Competing Smoke Control Systems: A Case Study in Elevator Shaft Pressurization with Stair Pressurization

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The Appleton Medical Center new Bed Tower included an addition to an existing building located in Appleton, Wisconsin. The design of the project occurred primarily in 2009, with construction being completed in the summer of 2010. As such, the applicable building code for the project was the 2008 Wisconsin Commercial Building Code (WCBC), which is based on the 2006 International Building Code (IBC). Further, as a health care occupancy, the Authority Having Jurisdiction (AHJ) also enforced the 2000 edition of NFPA 101 *Life Safety Code*.

The addition consisted of a new Bed Tower that is nine stories in height, not including a partial basement. The construction of the Bed Tower is noncombustible, fire-rated—Type I-B. The Appleton Medical Center proper is used as a hospital and medical office building, including emergency rooms, surgery wings, cancer center, etc.; and, the Bed Tower addition consists primarily of patient rooms. As such, the primary occupancy in the Bed Tower is Group I-2 (institutional). The main building and addition are provided with automatic fire sprinkler protection throughout.

The elevation of the top-most occupied floor of the Bed Tower exceeds 75 feet above the lowest level of Fire Department vehicle access; and, as such, the Bed Tower is classified as a "high-rise" building. Prescriptively, the IBC requires high-rise buildings to be provided with additional protection for egress stairs and elevator shafts against the migration of smoke vertically throughout the building under a fire condition. The IBC allows various options for providing the necessary protection of egress stairs and elevator shafts, including both passive and active means that are capable of satisfying the intent.

For taller egress stairways, "smokeproof enclosures" are required. Traditional methods of providing smokeproof enclosures are fairly well-established in the construction industry and have been utilized over the years, via both passive and active means. Although the code allows for passive means of providing smokeproof enclosures, active systems are often more preferable from an architectural standpoint. For example, exterior vestibules – an available option for passively providing smokeproof enclosures,– is likely infeasible for egress stairs that are interior to the building footprint. As such, it is very common for egress stairways to be provided with mechanical stair pressurization as a means of complying with the smokeproof enclosure requirements of the IBC.

Elevator shafts, on the other hand, have historically been protected using passive means – such as enclosed elevator lobbies, additional (UL listed) doors, etc. Enclosed elevator lobbies tend to be the most cost-effective solution, even though they are oftentimes not desirable. With the 2006 revision to the IBC, however, an additional option was included to allow mechanical pressurization of the elevator shaft in lieu of providing enclosed elevator lobbies. For the first time, elevator shafts were permitted to be protected with active systems, similar (in concept) to the stair pressurization systems commonly utilized in egress stairs. Unlike stair pressurization, however, elevator shaft pressurization systems are relatively new to the design and construction industry; and, as such, present unique challenges.

In the Bed Tower, the architectural desire was to achieve protection of the two egress stairs that served the entire Bed Tower via mechanical stair pressurization; and, similarly, provide elevator shaft pressurization in one of the two elevator shafts. Given that both the stair pressurization systems and the elevator shaft pressurization system would activate simultaneously under certain fire scenarios, standardized


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calculation methods were unavailable to provide design guidance and assure that the performance criteria of each pressurization system could be satisfied during simultaneous operation. Although the specified performance criteria for stair pressurization and elevator shaft pressurization differ in the IBC, both sets of criteria must be satisfied during simultaneous operation of the pressurization systems. So-called "competing" smoke control systems often require computer simulation modeling in order to estimate the design capacities and parameters for each pressurization system, since the available empirical equations typically apply to stair pressurization or elevator shaft pressurization – separately.


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Summit Fire Consulting utilized CONTAM for modeling the expected airflows in the Bed Tower under smoke control conditions. CONTAM is a computer simulation program that is available from the National Institute of Standards and Technologies (NIST) that was originally developed as a multi-zone model to analyze airflow, contaminant transport, personal exposure, etc., for building ventilation systems. The program has been adapted for applications involving pressurization smoke control systems, which rely on maintaining airflow criteria at distinct points in the building.

Data was input into CONTAM to create a computer model of the building. Input included the following: Stairwell enclosure and door locations, elevator shaft and door locations, wall areas, floor areas, roof areas, leakage areas and factors, shaft locations, building temperatures, expected exterior temperatures, and exterior door locations. In addition, conceptual wall routing and locations were input into the model, where such walls were expected to have an impact on the expected airflows – such as smoke barriers, separations from the existing hospital, etc. The primary intent of inputting the routing and locations of interior walls was to determine which areas (i.e., "zones") of the building communicate with each other for the purposes of leakage between zones. In this fashion, the airflow in the building is modeled from zone-to-zone, both horizontally and vertically.

Through a series of simulations, Summit Fire Consulting adjusted fan sizes, injection points, and other mechanical design features (such as relief vents) in order to estimate ranges of expected capacities that would accommodate the various design criteria of the "competing" smoke control systems. Such simulations included a wide range of exterior building temperatures, as well, in order to estimate their effect on the operation of the pressurization systems due to potential "stack effect" conditions in the stairwells and elevator shaft. In this fashion, the design of the pressurization systems incorporated the expected variations in exterior environmental conditions.

