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Correlation of Professional Performance to Acceptable IAQ in Critical Care Medical Facilities

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1. Introduction

Fundamentally, buildings are simple things. Its basic purpose is to provide shelter. Initially, caves, cow hides for tents, hay for roofs, and mud for walls fulfilled this function. As life became more complex, beyond looking for the next meal, buildings followed suit. Historically, humanity has evolved from utilizing natural materials and living with the inherent limitations of these materials to integrating manufactured products limited only by the imagination of the designer. But if form truly "follows function"[1] there is possibly no more of a complex and critical function than that of our critical care medical facilities. These functions are so critical that, for the most part, a team of specialists is required to provide a fully operational facility. The realization of a building from a building program (written statement of need) into a three dimensional form is typically "chaired" by the architect who similarly employs the talents of various engineers and other specialists. All of this talent demands, and deserves, a fee structure higher than what is typically seen for office and other commercial buildings. Yet, even with the skill levels in place to bring such a complex environment together, flawed and defective buildings are designed and constructed. The ramifications of unsuccessful hospitals impact the very purpose of its mission and impose unnecessary burden on staff and management, but more significantly: **Defective Buildings shorten the life of buildings and defective critical care medical buildings present serious health and safety risks to patients and staff.**

[1] "It is the pervading law of all things organic, and inorganic, of all things physical and metaphysical, of all things human and all things super-human, of all true manifestations of the head, of the heart, of the soul, that the life is recognizable in its expression, that **form ever follows function**. This is the law. "American architect, Louis Sullivan, (1856-1924)

Various sub-systems that comprise the whole building (thus making the building a system) include, but are not limited to, the roof, walls and fenestration, heating, ventilation and air-conditioning system (HVAC), plumbing, electrical, finishes, furnishings, equipment and communication systems. At present, the quality of the indoor environment for the health and safety of occupants and protection of assets is becoming a prime concern with end users. Prior to the 1970's, buildings were built with natural and conventional materials. Designers and constructors were well experienced and trained in working with those materials and systems that were straight forward in concept. In the early 1970's, an oil shortage created the need to design and build more energy efficient buildings. As a result, ventilation requirements were substantially reduced in the interest of saving energy. That decision proved to be problematic.

During the 1980's building boom in the United States, the goal shifted to building cheaply and quickly, rather than building with the care seen in previous decades. Combined with the dictates of the 1970's dealing with energy adverse human response to the built environment was becoming evident and the term sick building syndrome (SBS) was coined by the World Health Organization in 1982. In the 1990's, the ventilation standard was revised to increase ventilation to address the SBS issue, as it was believed that dilution would be the solution (American Society of Heating Refrigeration and Air Conditioning Engineers [ASHRAE], ANSI/ASHRAE Standard 62-1989 Ventilation for Indoor Air Quality). Building codes and standards of care were originally developed for basically one reason, public health and safety. As the building industry evolved other codes such as the energy codes have joined the family of public safety codes. However, codes set minimum requirements and thus cannot guarantee quality, longevity or a *healthful* indoor environment. The combination of cheaper built buildings with increased ventilation introduced unplanned for moisture into the indoor environment, and later, the understanding of the role of microorganisms into the SBS vernacular, especially in warm and humid climates (Cooley et al., 1988). In the 2000's, buildings became more complicated due to the need for specific functional use, rapidly changing technology, and the creative application of both conventional and newly developed composite and synthetic materials. Furthermore, the building contractor became more of a broker than a builder due to the economics of tight schedules and budget driven contracts. Today's hospital environment requires a healthcare facility's HVAC systems to provide excellent ventilation effectiveness in order to maintain appropriate indoor air quality, prevent the spread of infection, preserve a sterile and healing environment for patients and staff and to maintain space and comfort conditions. These demands require a healthcare facility's HVAC systems to provide significant quantities of total ventilation and outdoor air. They also require significant treatment of this ventilation air, including cooling, dehumidifying, reheating, humidifying, and filtration of the air to achieve these effective ventilation goals. Trends indicate that even more treatment of the air will be required to respond to infection control and bioterrorism issues in the future.

Given the evolution of the design and construction industry and the diminished quality of construction due to a steeply declining skill set in the building trades, the useful life expectancy of a building, other than strictly controlled construction for institutional buildings.[2] may no longer be 50-60 years, but significantly less.[3]

[2] The case studies presented here are small, regional facilities that lacked the staff and oversight typically seen in large university hospitals or similar facilities.

2. Contributing causes to a defective building

The following factors have played a part in our findings in addition to inadequate budgets and overly optimistic building programs.

2.1 The economy v. mentoring system

Most design professions require an advanced or professional degree at a recognized institution of higher learning. Internship requirements follow a professional education (three years for aspiring architects and engineers). Finally, a professional exam issued by a state is required for licensure. In the past, aspiring design professionals had the opportunity to sit by the side of the "master" and learn the craft of designing a building and its systems. Inflation and the demands of a super-heated economy have changed this scenario. Today, when everything is available instantly, and time is money, the opportunity to engage and learn from the "master" is long gone and this void is worsened by;

2.2 Computers v. knowledge

Although the use of Computer Aided Design systems (CAD) is now universal and certainly can be a great asset to the design team, detail "libraries" can subvert the process of thinking through how things fit together and perform within an overall system. The authors have reviewed construction documents that contain pages and pages of details with the notation that they "may not be a part of this project".[4] This language is completely unacceptable, but does support the notion that some architects either do not understand the importance of a clear set of construction documents, or are yielding to time constraints.

2.3 Specialization itself

The myriad complexities of the typical critical care medical facility require a significant amount of time in coordination with the end user and various disciplines required to ensure the efficient functioning of this facility. For example, Building codes, accessibility standards, and energy requirements must be addressed, as well as state health codes and the Center for Disease Control ("CDC") infectious disease control guidelines (CDC 2003). The authors' review determined 1) the architectural design team was so focused on the functional complexities that the fundamental task of ensuring that the building envelop would keep out the elements was overlooked; 2) the construction documents and or industry standards were not followed resulting in system failures; 3) the fundamentals of mechanical design for the climatic location of the building and or operating standards were not appropriately applied, and 4) the environmental systems were poorly installed, were not sufficiently commissioned, and did not perform to minimum standards.

