ASSESSMENT OF MODULAR CONSTRUCTION UTILIZATION ACROSS ALL CAMPUSES OF THE UNIVERSITY OF NORTH CAROLINA SYSTEM

A Thesis
by
ANTHONY SCOTT HOPKINS

Submitted to the Graduate School
at Appalachian State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

December 2014
Department of Technology and Environmental Design

ASSESSMENT OF MODULAR CONSTRUCTION UTILIZATION ACROSS ALL CAMPUSES OF THE UNIVERSITY OF NORTH CAROLINA SYSTEM

A Thesis
by
ANTHONY SCOTT HOPKINS
December 2014

APPROVED BY:

Marie C. Hoepfl
Chairperson, Thesis Committee

James A. Russell
Member, Thesis Committee

Jeffrey S. Tiller
Member, Thesis Committee

Jerianne S. Taylor
Interim Chairperson, Department of Technology and Environmental Design

Max C. Poole, Ph.D.
Dean, Cratis Williams Graduate School

Abstract

ASSESSMENT OF MODULAR CONSTRUCTION UTILIZATION ACROSS ALL CAMPUSES OF THE UNIVERSITY OF NORTH CAROLINA SYSTEM

(December 2014).

Anthony Scott Hopkins
B.S., Appalachian State University
M.S., Appalachian State University

Chairperson: Marie Hoepfl

Modular building construction can benefit a project by reducing construction time, delivering a consistently high-quality product, and potentially saving the owner money. Modular works best for structures with many repetitive elements; university dorms have many such elements and are prime candidates for modularization. Through a University of North Carolina (UNC)-wide survey and interviews with UNC decision makers across the state this research shows that, despite the potential advantages of using modular, most UNC campuses have neither used nor considered this technology for student housing projects. Campuses that have not used, or that have not considered using, modular construction cite concerns about quality, conflicts with the existing campus design and mode of operation, and questions about whether modular is acceptable to the NC State Construction Office standards as reasons for not pursuing modular.

The only UNC campus that has used modular construction in a residence hall to date is Appalachian State University (ASU), and that modular project, Mountaineer Hall, was a positive experience for ASU. This research includes a case study comparing two residence

halls on the campus of ASU, Mountaineer Hall and Summit Hall, that illustrates potential advantages of modular. Construction on both residence halls began in 2010. Mountaineer Hall is a 118,434 square feet, 460-bed facility that cost $16,500,000 and was built in less than one year. Summit Hall is a 106,820 square feet, 333-bed facility that cost $31,000,000 and was built in two years.

Acknowledgements

To my thesis committee, I express sincere appreciation and admiration. Throughout my graduate studies I learned a lot from all of you collectively, and many different things from each of you individually. Professor Tiller took me to jail; Dr. Hoepfl was my counselor; and Dr. Russell was my accomplice. Thank you all.

I owe a tremendous debt of gratitude to Andy McDonald with ASU University Housing. Without Andy, most of the data in this study would not have been collected. Thanks as well to all of the willing participants from all stages of the study. Prior to starting, I was concerned that I might consistently be stiff-armed by unwilling participants. My experience was the exact opposite. Nearly everyone who contributed to this research did so with tremendous enthusiasm, and was gracious with their time and knowledge.

To all of my fellow Department of Technology and Environmental Design graduate students and collaborators along the way, I say, in the words of Chuck Perry, “onward.”

Table of Contents

CHAPTER 1: INTRODUCTION

Building construction can be an arduous process, rife with complications ranging from extreme weather conditions to work at excessive height and with limited access. Indeed, the perils of the construction process are well known and documented, and are accounted for with a number of sophisticated schemes designed to make the work smarter and safer, as well as to mitigate risk. For many years, advocates of using prefabricated building components have purported that bringing the construction process indoors in an industrialized manner is one of the most efficient and effective ways to improve building operations (see, for example, Dietz, 1971). Prefabricating in a factory environment begins to move the construction process away from the field and shapes the process into one more akin to manufacturing. Work at the construction site then becomes a process of assembly rather than one of fabrication.

Prefabrication is not a novel or revolutionary practice; rather, it permeates the building industry, and has for decades. The master builder previously manufactured doors, windows, and even bricks at the building site. Today, all of those components, and many more, are manufactured far away from the site and delivered as completed assemblies, ready to be installed. Modular construction is one form of prefabrication that exploits the advantages of factory assembly to a great extent, the idea being that the greater the degree of prefabrication, the greater resultant benefit to the project (Smith, 2010).

The classic model for success relative to construction projects is a triangle of time-cost-quality. Any construction project can achieve all three of the objectives in the triangle, but not with equilateral results. For example, if an owner wants high quality and speedy delivery, then he can expect to pay a premium expense. Likewise, if lower cost and faster delivery are required, the quality will decrease. Proponents of modular construction cite advantages to each of these pillars inherent in the modular process as compared to conventional, on-site construction (Gibb, 1999; Hutchings, 1996; Smith, 2010). Indeed, if modular construction is effective at improving construction projects through each of these metrics, it should be used, or at least considered, for every prospective project. However, this is not the case. It is estimated that modular construction makes up just over 1% of construction revenue (Modular Building Institute, 2013b). If the preceding statements are factual, and modular construction is beneficial to time, cost, and quality of projects, then somewhere there is a disconnect. Why is modular construction not used more prolifically if it provides documented benefits to owners, designers, and builders?

Statement of the Problem

Modular construction is not a panacea for the woes of the construction industry. It is not appropriate for all sites or project types, and should not be considered in a vacuum, independent of other project variables. Yet, for many types of construction projects, modular construction is a viable option that can prove to be a boon to the key metrics of time, cost, and quality. Modular construction can be used for any type of construction project, but is especially well suited for certain project types. Multi-family housing is one of those project types due to the economy of scale achieved by the repetition of similar elements, or in this case modules (Dietz, 1971). Multi-family housing is prevalent across society. Owners of multi-family developments that are ubiquitous, but perhaps overlooked, are colleges and universities.

Most people probably do not consider a college dorm as a multi-family development. However, the composition is the same: a single building that contains and separates multiple residential inhabitants. The University of North Carolina (UNC) system owns 739 residence halls across its 16 campuses, housing nearly 56,000 students in 2012. The estimated cost to replace those buildings would be $3,433,410,726 (University of North Carolina [UNC], 2013), and most campuses have in place 50-year replacement plans for these structures. As such a capital-intensive endeavor, it is logical to expect that the university officials responsible for making housing decisions at each constituent university are exercising the necessary due diligence to select the most appropriate construction method for each new project. However, preliminary discussions and facilities review indicates that most new residence halls on the UNC campuses are not built using modular methods. If this is true, why is this the case, and was modular construction considered during the preconstruction planning phases? If not, what information is needed to promote the consideration of modular construction techniques for all new projects? The answer to these questions could potentially save the UNC system considerable sums of money and time, while also providing the students of each campus with residence halls that are of the same, or better, quality than those produced by other means.

