface contamination (light handle covers, jacket cuffs, sinks and floors)	Bacteria counts (colony-forming unit)	Before-after	A lower level of surface bacterial contamination was found after the environmental improvements together with stringent infection control procedures.	A large (>200-chair) dental clinic in Maryland	30 randomly selected dental operatories
Xu, P., Kujundzic, E., Peccia, J., Schafer, M. P., Moss, G., Hernandez, M., & Miller, S.L. (2005). Impact of environmental factors on efficacy of upper-room air ultraviolet germicidal irradiation for inactivating airborne mycobacteria. <i>Environmental Science & Technology</i> , 39 (24), 9656-9664.	Environmental factors influencing UVGI effectiveness	Air mixing (on/off); Relative humidity (%)	Ultraviolet germicidal irradiation (UVGI) inactivation rate; UVGI effectiveness	The rate at which UVGI inactivates microorganism over time in decay test condition (1/h); Percentage of bacteria concentration reduction (cfu/m3) due to UVGI in constant generation condition (Air sampling, culture, epifluorescent microscopy)	Experiment	UVGI inactivation rate was significantly higher in mixing condition than in non mixing condition. UVGI inactivation rate and effectiveness decreased significantly when relative humidity increased.	A simulated hospital room	NA

Healthcare-Associated Infections: Matrix of relationships

		Outcome						
	Variable	Air contamination	Inanimate surface contamination	Water contamination	Hand hygiene	Healthcare-associated infection	Length of stay	Mortality
Environmental feature	Patient room occupancy							
	Physical proximity							
	Air pressure difference between adjacent spaces							
	Laminar air flow							
	Location of ventilation grilles							
	Ventilation system type							
	Ventilation rate							
	Environmental factors influencing natural ventilation							
	High-efficiency particulate air (HEPA) filter							
	Mobile air-treatment unit							
	Ultraviolet germicidal irradiation							
	HVAC system maintenance							
	Construction work							
	Interior finish material							
	Furniture covering material							
	Antimicrobial-finished textile product							
	Surface cleaning							
	Number of hand hygiene device							
	Alcohol-based hand rub							
	Automatic computerized reminder of hand hygiene							
Copper-silver ionization								

Note: Cells shaded in gray indicate the existence of evidence supporting relationships between environmental features and outcomes