3. Case studies

The following case studies involved architects that were ostensibly seasoned and who had specialized in the design of critical care medical facilities.

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[3] Currently unknown as to unintended consequences "Green" or "Sustainable Buildings" associated with the U.S. Green Building Council's Leed Certifications have recently been developed to address energy issues and diminishing resources.

[4] Found on the construction document for a multi-million dollar renovation of a high school in Texas, circa 2005.

3.1 Case study 1("CS 1")

This single story surgery center was constructed in 2004. It was 19,000 square feet and constructed under a design/build delivery system.[5] Its exterior was composed of applied stone veneer and an Exterior Finish Insulation System (EFIS). The hospital staff noticed mold growth, wild swings in temperature, and wet indoor environment almost from the day they occupied the building. An investigation ensued and determined that defects discovered associated with the shell of the building, or envelope, was a major contributor, along with the HVAC, to the difficulties they were encountering. Site drainage violated code and held water against the building. It is fundamental to the proper placement of a building to locate it on the site both vertically and horizontally. The horizontal aspect of the placement is guided by local zoning codes. Vertical placement is guided by common sense, water should drain away from a building and thus, downhill. Building codes have language to ensure that the common sense approach is met. For example the building code reads: "The ground immediately adjacent to the foundation shall be sloped away from the building at a slope of not less than one unit vertical in 20 units horizontal (5-percent slope) for a minimum distance of 10 feet (3048 mm) measured perpendicular to the face of the wall or an approved alternate method of diverting water away from the foundation shall be used." (International Building Code [IBC] Chapter 18: Soils and Foundation, 1803.3 Site Grading, 2000).

Compounding this hospital's flawed start were flashings that were either missing or misapplied. It follows that if it is important to drain water away from a building, it is just as important to drain it out of the exterior wall systems. To accomplish this, drainage planes, flashings and weeps should be well known by architects, engineers and constructors and they are well documented in industry and professional publications. Codes, again, have language to ensure these fundamentals are met. For example, the 2000 Edition of the International Building Code reads: "Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing, as described in Section 1405.3. The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer, as described in Section 1402.2 and a means for draining water that enters the assembly to the exterior of the veneer, unless it is determined that penetration of water behind the veneer shall not be detrimental to the building performance. Protection against condensation in the exterior wall assemble shall be provide in accordance with the International Energy Conservation Code" (IBC, Exterior Walls, Section 1403.2, Weather Protection, 2000).

When combined with the fact that water stands against the building, the base flashing not only did not allow water to drain it instead reversed the flow of water such that outside water entered the building. The end result was mold growth along the entire perimeter of the building.

Doors, windows, and louvers all penetrate the walls, thus flashings are also used to divert water to the exterior of a building. Codes (IBC Section 1405.3; Flashing., 2003) and manufacturer's details leave no doubt that the flashing of openings is a requirement, and that information as to materials and methods are readily available. The consequence of ignorance or neglect is water pouring into the building.

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[5] Design/Build is where the builder contracts with the owner to design and construct a project as opposed to the traditional method where the owner hires an architect to design and a builder to construct.

Fig. 1. Site drainage violated code and, held water against the building.

Fig. 2. The copper-coated base flashing at the applied masonry veneer wall terminated below grade and therefore did not allow for the water to drain.

Although flashings are addressed in building codes (IBC Section 1405.3; Flashing., 2003), it is more perplexing as there were a myriad of opportunities for the CS 1 architect and contractor to determine the appropriate method to terminate the exterior wall. Industry organizations, product manufacturers and associations all have literature readily available on the internet.[6] This information is not only available but details and specifications can be downloaded for use by the architect.[7] Furthermore the General Conditions of the Contract for Construction Standard Form of Agreement A201 [American Institute of Architects (AIA), 1997] delineate processes to resolve conflicts. Above the veneered surface of the CS 1 exterior wall, and continuing to the roof was EFIS. EFIS has become widely popular as a light weight, inexpensive system that has the appearance of stucco. Early on, problems arose regarding this system's propensity to hold water between the insulation board and the exterior sheathing which led to mold growth and eventually, numerous law suits.[8] The industry responded by improving the product and producing numerous details and installation procedures, all of which can be accessed via the internet.[9]

Fig. 3. Mold caused by moisture in the wall cavity.

[6] For example, The Rocky Mountain Masonry Institute, Denver, CO; The Brick Industry Association, Reston VA; The Portland Cement Association, Skokie, IL.
[7] For example details and specifications regarding the detailing of masonry can be found at The Brick Institute of America's website: www.gobrick.com/TechinicalNotes/tabid/7658/Default.aspx (last visited on February 13, 2011)
[8] The most notable being the Marin County Courthouse, CA.
[9]http://www.dryvit.com/specs.asp?country_id=1. (last visited on February 13, 2011)

Fig. 4. Water entering the building because of inadequate flashing.

Negative building pressure and improper pressure relationships were the major contributor to the poor physical environment. Pressure relationships between critical care areas inside the building with respect to other spaces were not in accordance with [Title 25, Texas Administrative Code, Chapter 135, Ambulatory Surgical Centers Licensing Rules, (ASCLR), 2009]. Both design and installation defects contributed to these conditions. The design of the HVAC system was inadequate for humidity control. A test, adjust, balance, and commissioning process was obviously never completely performed for the performance aspects of the project other than the air volume measurements. The HVAC control system was deficient in that it was never commissioned to control to the various pieces of equipment as an integrated system.