Research Questions

1. What is the current status of modular construction for university housing projects across the sixteen campuses of the UNC System?
2. On UNC campuses with modularly-constructed residence halls, what has been the experience with respect to time, cost, and quality for each of these projects?

3. Considering the housing needs incurred by the UNC System, and the scheduled rebuilding plans, how could time, cost, and quality for future student housing projects be affected by adopting modular construction for new residence halls?

Purpose of the Study

The purpose of this study was to evaluate the status of modular construction for residence halls across all campuses of the UNC system. Through direct communication with housing, design, and construction officials from each campus, a comprehensive overview of extant modular projects was developed, as well as a framework for understanding why modular construction is not utilized more often. The modular project was evaluated from a time-cost-quality perspective, and its data were compared against similar data from a comparable site-built project. The purpose of this analysis was to determine if the perceived benefits of modular construction were actualized, and if so to what degree.

Significance of the Study

The findings of this study will inform university officials at the 16 campuses of the UNC System as they make future decisions about student housing projects. Additionally, the results may transfer to other colleges and universities throughout the nation. Aside from this type of institutional setting, the results could also be useful to private developers of multi-family housing. Specifically, the results could have implications for the following parties.

Commercial general contractors (GC) that regularly perform work for UNC institutions will be directly affected by a decision to use modular versus conventional construction. Generally, most GC’s do not self-perform work on the projects they oversee, so a decision to use modular would not take work away from them. However, their fee for administering a construction project could be affected if a majority of a structure is constructed and managed by a modular manufacturer, instead of by the GC at the jobsite.

Specialty tradespeople who work on university housing projects could be greatly affected if a factory provides their service. Most modular manufacturers have in-house plumbing and electrical branches. As such, a manufacturer assuming responsibility for certain trades' work could be detrimental to companies operating in that field. However, that does not mean that the tradespeople could not work at the factory. Many commercial projects set up factories to build high-tech and specialty modules, and they bring the tradespeople to those factories (Jackson, 2013).

UNC physical plant staff members are undoubtedly affected by a new building. If the structure is well built there should be fewer complaints, fewer work orders, and less routine maintenance. If one construction method consistently delivers a better-finished product, the physical plant staff would be interested in implementing that on all projects.

University administrations have the ultimate responsibility for providing housing for their students and for the financial health of the institution. Upper-level administrators expect that their constituent departments are seeking out the best solutions for each new project. For this reason, they should be aware of the potential benefits of using one method of construction versus another.

Students who will live in these buildings are directly affected by decisions pertaining to the buildings' design and construction. Ultimately, they are the jury when it comes to assessing quality. Efficiency, durability, comfort, noise attenuation, and every conceivable complaint visited upon university housing staff will come from these

Residents living and traveling near universities may be impacted as well. Major construction projects have considerable implications for transportation in those areas. Traffic flow is often obstructed by ongoing projects, and schedules are stretched thin due to long delays. Additionally, anyone who has ever awoken to a pile driver or the groan of a bulldozer can attest to the inconvenient noises emanating from a job site. A modular project could potentially reduce congestion and construction time, and most of the noise would occur in a factory located away (hopefully) from residential areas.

Limitations of the Study

The limiting factor for this study was the lack of data for comparison. Of the 16 university campuses in the UNC System, only two have verified modular projects. That makes the total number of modular residence halls less than 1/10 of 1% of the 720 total residential facilities. Another limitation is a lack of data with respect to the operation of these modular buildings. To get a more complete, life-cycle view of each project, there needs to be consistent operational data that documents the operational health and energy use of the building over its life-cycle. Such information is not available for a project with only a few years of use—it simply has not been operating long enough to provide consistent annual data. Additionally, a study designed to examine these structures over a longer period of time would provide a better perspective about the life-cycle costs of the building.

CHAPTER 2: REVIEW OF LITERATURE

The literature pertaining to prefabrication and modular construction runs the gamut from trendy photo books of sleek, modular, single-family detached dwellings to case-studies of modular projects—usually carried out by the module manufacturer—that are little more than a marketing ploy for that particular project. Modular construction received much fanfare over the last decade, notably, with the publication of *Prefab* by Allison Arieff and Bryan Burkhart in 2002. *Prefab* brought prefabrication and high-architectural design together in a book that permeated the design realm, and to the chagrin of modular proponents, unfortunately, aligned prefabrication with small one-off residential projects of modern design and exorbitant budget. However, as a counterpoint to this belief—and perhaps more appropriately, *Prefab* was a response to this conviction—modular construction is typically construed as low-budget, poor quality, manufactured homes. Or, in the parlance of our times, modular construction equals trailer parks.

Despite these preconceptions, ardent supporters of modular methods have for decades extolled the benefits of modular construction, citing its benefits to time-cost-quality. Modular building projects have consistently adorned the landscape without ever finding a firm footing with which to propel the process into the mainstream. Both commercial and residential modular projects were realized over a century ago—although without regularity—for their expeditious delivery method (Polito, 2014). Clients in the oil and gas, industrial, and infrastructure sectors have utilized modular construction for over 40 years to deliver projects in remote access areas, in severe climates, and according to tight schedules (Fluor

Inc., 2014). And, of course, the ubiquitous doublewide has careened down rural highways since the late 1960s (Smith, 2010).

However, in more recent years, as digital design improves and, along with it, computer-based manufacturing, modular construction is seeing a resurgence that could mark the beginning of a new position for the technology. Designers are leveraging the capabilities of 3D modeling coupled with Computer Aided Design / Computer Aided Manufacturing (CAD/CAM) to more accurately and efficiently manufacture components directly from the original design model. These new processes create a lean and streamlined approach that lends modular construction to new growth in the commercial sector, in addition to its already established use in the industrial and housing sectors.

One advanced modular project currently underway is using the aforementioned strategies in an attempt to set a new standard. The Hilton Palacio Del Rio has stood as the tallest modular structure in America since 1968 (Hilton, 1968). However, this feat will soon be surpassed by Building 2 (B2), a part of the Atlantic Yards project in Brooklyn, NY. B2 will be composed of 32 stories of steel modules, making it the tallest modular project in the world, and will be a mixed-use, residential building (Oder, 2013). The resurgence of interest surrounding B2 has pushed modular construction back into the spotlight, and highlights one of its greatest strengths: the economy of scale realized by the mass replication of similar elements.

And so the discussion comes full circle. Modular construction, for a number of reasons, has struggled to gain large-scale acceptance. Then at certain intervals books such as *Prefab* or the Sears and Roebuck housing catalog have thrust the technology back into the limelight, if only for a moment. When the excitement dwindles, another dormant period ensues, after which a high-profile project comes along and modular is once again a major player in the construction industry. The key to making the technology stay is consistently using it for appropriate projects, and when used, effectively leveraging its full potential.