The design guidance developed for the pressurization systems was communicated to the mechanical engineer, the project team, and the AHJ for the project via a design report. The design report documented, in detail, the rational analysis conducted, proposed design criteria, code background and applicable navigation, etc., for the purposes of final approval by the AHJ and incorporation into the Construction Documents for the project. In addition, given that both the WCBC and NFPA 101 applied to the project, the Design Report documented the means of complying with both codes – and/or the intent of both codes where prescriptive compliance was not possible. Although the stair pressurization and elevator shaft pressurization systems could not satisfy <u>all</u> of the prescriptive requirements of the applicable sections of the WCBC <u>and</u> NFPA 101, the proposed design satisfied the overall level of fire-and life-safety that is <u>intended</u> by both the WCBC and NFPA 101.

Special inspection of the stair pressurization systems and elevator shaft pressurization systems are also required by the IBC. Such tests and inspections are to be carried out by a qualified agency, and be sufficient to "verify the proper commissioning of the smoke control design in its final installed condition." In addition to the design consulting previously provided, Summit Fire Consulting was also selected as "Special Inspector" for the stair pressurization systems and elevator shaft pressurization system in the Bed Tower.

The special inspection generally occurs over the course of the construction and installation process, and is recommended to include three primary phases: documentation review, equipment inspections, and sequence testing. Each phase of the Special inspection is utilized to confirm specific design and installation requirements for the pressurization systems that are detailed in Section 909 of the IBC and the Construction documents. Documentation review includes the review of pertinent shop drawings and product submittals to confirm that certain equipment requirements – such as listings for mechanical or fire alarm equipment – are satisfied. Equipment inspections, on the other hand, include actual field observations at key milestones during the course of construction to confirm that the installed equipment corresponds to the shop drawings and product submittals, as well as additional equipment requirements specified by the IBC – such as wiring installation requirements, pressure testing of ductwork, etc. Finally, sequence testing occurs near the completion of construction and involves physical testing of the activation features for the pressurization systems and airflow measurements.

All three phases of the special inspection were conducted over a six-month period of time, concluding with final sequence testing in the summer of 2010. Sequence testing involved multiple "pretests," during which the project team identified discrepancies between the installed condition and the approved design—in order to make any necessary modifications to ready the pressurization systems for a final demonstration with the AHJ. The scope of the final demonstration was ultimately at the discretion of the AHJ and involved limited sequence testing and airflow measurements. Ultimately, adequate performance of the pressurization systems was observed during the final demonstrations; and, upon completion and issuance of a special inspection report, a Certificate of Occupancy was issued for the new Bed Tower.

Given the relatively limited implementation of elevator shaft pressurization systems, compounded by the complexity of utilizing "competing" smoke control systems, the project team encountered many unique challenges throughout the design and construction process. For example, the CONTAM model idealized the Bed Tower as essentially a separate, isolated building. In reality, however, the separation of the Bed Tower from the existing Appleton Medical Center proper was not complete – as far as airflow and communication between the spaces is concerned.

Additionally, due to the nature of health care occupancies and the use of the Bed Tower, the integration of the fire alarm system with normal building tempering involved different sequences for different levels of the building as well as different areas within a single level of the building due to the compartmentalization of individual levels of the Bed Tower with smoke barriers. From a smoke control perspective, however, the desire was to *minimize* the number of possible activation sequences and "airflow" conditions under which the pressurization systems would operate. The desired sequencing in the Bed Tower created multiple "airflow" conditions which introduced factors of uncertainty into the design, as well as cause for additional testing to be conducted during the special inspection.

Finally, perhaps the greatest challenge in the design of the pressurization systems (and, thus, the subsequent balancing of the systems) was in the estimation of leakage areas and leakage factors for the building. For input into CONTAM, an approximation of the actual amount of leakage in the building construction is required. Such leakage is inherent to all building construction, to some extent, and can play a significant role in the sizing of fans utilized for pressurization systems. While some data is available in fire protection engineering literature for approximating expected building leakage, the available data is very limited and are only approximations for leakage based on the type of component (i.e., interior wall, exterior wall, roof assembly, floor assembly, etc.) and the qualitative type of construction (i.e., loose, tight, etc.). Slight errors in estimating the leakage expected for the building can cause significant errors in the actual airflow requirements to achieve the performance criteria of pressurization systems.

In the end, through mechanical balancing and sealing of visible leakage points, adequate airflow was observed during testing. In addition, simultaneous operation of the stair pressurization systems with the elevator shaft pressurization system was successfully tested and confirmed under multiple activation sequences and "airflow" conditions in the Bed Tower.

Even as soon as the 2009 edition of the IBC, modifications and revisions to the performance criteria for elevator shaft pressurization systems have been implemented, undoubtedly due to the growing pool of experience with respect to implementation of elevator shaft pressurization systems in building construction – transitioning from theory to reality. In a realm where active fire protection and life safety systems are becoming ever more prevalent, there is reason to anticipate that elevator shaft pressurization will continue to be refined in building construction as a reliable means of protecting elevator shafts. In the meantime, projects such as the new Bed Tower at the Appleton Medical Center will continue to pioneer the design and installation of such systems. ■

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