In a response to uncontrolled high indoor humidity, areas were over-cooled including operating rooms (OR), which resulted in frequent condensation on the interior surfaces, medical equipment, and supplies to the extent surgeries had to be rescheduled or cancelled. Water stained building materials, indoor mold growth, temperature fluctuations, high humidity, and condensation all contributed to an unsatisfactory environment for patients and staff and *violated state licensing rules.* Roof top air handling unit panels for access to the internal equipment and penetrations for conduit, refrigerant lines, etc. leaked water, air, and dust into the interior of the units. Water intrusion stains, mold growth, and debris were found in the air handling units and on ceilings below the air handling units. This project was a classic example of poor coordination. As examples: 1) it is common knowledge that vinyl wall coverings in a hot and humid climate are doomed to failure, yet vinyl wall coverings were specified and installed; 2) engineers know that buildings located in hot and humid climates need HVAC systems designed to work in that climate, yet only the dry-bulb/coincident wet-bulb design condition was used for coil selections resulting in high humidity indoors; and 3) the contractor and subcontractors not only performed substandard and incorrect work, they ignored the consultants' notice of such. Both the architect and contractor failed to provide the quality control and oversight required to deliver an acceptable project. The architect 1) failed to confirm that the site design conformed to code and common sense; 2) failed to detail the flashings to prevent water intrusion, and 3) failed to observe that the weather barrier behind the EFIS was missing. The contractor failed to notify the architect of this omission. The information regarding all of these discovered defects was readily available. The defects caused the building materials to be wetted for prolonged periods of time resulting in mold growth in walls, behind millwork and on ceilings. In short, this project failed "Design and Construction 101" and corrections that should have been made in the field are now to be made in the courtroom.

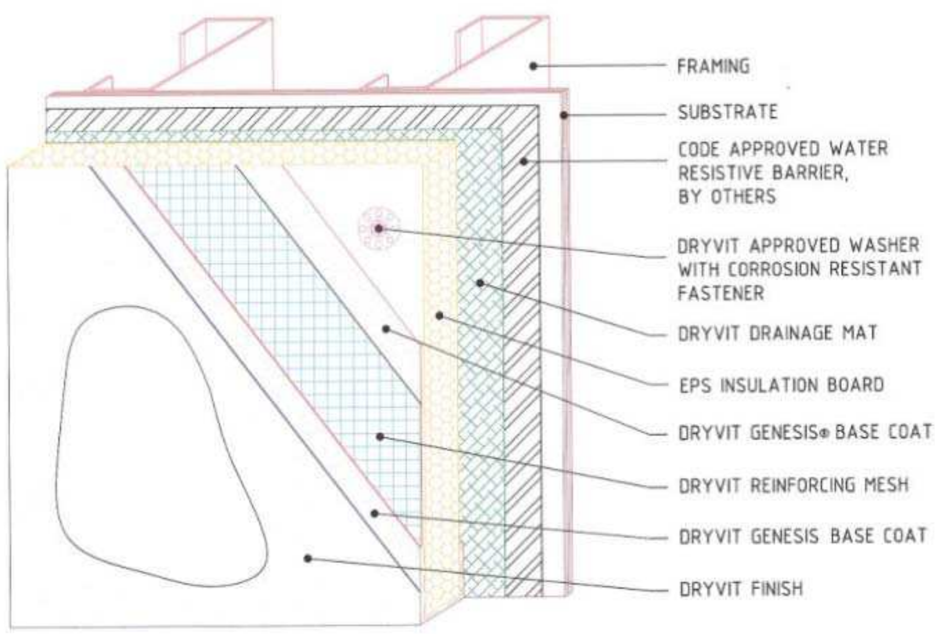

Fig. 5. Typical detail.

Rule #	Subject	Violation (rule language)
§135.52.(h)(5)	HVAC	All rooms and areas in the ASC shall have provision for positive ventilation. Fans serving exhaust systems shall be located at the discharge end and shall be conveniently accessible for service. Exhaust systems may be combined, unless otherwise noted, for efficient use of recovery devices required for energy conservation. The ventilation rates shown in Table 1 of §135.56(a) of this title shall be used only as minimum requirements, since they do not preclude the use of higher rates that may be appropriate.

Rule #	Subject	Violation (rule language)
(C)	General ventilation requirements	All rooms and areas in the ASC shall have provision for positive ventilation. The ventilation rates shown in Table 1 of §135.56(a) of this title shall be used only as minimum requirements, since they do not preclude the use of higher rates that may be appropriate.
(C)(iv)	Temperatures and humidities	The designed capacity of the systems shall be capable of providing the ranges of temperatures and humidities as shown in Table 1 of §135.56(a) of this title.
(C)(viii)	Directional air flow	Ventilation systems shall be designed and balanced to provide pressure relationships contained in Table 1 of §135.56(a) of this title.
(C)(x)	Ventilation start-up requirements	Air handling systems shall not be started or operated without the filters installed in place. This includes the 90% and 99.97% efficiency filters where required. This includes during construction operations. Ducts shall be cleaned thoroughly and throughout by a National Air Duct Cleaners Association (NADCA) certified air duct cleaning contractor when the air handling systems have been operating without the required filters in place. When ducts are determined to be dirty or dusty, the department shall require a written report assuring cleanliness of duct and clean air quality.
(C)(xi)	Humidifier location	When duct humidifiers are located upstream of the final filters, they shall be located at least 15 feet from the filters. Duct work with duct-mounted humidifiers shall be provided with a means of removing water accumulation. An adjustable high-limit humidistat shall be located downstream of the humidifier to reduce the potential of condensation inside the duct.
(C)(xii)(V)	Pressure monitoring devices	A manometer or draft gauge shall be installed across each filter bed having a required efficiency of 75% or more, including laboratory hoods requiring high efficiency particulate air (HEPA) filters. The pressure monitoring device shall be mounted below the ceiling line within the ASC such that it can be observed by staff.
(H)	Fire damper requirements	Fire dampers shall be located and installed in all ducts at the point of penetration of a required two-hour or higher fire-rated wall or floor in accordance with the requirements of NFPA 101, §18.5.2.
(I)	Smoke damper requirements	Smoke dampers shall be located and installed in accordance with the requirements of NFPA 101, §20 .3.7.3, and NFPA 90A, Chapter 5.
(M)	Make-up air	If air supply requirements in Table 2 of §135.56(b) of this title do not provide sufficient air for use by exhaust hoods and safety cabinets, filtered make-up air shall be ducted to maintain the required air flow direction in that room.

Table 1. Nine of twenty-four rules in ASCLR for HVAC systems were noncompliant.

3.2 Case study 2 ("CS 2")

This single story hospital was constructed in 2006. It was 33,000 square feet and constructed under a design/build delivery system. Its exterior was composed of brick veneer with a modified bitumen roof over a steel roof structure. The hospital staff noticed mold growth, wild swings in temperature, and wet indoor environment almost from the day they occupied the building. An investigation ensued and determined that defects discovered associated with the shell of the building, or envelope, was a major contributor, along with the HVAC to the difficulties they were encountering.