Prefabrication

Prefabrication, in its most elemental sense, has been used in modern society since the Industrial Revolution. With the advent of the power saw, predetermined sizes of lumber were cut and delivered to building sites to be assembled into stud-walls using machine-cut nails. Previously, bricks were always manufactured on site from the clay that the building was built upon; this process shifted to the factory, where bricks could be mass-produced to precise dimensions (Bruce & Sandbank, 1944). In spite of the relative modernity of prefabrication, there is evidence of prefabricated elements on Roman shipwrecks, which suggests that certain building elements were fabricated at quarries and then transported to the construction site for assembly (Urban, 2012). Along the same lines, colonial expansion necessitated the rapid deployment of hasty structures, especially for medical purposes. Sketches from the late 1800s depict portable barrack and field hospitals envisioned as quick ways to set up infrastructure and facilities for military purposes (Dietz, 1971). Disease demanded many beds, and quickly.

However, specific to modern building methods, the demand for housing following World War II was the great impetus for prefabrication, or what was then termed industrial construction. The Great Depression made manifest the lack of traditional, affordable housing across the American landscape (Bruce & Sandbank, 1944). During this period, many technologists, designers, and entrepreneurs were eager to develop the perfect solution for the masses. Many innovative, and now storied, housing solutions emerged, drawing inspiration from the work of Henry Ford and Frederick Winslow Taylor. Some companies, such as Lustron, tried to capitalize on the precision of the automobile manufacturing process and developed a steel house in the same fashion. Others, like Levitt, tried to bring the factory to the field, and had a veritable assembly line that spanned multiple lots with crews hopping from house to house performing their respective, specialized tasks (Smith, 2010). However, these housing experiments were not widely adopted, and utopian visions of mass-produced housing for the masses waned.

In recent decades, prefabrication holds different connotations for different people. To the general public, prefabricated may connote manufactured housing, indicative of the ubiquitous trailer park. To the building professional, prefabricated could imply a radically different meaning ranging from a roof or floor truss to a bathroom module or a complete commercial building. In both cases, the definition for prefabrication is accurately applied. Most new construction projects employ prefabricated methods to some degree. Prefabricated components, such as pre-hung doors, are universal elements that are standard operating procedure for the construction industry, and their inclusion has greatly enhanced the standardization and customization of the trade.

The elemental composition of a prefabricated building can take three general forms. Smith contends “components, panels, and modules are general categories in which buildings are fabricated or manufactured offsite and assembled” (2010, p. 127). This breakdown by component is referred to by Gibb (1999) as non-volumetric and volumetric. Volumetric is a term frequently used in European cultures, and was formerly the descriptor for module construction in the US. Dietz (1971) has also referred to volumetric construction as monolithic box construction, but that is dated terminology today. In this study, modular will be used to describe any volume-encompassing construction technique that is factory made and site assembled. Figure 1 details the possible applications as suggested by both Smith (2010) and Gibb (1999). Proponents of modular contend that greater benefits are reaped as the degree of prefabrication increases. From this perspective, a volumetric, trimmed-out module is more advantageous to use than unfinished wall and floor panels (Smith, 2010).

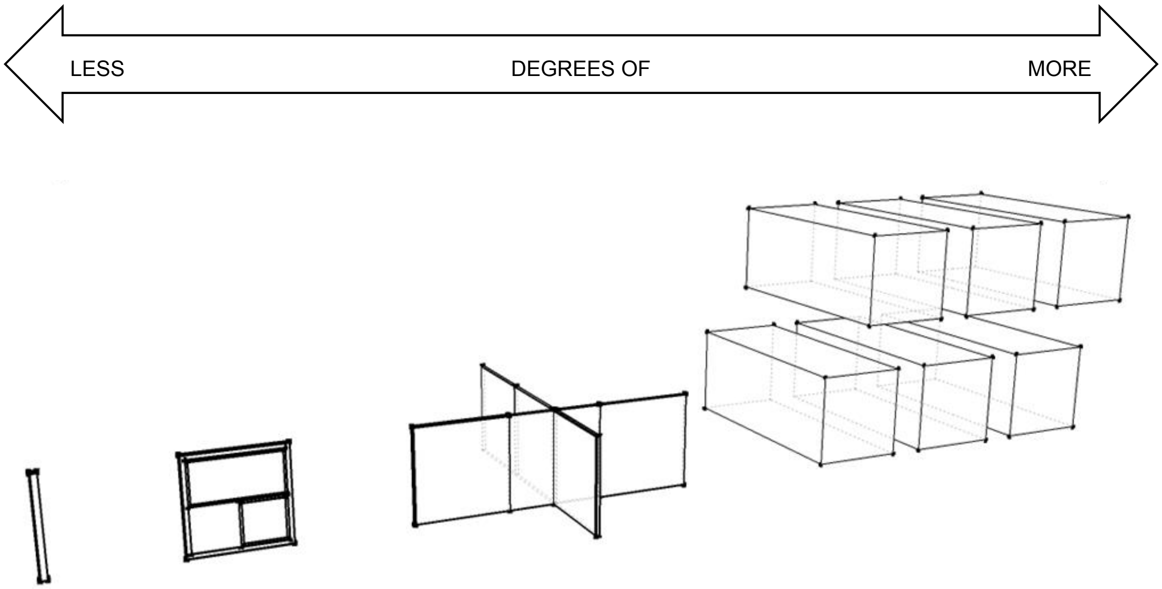


Figure 1. From left to right, materials, components, assemblies, and modules represent differing degrees of prefabrication (Smith, 2010. Adapted with permission).

Prefabrication is used for all types of construction projects, with every sort of end use from single-family residential to multi-million dollar commercial structures (Gibb, 1999). The degree of prefabrication differs from project to project based on the parameters dictated by that specific job. Additionally, the degree of prefabrication varies greatly based on geographic location. Most developed countries have manufactured truss components, panelized systems, and the capacity to produce modules in a range of configurations. However, some nations have a building climate that encourages greater use of prefabrication.

For instance, Japan is cited by Gibb (1999) for boosting industrial and manufacturing principles in the production of housing.

Contrarily, in developing nations, the push for prefabrication is often less pronounced because developers and government officials see more benefit from using the abundant labor force surrounding a project site. This is beneficial for developers because the labor is cheap and they can reap rewards from exploiting the accessible resource. At the same time, the government and the local population benefits because unemployment is reduced by the ongoing capital projects (Gibb, 1999). In China, for example, during the build-up for the 2008 Beijing Olympics, designers of the Water Cube project considered building with Computer Numeric Controlled (CNC)-cut components to frame the intricate steel structure. However, the developer chose to employ an ample workforce of 3,000 local laborers, including 100 welders, to fabricate the structure (Smith, 2010).