Fig. 6. Site drainage violated code and held water against the building.

As in CS 1, common sense and conformance to building codes were not observed at this project. For example, fig. 7 showed water standing at a door that subsequently entered the building.

Fig. 7. A flawed detail at the base of the building compounded the threat to the building posed by standing water.

A standard detail that would allow a veneer to terminate below grade calls for a flashing to be installed at a brick or masonry course above grade. The void below the flashing is then filled with grout that, essentially, makes the veneer below grade a part of the foundation.

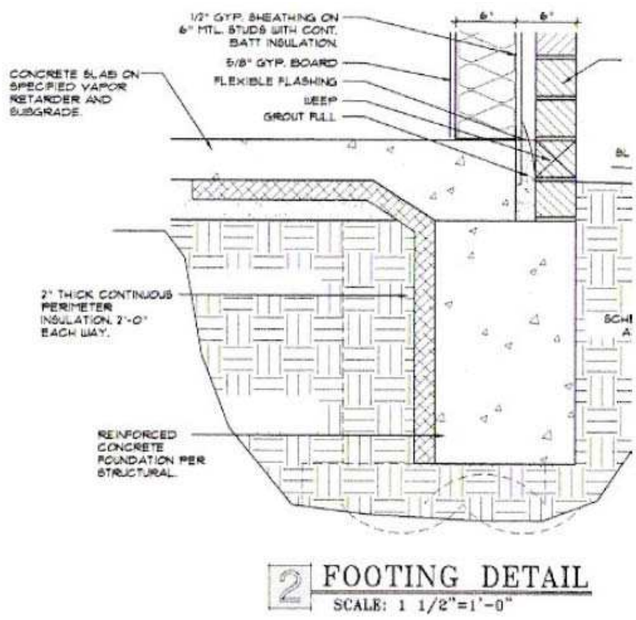

Fig. 8. The architect’s detail correctly shows the acceptable method of installing base flashing when the masonry terminates into grade.

However, he failed to follow manufacturer’s recommendations and buried the exterior sheathing into the grout fill. Inattention to detail by both architect, who failed to refer to the manufacturer’s guidelines, and contractor, who failed to notice the defect, led to the unacceptable condition. As a result of these errors water stands within the wall cavity posing a continuing threat to building materials.

Fig. 9. Water standing inside the wall cavity.

Roof coverings have evolved over time allowing several systems from which to choose. All of these systems have advantages and disadvantages. Depending on the selection, warranties are available for up to twenty-five years.[10] Manufacturer's standard details are typically incorporated into the construction set of drawings. Additionally, there is typically a requirement within the construction documents (drawings and specifications) for the roof manufacturer to be present during certain phases of the work, including a pre-construction meeting. Even so, roofs fail as do roofing contractors. So it becomes essential that the details are followed by the roofer and the installation is closely scrutinized by third-parties. Perhaps the biggest challenge in accomplishing a sound roof rests in the details that deal with roof penetrations by pipes, vents and ducts. In this hospital, the architect and mechanical engineer provided details to ensure the roof would be sound. Roof details were included in the construction documents by the architect and the mechanical engineer to accommodate thermal movement that can result in tearing of the roof membrane, and to prevent water from entering the building. These details were ignored, resulting in water damage to materials and, of critical importance, added moisture into the building that exacerbated the already poor environmental condition within the hospital.

The CS 2 facility is under assault from above and below. Water entered the building from the site that was poorly graded and was retained in the wall system by a detail that was poorly executed. As in CS 1, adherence to common sense should have dictated a positive flow of water away from the structure. The architect was not retained to perform Construction Administration Services ("CA"), thus severing a key element of quality control during the construction process. "Full service" would have called for checks and balances as dictated by the American Institute of Architects Contract Documents A201, General Conditions and supported by AIA Documents G711 (AIA, 1972), 712 (AIA, 1972), 714 (AIA, 2007) and 716 (AIA, 2004) for use by both the contractor and architect. By not having CA in place, the contractor implies that all elements of the project conform to the Contract Documents (plans and specifications), as well as building codes, which is not the case here.

Fig. 10. Water running out of insulation.

10 http://www.specjm.com/commercial/roofing/peakadvantageguarantees.asp (last visited on February 13, 2011)

Fig. 11. Improper site grading.

A value engineering (VE) exercise resulted in the use of direct expansion (DX) roof top units with coils that had a sensible heat ratio too high to effectively dehumidify. Exhaust fans were VE and as a result the fans were located below the roof which was a violation of [Title 25, Texas Administrative Code, Chapter 133, Hospital Licensing State Regulations (HLSR) 2007]. It was obvious that the VE items selected were money driven and health and safety concerns and/or the HLSR rules were ignored. Without an architects CA services in place to mind the store and with an unsophisticated owner, the contractor and his subcontractors did whatever they wanted to do. Negative building pressure and improper pressure relationships were the major contributor to the poor physical environment. Pressure relationships between critical care areas inside the building with respect to other spaces were not in accordance with HLSR. Both design and installation defects contributed to these conditions. The design of the HVAC system was inadequate for humidity control. Engineers know that buildings located in hot and humid climates need HVAC systems designed to work in that climate yet only the dry-bulb/coincident wet-bulb design condition was considered for coil selections. A test, adjust, balance, and commissioning process was obviously never completely performed for the performance aspects of the project other than the air volume measurements. The HVAC control system was deficient in that it was never commissioned to control to the various pieces of equipment as an integrated system. In fact the maintenance staff at the facility was never trained to operate the system and they had to resort to an on-line third party provider for day-to-day control.