Although most common building materials are utilized for prefabricated construction, there are still innovations emerging from the use of existing materials in novel ways. Cross Laminated Timber (CLT), for example, is an engineered wood product that has been used extensively in Northern European countries for a few decades, but is slowly exhibiting more use in North America (Figure 2). CLT panels are manufactured by layering dimensional lumber in a perpendicular build-up, where each layer is positioned 90° to the adjacent layer, forming a strong, stiff panel that takes advantage of the wood's mechanical properties in all directions. These panels can be manufactured with three to nine layers, and can be used for floors, walls, and roofs. Although they are still relatively unknown in North America, CLT panels are simply another version of the engineered wood products used extensively every day across the globe (Gagnon & Pirvu, 2011).

Figure 2. A building module constructed of CLT is removed from adjoining modules (photo courtesy of Dudley Carter).

One of the limitations of prefabrication, especially with regard to modular construction, is limited building size. Wood construction, for instance, is typically restricted in height to no greater than three stories due to the capability of the material (Gibb, 1999; Smith, 2010). Taller modular buildings are traditionally built with materials with greater compressive, tensile, and shear strength such as concrete and steel which also have the added benefit of increased fire resistance. However, the mechanical and physical properties of CLT allow for much taller wood structures. In London, a project constructed with CLT is nine stories, and testing indicates that CLT buildings are capable of going higher, although they are not yet permitted by building code to do such (Gagnon & Pirvu, 2011). What is more, these all-wood CLT structures are prefabricated no matter how they are built. If desired, CLT panels can come from the factory CNC pre-cut, drilled, routed for services, and finish-grade sanded—a veritable prefabricated, panelized construction system—or they can be assembled in modules and craned into place as finished entities. Further shattering the size ceiling imposed on prefabricated buildings is the previously mentioned B2 project in Brooklyn, NY. B2 is a modular project that is being constructed from steel modules fabricated at a converted Navy Shipyard in Brooklyn. Interestingly enough, although it is a factory fabricated structure, this project also employs local construction tradespeople, because the factory was developed in Brooklyn for this purpose, thereby thwarting claims that prefabricated buildings disenfranchise local workers. In this instance, B2 is effectively utilizing and ensuring the welfare of the workforce by putting them in a more controlled working environment (Oder, 2013). The B2 project is innovative for exceeding the previous limits of modular construction, and for also forging a new business model for the prefabricated construction industry.

Applicability of Prefabrication for Construction

Prefabrication, as previously mentioned, is utilized in all aspects of construction and has a range of applicable purposes depending on the scenario. In commercial buildings, this can range from a pre-cut and labeled kit of parts to a series of finished modules that compose the entire building. Figure 3 shows the range of options typically available from a commercial perspective, although this list is not exhaustive. According to *Constructor,* a publication of the Associated General Contractors of America (AGC), a 2011 survey found that “98 percent of respondents use some form of prefabrication or modular construction but the use is limited to a small portion of the project” (Jackson, 2013, p. 27). Those contractors using prefabricated methods more typically tend to focus their efforts on repetitive elements as much as possible. Items such as pre-finished bathroom modules, cable trays, hospital headwalls, and architectural metal panels are prefabricated items most frequently used by large commercial general contractors such as Balfour Beatty and Skanska (Jackson, 2013).

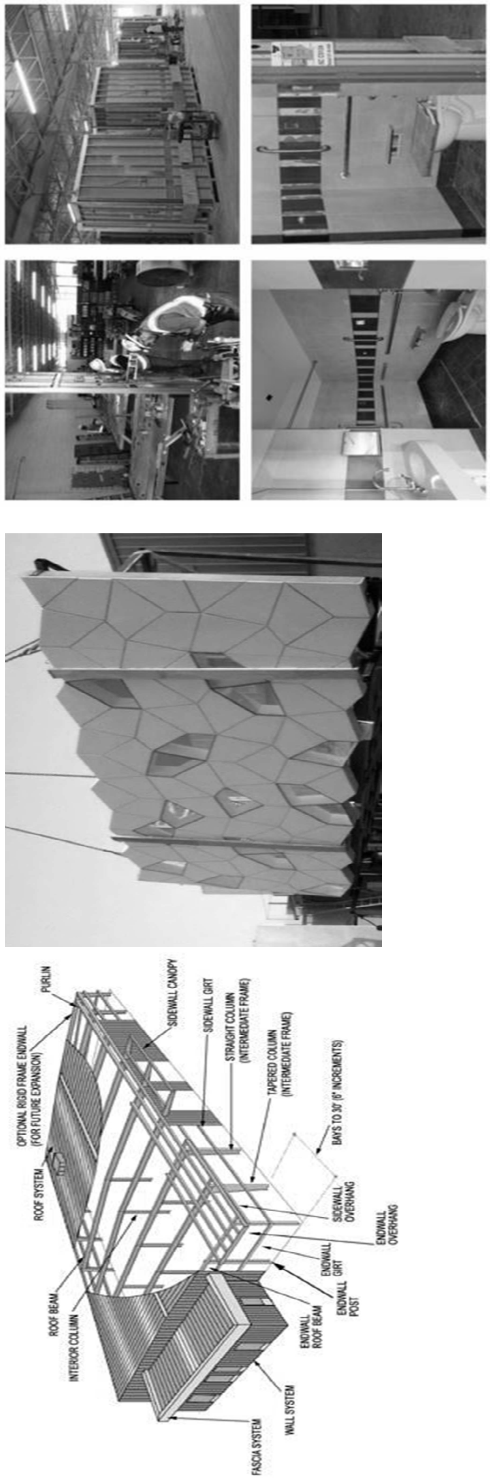


Figure 3. Typical applications of prefabrication in commercial construction. From left to right: a Butler metal building that comes to the site ready to assemble; a custom, composite wall panel; and prefabricated bathroom modules used by Balfour Beatty Construction (Butler Manufacturing, 2013; Balfour Beatty Construction, & Lean Construction Institute, 2014. Reprinted with permission).

Commercial general contractors use prefabrication to take advantage of multiple trades in one unified location. Usually, there is a chaotic sequence requiring mechanical, electrical, plumbing (MEP), and other specialty trades to step over each other while completing their work (Jackson, 2013). This means that these subcontractors are beholden to the overall project schedule, and the project is beholden to the individual schedules of the different trades (Kaysen, 2011). On exceptionally complicated projects, this creates a melee of wires and pipes, and the potential for excessive re-work; even on the simplest of jobs, this parade-of-trades is a tango. By moving these complicated processes into the factory, MEP contractors can fluently rotate between tasks on pods that are assembled in a row. This places all of the trades in the desired location and eases the strain of differing schedules by allowing tradespeople the flexibility to work on multiple pods, and multiple stories, in one contained factory, and on one safe plane (Kaysen, 2011).