In a response to uncontrolled high indoor humidity, areas were over-cooled including OR, which resulted in frequent condensation on the interior surfaces, medical equipment, and supplies to the extent surgeries had to be rescheduled or cancelled. Water stained building materials, indoor mold growth, temperature fluctuations, high humidity, and condensation all contributed to an unsatisfactory environment for patients and staff and *violated state licensing rules.*

Rule #	Subject HVAC	Violation (rule language)
§133.162.(d)(3)	General Mechanical Requirements	All rooms and areas in the ASC shall have provision for positive ventilation. The ventilation rates shown in Table 1 of §135.56(a) of this title shall be used only as minimum requirements, since they do not preclude the use of higher rates that may be appropriate.
(C)	Performance and acceptance	Prior to completion and acceptance of the facility, all mechanical systems shall be tested, balanced, and operated to demonstrate to the design engineer or his representative that the installation and performance of these systems conform to the requirements of the plans and specifications.
(C)(i)	Material lists	Upon completion of the contract, the owner shall be provided with parts lists and procurement information with numbers and description for each piece of equipment.
(D)(i)(III)	Outside air location	Outside 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 which may collect vehicular exhaust or other noxious fumes. (Prevailing winds and proximity to other structures may require more stringent requirements). Plumbing and vacuum vents that terminate five feet above the level of the top of the air intake may be located as close as 10 feet.
(D)(i)(VI)	Directional air flow	Ventilation systems shall be designed and balanced to provide directional flow as shown in Table 3 of §133.169(c) of this title. For reductions and shutdown of ventilation systems when a room is unoccupied, the provisions in Note 4 of Table 3 of §133.169(c) of this title shall be followed.
(D)(i)(IX)	Humidifier location	When duct humidifiers are located upstream of the final filters, they shall be located at least 15 feet from the filters. Ductwork with duct- mounted humidifiers shall be provided with a means of removing water accumulation. An adjustable high-limit humidistat shall be located downstream of the humidifier to reduce the potential of condensation inside the duct.
(D)(iv)(II)	Smoke removal systems	Smoke removal systems for surgical suites. Smoke removal systems shall be provided in all surgical suites in accordance with NFPA 99, §6.4.1.3.
(D)(vii)	Fire damper requirements	Fire dampers shall be located and installed in all ducts at the point of penetration of a required two-hour or higher fire rated wall or floor in accordance with the requirements of NFPA 101, §18.5.2.

Rule #	Subject HVAC	Violation (rule language)
(D)(viii)	Smoke damper requirements	Smoke dampers shall be located and installed in accordance with the requirements of NFPA 101, §18.3.7.3, and NFPA 90A, Chapter 5.
(D)(xii)	Make-up air	If air supply requirements in Table 3 of §133.169(c) of this title do not provide sufficient air for use by exhaust hoods and safety cabinets, filtered make-up air shall be ducted to maintain the required air flow direction in that room.
§133.162.(d)(4)	General Piping Systems and Plumbing Fixture Requirements	All piping systems and plumbing fixtures shall be designed and installed in accordance with the requirements of the National Standard Plumbing Code Illustrated published by the National Association of Plumbing-Heating-Cooling Contractors (PHCC), 2003 edition, and this paragraph.

Table 2. Ten of forty-four rules in HLSR for HVAC systems were noncompliant.

3.3 Case study 3 ("CS 3")

This single story hospital was constructed in 2009. It was 70,000 square feet and constructed under the more traditional design/bid/build delivery system. Its exterior was composed of concrete masonry units with accent bands of cast stone. In the previous two studies the issue of prime importance was water intrusion caused by site and envelope issues and the inability of the HVAC systems to control the environment. Water intrusion was an issue in this case, however, the prime concern was an unsecured envelope that allowed unacceptable levels of particulate (dust) into the hospital. Early on the hospital was notified by the State Licensing Agency that they must gain control of the dust.

As in the previous two case studies, the "broken record" continues as the CS 3 site does not sufficiently drain water away from the building. In CS 3, the civil engineer apparently was not aware of the code requirement that called for a 5% slope away from the building for a distance of ten feet. Additionally, the architect, who claimed to not have the responsibility for the Civil Engineer's work set the finish floor height. In a memo, the architect chided the engineer for delays and stated "…we have done most of the work anyway".[11]

Here, there are two professionals that do not have a working knowledge of the building code. Unit pricing for earthwork was relatively low compared to the overall budget for this building, and had the error been corrected at the outset, the cost to raise the building would be negligible to the overall budget. With a completed building that includes parking on four sides, sidewalks, and the complication of a very flat terrain, what should have cost a few thousand dollars to add fill under the slab was budgeted at close to a million dollars to rectify.

In spite of the lapse of coordination regarding the site, the architect provided numerous and correct details regarding the exterior of the building and its fenestration. The sections and details were supported by 1,162 pages of specifications. The architect had made 151 key references on the drawings alone that dealt with flashings and the job of directing water away from the building. These details were all ignored. As in CS 2 the flawed site and defective base condition caused water to stand within the exterior wall cavity.

[11] Memorandum from the Architect to the Civil Engineer obtained in pre-trial discovery.

The Architect's specifications and drawings were consistent and complementary. The contract with the general contractor (constructor) states that if the plans and specifications are in conflict, the most stringent requirement governs. In this case, the contractor saw fit to ignore both plans and specifications.
The CS 3 roof was also problematic and let particulate matter into the exterior walls and spaces above the ceilings. This hospital is located in an agricultural area, and dust is a continuing issue.

Fig. 12. Water standing inside wall cavity.

Figures 13, 14 and 15 show the progression of dust (particulate) from the parapet, into the exterior wall via mislapped flashing and finally into the ceiling space of the hospital. In agricultural settings dust is especially problematic in a critical care hospital. In a 2009 published study dust was found to contain endotoxins, allergens, microbial pathogens, bacterial toxins, fungal spores, and mycotoxins that can cause adverse human reactions. (Purdy & Straus 2009)

Fig. 13. Infiltration of dirt and moisture under parapet cap.

Fig. 14. Infiltration of dirt and moisture under parapet wall.

Fig. 15. Infiltration of dirt into the attic space above lay in ceiling.

With the exception of civil engineering, the quantity and quality of the architect's and structural engineer's documents (plans and specifications) were exceptionally good. Unlike CS 2, the architect here had a full service contract and attended regularly scheduled job site meetings. In spite of his presence at the job site, virtually all of his details regarding openings (windows and doors) were ignored by the contractor. The architect, who performed well on 80% of his contract with the owner will have to answer for the representative 20% of failed CA when he did not take the contractor to task for violating the contract for construction. This project was located in the southern high plains and one would think that humidity control would not be much of a concern. A chilled water HVAC system design was replaced in a VE exercise to direct expansion (DX) roof top units with coils that had a sensible heat ratio too high to effectively dehumidify during the relatively few hours of the year when dehumidification was required. This resulted in excursions of high indoor humidity where control of the indoor environment could not meet the HLSR requirements. Negative building pressure and improper pressure relationships were the major contributor to the poor physical environment. Pressure relationships between critical care areas inside the building with respect to other spaces were not in accordance with the HLSR. Both design and installation defects contributed to these conditions. The primary design defect of the HVAC system was the variable air volume (VAV) application with the VE DX cooling roof top units that need constant volume air flow. Frequent cycling of compressors resulted in temperature swings in the occupied space. The primary HVAC installation defect was excessive duct leakage which contributed to negative building pressure. However, there was a heating problem that no one seemed to be able to solve other than to reduce the amount of outside air to increase the discharge temperature, which increased negative building pressure. The mystery turned out to be a plumbing problem. The plumber located the natural gas pressure regulators in the medium pressure gas system too far from the unit and the pressure drop in the gas line starved the units for gas which reduced the capacity and did not heat the air effectively.

Excessive dust in the air is a common problem in the location of CS 3. Normal operation of the HVAC system filtered the outside air being introduced through the roof top units. During the frequent dust storms common to the area, the HVAC filters could be used up in one day. In an effort to deal with these frequent dust storms a “dust mode” control sequence was designed and installed into the HVAC control system. What seemed to be a good idea to someone turned out to be a disaster. Exhaust fans were not turned off in the dust mode because exhaust must be maintained in many areas (isolation rooms, certain critical care areas, etc.) of a hospital. Therefore, during dust mode the roof top units were not introducing outside air and the exhaust fans were sucking dust in from where ever it could find its way into the building. Even during ordinary operation (not dust mode) the building was operating in a negative pressure and sucking dust into the building creating an unsatisfactory environment for patients and staff.

A test, adjust, balance, and commissioning process was obviously never completely performed for the performance aspects of the project. Deficiencies were noted and sent to the engineer and contractor but were never followed-up. The HVAC control system was deficient in that it was never commissioned to control to the various pieces of equipment as an integrated system. In fact the maintenance staff at the facility was never trained to operate the system and they had to resort to an on-line third party provider for day-to-day control.

The building was under construction for a long time and the duct work was never protected during construction. The duct work was not cleaned before operating the equipment. Dust in the ductwork was deep enough to leave ruts when a robot was used to photograph the ductwork to an operating room.

Fig. 16. Tracks of robotic camera in the dust of the HVAC ductwork.

Rule #	Subject HVAC	Violation (rule language)
§133.162.(d)(3)	General Mechanical Requirements	All rooms and areas in the ASC shall have provision for positive ventilation. The ventilation rates shown in Table 1 of §135.56(a) of this title shall be used only as minimum requirements, since they do not preclude the use of higher rates that may be appropriate.
(C)	Performance and acceptance	Prior to completion and acceptance of the facility, all mechanical systems shall be tested, balanced, and operated to demonstrate to the design engineer or his representative that the installation and performance of these systems conform to the requirements of the plans and specifications.
(C)(i)	Material lists	Upon completion of the contract, the owner shall be provided with parts lists and procurement information with numbers and description for each piece of equipment.
(D)(i)(VI)	Directional air flow	Ventilation systems shall be designed and balanced to provide directional flow as shown in Table 3 of §133.169(c) of this title. For reductions and shutdown of ventilation systems when a room is unoccupied, the provisions in Note 4 of Table 3 of §133.169(c) of this title shall be followed.

(D)(i)(VIII)	Ventilation start-up requirements	Air handling systems shall not be started or operated without the filters installed in place. This includes the 90% and 99.97% efficiency filters where required. Ducts shall be cleaned thoroughly and throughout by a certified air duct cleaning contractor when the air handling systems have been operating without the required filters in place.
(D)(iv)(II)	Smoke removal systems	Smoke removal systems for surgical suites. Smoke removal systems shall be provided in all surgical suites in accordance with NFPA 99, §6.4.1.3.
(D)(ix)	Acceptable damper assemblies	Only fire damper and smoke damper assemblies integral with sleeves and listed for the intended purpose shall be acceptable.
(D)(xii)	Make-up air	If air supply requirements in Table 3 of §133.169(c) of this title do not provide sufficient air for use by exhaust hoods and safety cabinets, filtered make-up air shall be ducted to maintain the required air flow direction in that room.
§133.162.(d)(4)	General piping and plumbing	All piping systems and plumbing fixtures shall be designed and installed in accordance with the requirements of the National Standard Plumbing Code

Table 3. Nine of forty-four rules in HLSR for HVAC systems were noncompliant.

4. Common elements

4.1 Budget and cost savings

Discovered defects were not a result of cost savings or inadequate budgets. In the instances where the termination of the exterior wall was the issue (found in all three of these studies) the specified materials were in place although out of order, therefore the labor and material costs would be the same whether done correctly or incorrectly. The missing weather-resistive barrier of CS 1 does not represent more expense to the owner because no credit was given. In other words the contractor received money for materials and labor he did not provide. In every case the site grading and vertical placement of the building was problematic. Solutions and costs to bring the site into compliance and to remove the threat to the building were both complex and costly. A sixty thousand dollar increase in the original budget for CS 3 would have eliminated a nearly one million dollar repair.

4.2 Noncompliance with regulatory authority

Codes are minimum and not something to attain. Life safety is the basis for professional licensure. Numerous codes including the International Building Code, Plumbing, Electrical and Energy Codes are in place to protect the public. Non-compliance with code is inexcusable and can threaten life safety. Each design professional, contractors or sub-contractors is required to know the laws relating to their profession or avocation. Licenses are granted by the states and continuing education is mandatory. The excuse by a contractor or sub-contractor that they built what was drawn does not hold water.
All three case studies show that negative building pressure and improper pressure relationships between critical care areas with respect to other spaces was a, if not the, major contributor to a poor physical environment. A common design defect seen in most designs

for medical facilities was an insufficient initial evaluation of fundamental design criteria for the HVAC systems cooling coils. In the above case studies it was obvious that the HVAC units were designed using dry bulb/coincident wet-bulb conditions and the wet bulb/coincident dry-bulb and the dew point/coincident dry-bulb conditions were not considered. In general, it appears to have been a business as usual approach, “what was done on the last job”, when it came to criteria development, detail of design, equipment selection, and application decisions. The bottom line results were a flawed design that did not meet the letter or intent of minimum code and/or licensing rules.