Heavy-civil projects—roads, bridges, dams, waterworks, and the like—take advantage of prefabrication on a large scale. Civil projects are often lacking in dainty bells and whistles, but are usually heavy on repetitive elements, even if there are only a few of them used throughout the project. For example, a bridge can utilize four or six similar elements to span a large expanse, and each one of those elements can be a massive prefabricated component (Sundt, 2013a). To construct each component on site would require a copious amount of formwork that is both costly and time-consuming. However, these components can be cast off site in a dedicated casting-form. The crux is determining if the cost deferred in casting off site is substantial enough to offset the cost of transporting the precast element to the job site.

One such project was recently completed by Sundt Construction in Fort Worth, Texas. Sundt reconstructed the Seventh Street Bridge that ties the city's downtown and cultural district together (Sundt, 2013b). The bridge is built with 12 (six on each side) prefabricated concrete arches, each spanning more than 160 feet and weighing more than 640,000 pounds. The arches were precast offsite (although not inside a factory) and pre-stressed prior to transportation to the bridge building site (Jackson, 2013). Although in this case there are only 12 prefabricated elements, this project illustrates how prefabrication allows construction projects to proceed long before the first shovel touches the ground. After the design was complete, and all stakeholders were comfortable moving forward with the bridge project, Sundt constructed an off-site fabrication yard and began casting and storing the prefabricated arches. Then, in a span of only four months, Sundt demolished the existing structure and transported each arch to the building site to be assembled into one cohesive structure. The project finished a month ahead of schedule (Sundt, 2013b).

The Linn Cove Viaduct, an icon of the Blue Ridge Parkway, also benefited from prefabricated construction (Figure 4). The Viaduct was completed in 1982, although construction of the Parkway began in the midst of the Great Depression in 1932 (Huso, 2010). The Viaduct was the last segment of the Parkway to be completed due to a number of setbacks and concerns. Several national wars and administrations obstructed funding for the Parkway, and many ecological and technological challenges could not be satisfied until after the Vietnam War. The Grandfather Mountain ecosystem that surrounds the Viaduct is extremely sensitive, with rare and endangered flora and fauna, and the terrain is a tenuous collection of craggy-boulders. For these reasons, the Viaduct was designed and constructed using precast concrete box-girders. Each precast element was formed off site by one reconfigurable formwork, and was set in place by cantilevering off of the end of the adjacent element, thereby eliminating the need to build from the ground up and leaving the surrounding site nearly untouched (Huso, 2010).

Figure 4. Precast concrete element is lifted into place by a stiff-leg derrick in the construction of the Linn Cove Viaduct (Morton, 1983. Reprinted with permission).

Prefabrication for residential construction employs many of the same characteristics seen in commercial applications. However, in residential construction the scale of an individual project is generally small enough that prefabrication can easily scale to panelized and modular construction that completes the entirety of the building. For simplicity, I will avoid any prefabrication at the material level (such as a pre-hung door), and instead focus on prefabrication at the large or intricate component level.

Housing has long been the focus of attention for prefabrication, both in terms of providing a universal solution for affordable housing and as a means to revolutionize the way that houses are built (Arieff & Burkhart, 2002). For decades, manufactured housing and mobile homes have been consistently built to an acceptable, but publicly derided, standard. Mobile homes—which are different from manufactured homes in that they existed before the HUD code—adhere to U.S. Housing and Urban Development (U.S. HUD) building codes, and not typically to state or regional building codes. The HUD code dictates that manufactured housing be constructed on a permanent chassis rather than a permanent foundation, thus clearly indicating the difference between a modular home and a manufactured home in the letter of the law (U.S. HUD, 2013). However, many manufacturers of modular homes also produce HUD code homes, thereby creating confusion as to whether modular homes and manufactured homes are the same thing. Suffice to say that manufactured homes and modular homes are two different products, both of which are prefabricated. Modular buildings in particular are addressed in a later section.

Manufactured housing has long labored under a bad reputation mostly caused by decades of poor quality prior to the passing of the U.S. HUD code in 1976 (U.S. HUD, 2013). Since then, manufactured housing has fared little better due to the undeniable fact that it is the cheapest housing per square foot, bar none, and it is also the least efficient in terms of operations, and performance during natural disasters (Smith, 2010). Additionally, the mobility of what used to be termed mobile housing has precipitously declined since the 1970s. Mobile homes were previously eight feet or less in width and easily transportable down the road with standard transportation methods. During the 1970s they jumped up to 12 and 14 feet, drastically reducing the mobility of each manufactured unit. In 1976, the doublewide was introduced, which produced a 28 foot-wide home by adjoining two 14-foot sections together along the long axis of the building. This style of home is definitely not mobile. Compounding these factors, the value of manufactured housing does not increase at a comparable rate to site-built housing, and often decreases, making the purchase of a manufactured home less appealing from an investment point of view (Smith, 2010).

Figure 5. A panelized log-home kit that comes to the job site as panels and labeled components ready for assembly (Grizzly Log Builders, 2014. Reprinted with permission).

Kit homes have been available for decades, and were popularized by the Sears and Roebuck and Aladdin mail-ordered homes of the early 20th Century (Smith, 2010). Today, many business models similar to that of Aladdin and Sears are still around, although financing is usually not something provided by the home manufacturer, as was the case with Sears. Companies such as Deltec Homes and Rocio Romero Prefab produce homes that are panelized, in some cases itemized as a kit, and shipped to the buyer for assembly. A range of prices is available, with most comparable to site-built homes. Many of these kit homes are marketed to do-it-yourselfers; however, many speculative builders find them appealing due to the ease of construction and the design that comes with the package (Romero, 2014). Often, log homes are built from kits that are precut at the factory, and ready to be set at the jobsite (Figure 5). These are often finished with stick-built end walls and prefabricated roof-systems, but the possibilities are too many to enumerate (Law, 1985).

Importance of Prefabrication

The National Research Council, which is part of the National Academy of Sciences, in its 2009 report on improving construction productivity, recommended five activities for implementation within 20 years. Prefabrication was one of those. However, prefabrication was not isolated as an activity to be pursued in a vacuum. The entire list of recommendations for improved productivity includes:

1. Widespread deployment and use of interoperable technology applications, also called Building Information Modeling (BIM);
2. Improved jobsite efficiency through more effective interfacing of people, processes, materials, equipment, and information (lean construction);
3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes;
4. Innovative, widespread use of demonstration installations (mock-ups); and
5. Effective performance measurement to drive efficiency and support innovation (National Academy of Sciences, 2009).

The key premise to understand about this list of activities is that they are all interrelated. BIM makes coordinating the prefabrication process more streamlined, and capable of producing a greater range of items. Lean construction encourages practitioners to trim the fat, and to work more resourcefully, with mechanical efficiency aimed at eliminating activities that do not add value for the customer; thus, prefabrication fits nicely into that mold. Prototypes are an integral part of the prefabrication process, and a mock-up is basically that: it demonstrates the materials, methods, and techniques to be used in the actual assembly. The last proposed improvement, monitoring and verification of performance, is a vital step that is often not well practiced in construction.