Not evaluating all three design conditions for the location of the project can result in an uncontrolled humid indoor condition and the results can be ugly.

When DX HVAC systems end up on a hospital project either by design or VE, humidity control is severely compromised if not eliminated unless the latent cooling (dehumidification) is decoupled from the sensible cooling with dedicated outdoor air systems. DX HVAC systems that introduce outside air for ventilation and building pressurization directly into the air handler unit to mix with return air before entering the cooling coil are at a huge disadvantage when it comes to humidity control. The direct expansion refrigeration equipment used a hot gas by-pass and an “on/off” operation of compressors to control capacity. This resulted in broad temperature and humidity excursions in the conditioned space, condensation, and mold growth on surfaces. Designing successful hospital HVAC projects of any size is not rocket science. It is almost connect the dot technology for those who are willing to break away from the “way I did last time” modus operandi. ASHRAE has produced many guidelines (Harriman et al., 2001), standards of care (ASHRAE 2007), and training materials (ASHRAE 2003) for properly designing medical facilities. Decoupling the latent load from the sensible load with dedicated outside air systems (DOAS) is the most efficient and effective way to maintain an acceptable indoor environment, especially in a humid or moderate climate. Although it can be done other ways, those methods seem to get complicated for the normal staff of a small to regional sized facility.

Fig. 17. Mold under a nurses desk.

4.3 Poor contractor quality control

In the past building contractors "self performed" some of the work and sub-contracted out specialized trades. Increasingly contractors now take on more of the role of a "broker" and have less of an interest and relationship with the day to day operations of the construction site. Virtually all trades are now sub-contracted. The "broker" role tends to lessen the traditional responsibility of the contractor who, by contract, is to schedule, manage and coordinate the quality of the work and certify its conformance to the construction documents. Too often many projects are "run by the subs" meaning that the contractor is aloof to the daily operation of the job.

4.4 Inadequate or poor site observations by design professionals

In every case study the architect failed to observe major discrepancies with his construction documents. The contractor, as well, failed to notify the architect of possible discrepancies to be resolved. CS 3 was especially insightful and led to the conclusion that the complexities of a hospital's internal systems caused the architect to either delegate oversight of the building proper to an intern, assume that his details were followed without checking, or he forgot about it. In CS 3 the construction documents were exceptional yet virtually the entire exterior was flawed to the extent that it had to be replaced.

4.5 All critical care facilities receive co and license but does not mean it is OK

Because a building has periodic inspections by the Building Official after the initial review and issuance of a Building Permit and, later, a Certificate of Occupancy does not mean that defects are acceptable. Building officials, and other regulatory agencies, deal with entire communities and therefore must have some reliance on the professionals and their processes to provide a compliant building. Architects make periodic visits to a building site to view progress and to certify monthly that work is on schedule and the amount requested by the contractor is justified. The architect's periodic visits are not sufficient, and are not intended to be so thorough that all defects, misapplications or misinterpretations of his documents are observed. The building officials make far fewer site visits and the argument that they must have seen and approved of every element is hard to make with a straight face.

4.6 Value engineering

This is becoming industry short hand for "cheap". VE typically comes into play when cost overruns are encountered prior to the start of the construction itself. All parties participate-contractor, architect, major sub-contractors and the owner. Too often the major cost reduction will be in the HVAC system and inadequate systems are often offered as "savings". Furthermore, most VE offerings are several single systems, one being the HVAC, and little thought or engineering has gone into how VE changes effect the other systems and the building system as a whole. Although the HVAC system is a substantial part of the overall construction cost it must be the considered too vital to compromise with a VE exercise as it is obvious that even more treatment of ventilation air will be required to manage infection control and bioterrorism issues in the future. With a hospital, where infection control depends on ventilation effectiveness, the risk of making a VE decision on the basis of saving money could very well defeat the entire purpose of a hospital.

4.7 Noted deficiencies on day one

In every case the site preparation was wrong and violated code. In every case the start of the wall (base condition) was wrong. Had there been any challenge to the processes being employed on day one, or a pre-construction meeting to go over critical elements, or peer review, many of the more egregious defects may have been avoided. The AIA has no less than thirty-four documents that deal with project management and construction administration.[12]

5. Conclusion

5.1 Avoiding the pitfalls

5.1.1 The owner should define expectations up front and follow through

In the design phases both general contractors and major sub-contractors should be consulted regarding budgets and components. The owner should involve their facility managers and engineers in the design process from day one (programming) and should either make certain that the systems proposed do not exceed the skill level of their staff or, that training of their staff will be part of the construction process. The construction documents should be enough to ensure the quality of the building. As stated the perfect set of construction documents and the perfect contractor has yet to be seen. Periodic job site meetings with the owner in attendance should be mandatory. The contractor should provide and maintain a current schedule to enable the architects and engineers to review the critical elements of each phase. The owner should make it clear that problems are expected and they should not be glossed over but solved early.

Division Number	Division Title	Envelope Related	MEP and Controls Related	CS 1	CS2	CS3
1	General Conditions	Y	Y	√	√	√
2	Site	Y		√	√	√
3	Concrete	Y				√
4	Masonry	Y		√	√	√
5	Metals	Y				
6	Wood and Plastics	Y				
7	Thermal & Water Proofing	Y		√	√	√
8	Doors and Windows	Y		√	√	√
9	Finishes	Y		√		√
	Subtotal Envelope % non-conformance			66	55	78
10	Specialties	N				
11	Equipment	N				
12	furnishing	N				
13	Special construction	n/a				
14	Conveyance	n/a				
15	Mechanical		Y	√	√	√
16	Electrical		Y	√	√	√
	Subtotal Systems % non-conformance			100	100	100
	Total % non-conformance			72	63	82

Table 4. Identifies the topics covered within the CSI format that has been developed to cover all aspects of building construction. Y = yes, the Case Study included this section. √ = key elements within this division were found to be defective.

[12] AIA; G-Series.

5.1.2 The architect should produce a complete set of construction documents and a full service no matter what the delivery system[13]

Design/Build and Fast Track Projects have their place in the industry. However, even if budgets and contracts are made with preliminary designs or assumptions regarding a building's quality, the architect must not be swayed to reduce or eliminate services. In no case should he trust that the contractor (or some yet unidentified sub-contractor) will provide the detail that the architect would otherwise produce.