When building a project with new methods there are bound to be many snags and change orders along the way. Learning from those snags and striving for continuous improvement is the end goal; however, construction projects of a large scale differ so much from one to the other that it is often hard to replicate a successful process that was previously used (National Academy of Sciences, 2009). When a residential developer builds thousands of tract homes with twenty different designs over five years, they are unquestionably going to become proficient at building those twenty homes. When a commercial developer builds one project that takes five years to complete, they will develop proficiency with repetitive tasks throughout the course of that project. In each of those cases, after five years the companies are moving on to other projects, and the lessons learned on the previous projects do not always transfer over. This is sort of like transferring college credit from one institution to another: you took the courses and learned the content at one place, but you have to learn it again at a different place because the syllabus is slightly different. The key is to take the time at frequent intervals throughout and between projects to absorb what has been learned, understand how effective your processes were, and implement a culture of study and improvement to capitalize on what went well and change what did not, all in an effort to eliminate processes and activities that do not add value (Butts, 2012).

There is a heightened need for innovation and performance enhancement in construction because the industry is one of the least efficient:

> One note of agreement is that there is significant room for improvement. Studies focusing on construction efficiency, in contrast to productivity, have documented 25 to 50 percent waste in coordinating labor and in managing, moving, and installing materials (Tulacz and Armistead, 2007); losses of $15.6 billion per year due to the lack of interoperability (NIST, 2004); and transactional costs of $4 billion to $12 billion per year to resolve disputes and claims associated with construction projects (FFC, 2007). (National Academy of Sciences, 2009, p. 2)

Although buildings have become more challenging to construct, the tools available to practitioners to design and build them have not developed at the same rate. This has caused the productivity of the construction industry to lag far behind comparable industries, with some claiming that construction productivity is worse now than it was 50 years ago (Gibb, 1999). However, improvements in BIM have made prefabrication more successful because entire assemblies can be constructed in virtual reality and proposals can be vetted before shovels turn dirt. As indicated in Figure 6, contractors are using prefabrication because they experience improvements in productivity. The collaboration between virtual and physical realities makes both of these processes more productive as a fully-developed virtual component results in a higher-quality, prefabricated component. In this reciprocal way, improvements in one area pull all the others along (National Academy of Sciences, 2009; Smith, 2010).

McGraw Hill Construction (Bernstein, Gudgel, Laquidara-Carr, & Russo, 2011) acknowledges that prefabrication processes have developed a stigma of poor quality over the past century. However, this industry organization goes on to explain that prefabrication has evolved to become a key component of the push for improved construction productivity (Bernstein et al., 2011). According to their 2011 survey of 809 building professionals, McGraw Hill reports that 84% of contractors surveyed use prefabrication to some degree, and 63% have been using prefabrication for more than five years. Furthermore, 98% of respondents expected to be using prefabrication by 2013. The strongest driving force (Figure 6) behind the surge in prefabrication use is the belief that prefabrication improves productivity (Bernstein et al., 2011).

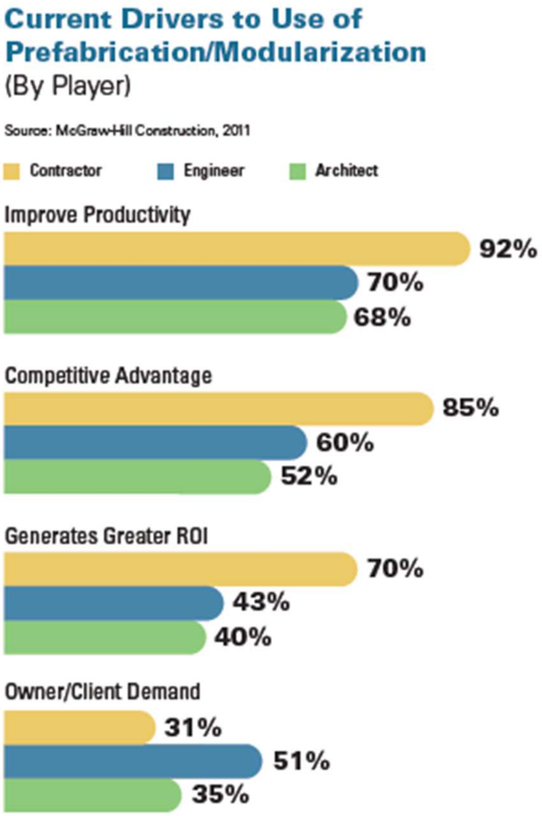


Figure 6. Productivity improvements are perceived as the leading benefit to using prefabrication (Bernstein, Gudgel, Laquidara-Carr, & Russo, 2011. Reprinted with permission).

Modular Construction

As previously noted, modular construction in the simplest sense is a high degree of prefabrication. However, it is important to denote the difference between modular and prefabricated construction because the two are not synonymous. What differentiates modular construction from other forms of prefabrication is the notion of the module. A module is a standardized unit of construction, relatively unlimited in scale that is designed with easy assembly and transportation in mind. Bear in mind, however, that there are limits to what can be transported on the highway. Modules can arrive on site upward of 95% complete, and with the addition of a foundation become finished buildings (Smith, 2010).

Figure 7. Factory floor of Carolina Building Solutions, a North Carolina-based manufacturer of modular buildings (photo by author).

Regardless of the construction classification, be it commercial, residential or other, the process used in modular construction is the same. The structure is built in a factory, transported to the job site, and assembled as a stand-alone building or in conjunction with other modules, assemblies, and in situ works to form the whole building (Modular Building Institute, 2014).

Materials Used in Modular Construction

Modular buildings are constructed with a range of materials similar to conventional site-built construction. The most common materials used for commercial and residential modular construction are wood and steel (J. Mooring, personal communication, July 23, 2013). Wood modular construction is quite similar in form to stick-built construction, except the process takes place in a factory (Figure 7). There are several innovations in a modular building, however, that differentiate it from one that is stick-built. For instance, in a modular home with a sloped roof, the roof—if steep enough to warrant—is often a knockdown structure. This refers to a technique that hinges the roof so that it can ride flat for transport and then tilt-up when the module is assembled on site (Figure 8). Wood modules are often lifted by cranes without additional structure required for the lifting. This is accomplished by lifting from the bottom of the module with wide straps that wrap the entire building, which are then supported by a load spreader from the crane. This method keeps the module undamaged, and has successfully been used for decades (J. Mooring, personal communication, July 23, 2013). The limitation with wood modules is height. Wood modular buildings cannot be more than three stories in height unless they have substantial structural elements added to them, which makes them uneconomical. For this reason, steel is often used when a more robust structure is required (Smith, 2010).

Figure 8. Knock-down, hinged trusses allow the sloped roofs of modular buildings to tilt-up on site, and transport flat (photo by author).

Steel modular structures are common in areas with specific seismic concerns. For this reason, the west coast of the US and many Asian countries frequently use steel modular components (Smith, 2010). Additionally, developers use steel modules to break through the three-story height ceiling. The previously mentioned B2 project utilizes steel modules to achieve over thirty stories (Atlantic Yards, 2013). Other commercial projects also use steel modules to capitalize on their strength, but without much attention to overall project height. Bathroom pods are typically constructed from steel members because non-flammable materials are commonly required in commercial occupancy classifications (Ching & Winkel, 2007). As with conventional construction, the deciding factors for choosing one material over another are driven by the parameters of the project; if these dictate that steel is necessary, then it will be used (Jacobson, Silverstein, & Winslow, 2002). Ultimately, the same principles guiding modular construction apply to both wood and steel: each can be used effectively and efficiently if a modular strategy is implemented from the beginning of a project (Gibb, 1999).

Concrete modules were used during the 1960s during many social housing experiments (Urban, 2012). The tallest modular building in the US, the Hilton on the Riverwalk in San Antonio, was built from precast concrete modules by the Zachary Construction Corporation in 1968 (Hilton, 1968). Today, however, in the US, most concrete modular projects are limited to prisons and industrial applications (Smith, 2010). Nonetheless, many Asian countries use concrete modular construction to build multi-family residential buildings on a regular basis. The Daewoo multi-room modular construction system is a precast concrete system, used extensively in Korea, that utilizes an on-site factory to cast an entire floor at a time. These precast modules are then set in place at the rate of one floor per day (Figure 9). The concrete modules are fit-out in place with prefabricated, panelized wall components that have integral Mechanical, Electrical, and Plumbing (MEP) equipment. Daewoo claims this method is up to three times faster than conventional construction (Gibb, 1999).

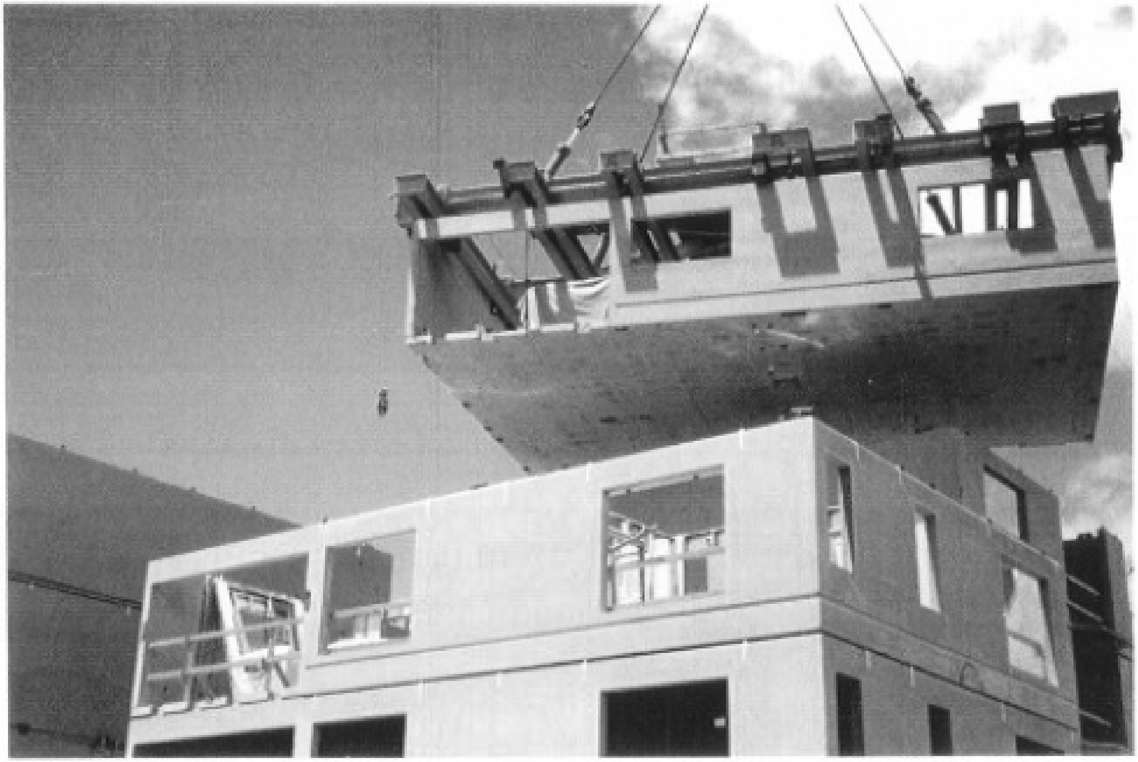


Figure 9. The Daewoo Corporation's Multi-room Modular Construction System, shown with a concrete module suspended (DISI Homes, 1995. Reprinted with permission).

Transportation Considerations for Modular Construction

One of the most significant aspects of modular construction that must be considered early in the design phase is how a module will be transported and assembled (Reid, 2013). If a project team has decided to use modular methods, the designers need to evaluate how the overall design intent can be accommodated within the modular framework. This means understanding the transportation regulations of each state or territory where the modules will travel, as well as grasping raising and rigging methods, and how these might impact the design of each module (A. Rand, personal communication, August 05, 2013). Although each state in the US has specific restrictions on maximum sizes and weights that can be trucked on their roads, general guidelines can be identified. Table 1 contains some standard rules of thumb, as adapted from Smith (2010).

Table 1. *Rules of Thumb for Module Transport Limits.*

	Module Width	**Module Length**	**Module Height**
Common Maximum	13 FT	52 FT	12 FT
Oversize Maximum	16 FT	60 FT	Varies

In addition to transportable sizes, modules must also be protected during transport. On-the-road transportation is the most common mode for modular projects, and for this type of transport each module must be secured to the vehicle and protected from the weather (A. Rand, personal communication, August 05, 2013). Most modular manufacturers use a polyolefin sheet to protect open module cavities; however, custom tarps of differing materials are available for longer-term transport (J. Mooring, personal communication, 23 July, 2013). In addition to weather protection, modules must also be secured to the trailer on which they are transported. Commonly, tie-down points are located at the base of the module; however, straps can also extend over the top of the module. In either scenario, it is vitally important not to damage the module while trying to protect it. In most cases, the module will be placed on a flatbed trailer of some variety (T. Graefe, personal communication, August 05, 2013). Figure 10 depicts the standard flatbed trailers available. It is important to realize what trailers are available early in the design process because of height limitations. Essentially, it is fair to reason that the taller the module gets, the more it will cost to transport it (T. Graefe, personal communication, August 05, 2013). For these reasons, transportation needs to be a guiding principle of the design.