This is problematic for both parties. By either allowing or asking for "minimum" detail the contractor is telling the owner that he will provide industry standard and code compliant details and systems. He is, essentially, assuming the entire risk for the end product. Similarly the architect, by allowing the contractor that amount of leeway, may be faced with a claim of negligence. In a recent court decision an architect performing construction administration services could be held liable to third-party house guests injured by the contractor's failure to construct the project according to plans and specifications.[14]

5.1.3 The owner should consider peer review of the construction documents

Rarely done in the building industry peer review of the design (architectural and engineering) should be welcomed by the design professionals. Peer review would reduce the risk of having errors or omissions within the documents and, as with most peer reviews, challenge the designers to clarify and delineate their intent.

5.1.4 The owner should demand that only experienced professionals oversee the construction

Contractors can be intimidating to young professionals. In CS 3 the role of working with the contractor was delegated to a young designer. The project was sufficiently large enough that all of the elements that were found by the authors to be defective took weeks and months to construct thus allowing sufficient time for a seasoned professional to have the contractor replace defective work. Owners should insist that the architect provides experienced personnel during the construction phase of the work and that he, or she, is not replaced.

5.1.5 Thoroughly test layers of waterproofing systems

All three studies revealed leaks at the openings. Many specifications make reference to leak testing but it is often overlooked. The owner should demand that a formal process be included in the specifications and that it be performed by an independent party. The specification should require the leak testing be done before the exterior cladding is in place, IE after the weather-resistant barriers have been installed. The owner should have the testing company peer review all of the architect's details involving openings, base flashing, parapets, etc.

5.1.6 Inspect-inspect-inspect

In a project as critical as a hospital it is strongly advised to either expand the architect's visits to the site or hire an independent agent to fill in the gap between visits. As in peer

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[13] The traditional Design/Bid/Build is a delivery system. Others include Design/Build, Fast Track and various forms of Construction Management services.

[14] Black + Vernooy Architects v. Smith, ___S.W.3d___, 2010 WL 5019659 (Tex.App. -- Austin 2010, no pet. h.),

review the third party involvement may result in the project being what the architect envisioned rather than having his and his owner's project discussed in front of a jury.

5.1.7 HVAC commissioning vs. test-adjust-balance

Construction documents always include a test, adjust and balance (TAB) section in Division 15 of the specifications. This specification require procedures usually performed by an independent agent to set-up air flows to design quantities, check and document the operation of components in the HVAC system such as, fans, compressors, pumps, etc. The data is then submitted to the engineer of record and the contractor with a list of deficiencies. In the case of the three case studies presented here, there was no follow-up. However, had they been follow-up, the root problems at these buildings would not have been solved. What a standard TAB does not do is integrate the various systems in the building with the HVAC system so that the whole building can be operated as a system.

The HVAC commissioning process provides a comprehensive overview of the building as a system. The procedures, methods, and documentation requirements in the document ASHRAE Guideline 1, HVAC Commissioning Process cover each phase of the commissioning process for all types and sizes of HVAC systems, from pre-design through final acceptance and post-occupancy, including changes in building and occupancy requirements after initial occupancy. Commissioning in accordance with ASHRAE Guideline 1 provides assurances and validates that the building's HVAC systems will perform as intended and will work with other systems in the building system as a whole. Commissioning procedures includes TAB.

Obviously commissioning is the preferred method. Although it cost more than TAB, it provides solutions to problems discovered during the construction process or immediately after occupancy. If the project team has an unsophisticated owner, builder, and/or design professionals VE may look attractive. Sophisticated owners and operators will probably recognize the value of commissioning and VE suggestions will be analyzed for what they really are. Regardless, it is the design teams responsibility to keep it on track.

5.1.8 Avoid being swayed by the latest and greatest "thing"

When we talk about sustainability or sustainable can we change that to "green". Green is not defined but it is understood by most. Sustainability/sustainable is also not defined but it is about to be defined by Department of Homeland Security in that when they talk about sustainability it will mean whether or not a building can sustain itself and continue to function to its design intent when it has suffered a disaster, natural or man-made.

Advocates in the theoretical "green world" get so preoccupied with finding and using "green materials" that they forget that at the end of the day the assembly still has to work as a high performance building, and that performance begins with the envelope. People are so enthralled with the idea of a "zero carbon footprint" that they are ignoring some of the basic principles of design that are already in our existing building codes and standards. This oversight, on their part, has resulted in the false understanding that existing codes and standards are not capable of dealing with the problems of energy conservation and they totally ignore that "organic architecture" has dealt with the problems they believe are new. Additionally the un-intended consequences of some of the proposed approaches to sustainability have yet to surface. What has surfaced, in 2010, is a class action lawsuit filed against the U.S. Green Building Council filed in U.S. District Court, Southern District of New York.

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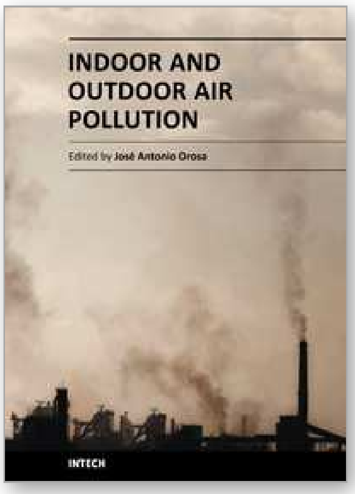

Indoor and Outdoor Air Pollution
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Air pollutants are continuously released from numerous sources into the atmosphere. Several studies have been carried out on the quantification of pollutants and their consequences on public health. Identification of the source characteristics of air pollution is an important step in the development of regional air quality control strategies. Air quality is a measure of the degree of ambient atmospheric pollution. Deterioration and damage to both public health and environment due to poor air quality have been recognized at a legislative and international level. In consequence, indoor and outdoor air quality must also be considered. This book tries to reveal different points of view of the wide concept of air quality in two different sections. In this context, there will be an initial introductory chapter on the main concepts of air quality, following which there will be real case studies on outdoor and indoor air quality with an aim to provide a guideline for future standards and research works.