When the modules arrive safely on site, assembling them is another sizeable challenge. A crane is required to set each module. The crane and rigging for each lift must be sized to safely move each module. Rigging includes cables, straps or chains, hooks and clevises, load spreaders, and all necessary hardware to get the module on and off of the trailer (Riggs, 2013). Depending on the dimensions and weight of the module, and the number of modules to be set, there are a few options for choosing the right crane. In any case, the capacity of the crane and the weight of the module must be compatible (A. Dink, personal communication, February 03, 2014).

On-Site Assembly Strategies for Modular Construction

After modules are set within reasonable tolerances, they must then be stitched together with adjoining modules. Stitching is the process by which the modules are held together, and their interior and exterior finishes are field-applied to unify one or more modules at their seams (Smith, 2010). Depending on the design of the building, joints can be concealed with finish materials or they can be expressed as elements of the design. In either scenario, care must be taken to ensure that the joint is air and water tight, structurally sound, and aesthetically pleasing (A. Rand, personal communication, June 06, 2013). Depending on the tolerances adhered to during the fabrication of the modules, stitching them together can be an arduous task. As such, design details that accommodate reasonable expectations for quality are best suited for modular applications. For example, drywall can be applied in a factory and then easily finished between modules in the field. Tongue and groove boards, however, are a different story. They will install easily enough in the factory and in the field, but the variability that exists when setting modules could make a gap that is not easily filled with an even number of boards, and so one or more of them may have to be ripped down to an appropriate width (J. Morring, personal communication, July 23, 2013).

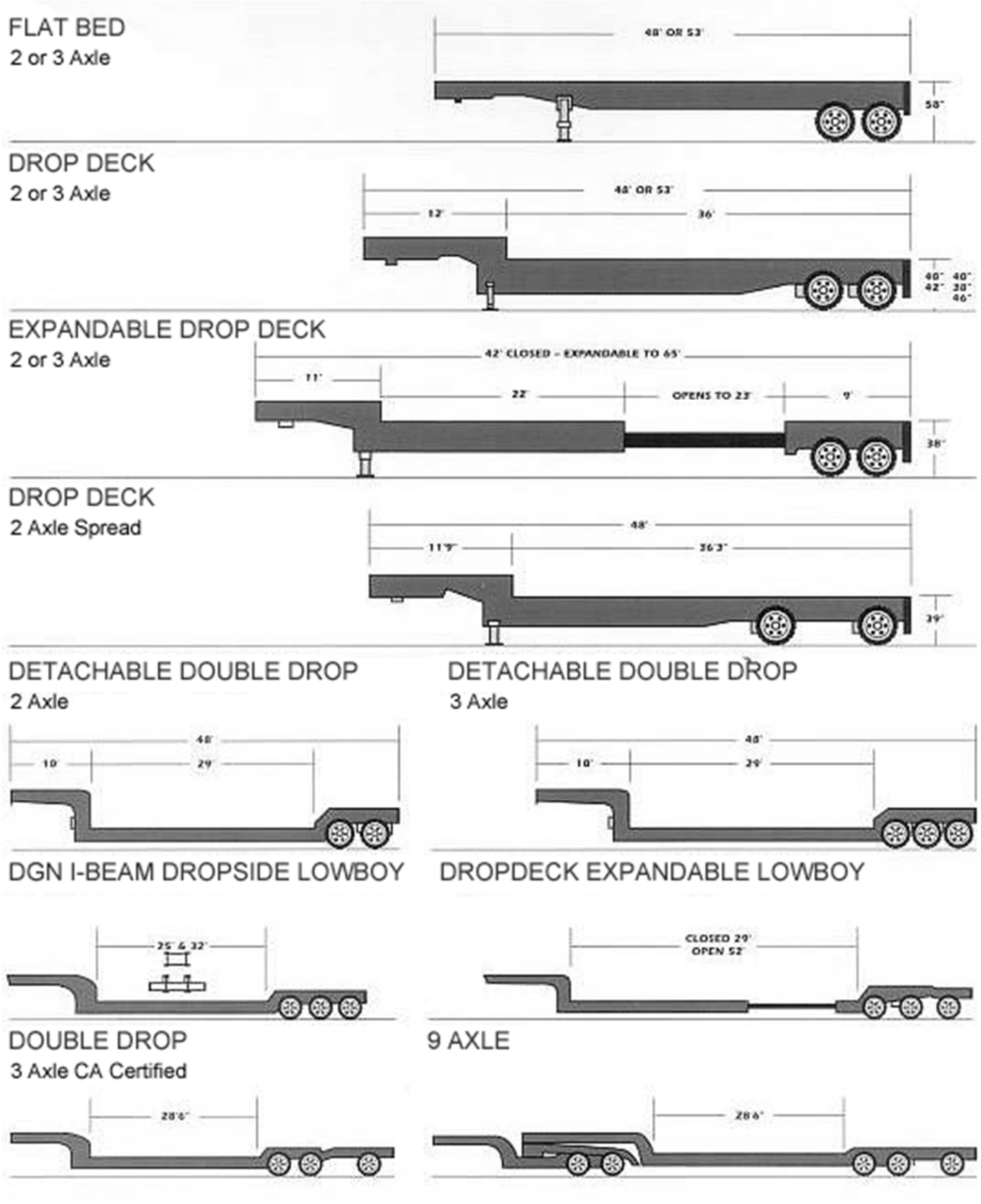


Figure 10. Commonly available flatbed trailers used for transporting out-of-gauge cargo such as modules (Stein Transportation, 2014. Reprinted with permission).

Project Duration

For the aforementioned logistical challenges, closely coordinated and collaborative design is imperative in modular construction projects. As dictated by transportation regulations, modules have to stay within a window of acceptable sizes. Thus, designers must ensure that the module will accommodate the programmatic needs of the building, and also provide reasonable transportation and assembly (Azari, Javanifard, Markert, Strobel, & Yap, 2013). This does not necessarily translate into a longer design period; however, if the decision to use modular construction is not made early in the project it can cause complications that will result in a longer project duration. For instance, if a project is designed for conventional construction, and is dimensioned without regard for what needs to be transported, it will be problematic to segment that design into 12 or 14 foot wide modules that are both independently viable, and also smoothly transition from one module to the next for a complete assembly (Azari et al., 2013).

The main benefit of modular construction is delivery time (Gibb, 1999). As mentioned, design time is relatively unaffected by the decision to use modular, but time is made up during the construction phase, and this makes the overall delivery quicker. Time is made up during the construction phase because off-site and on-site activities are able to occur simultaneously (PCL Construction, 2014; Gibb, 1999; Smith, 2010). Figure 11 compares the project timelines of a site-built building with an identical building constructed modularly. As depicted, while site work occurs at the building site, the modular structure is being built at the factory. The site-built project must proceed sequentially, therefore the structure cannot go up until the site work is complete and the foundation is built. For this reason, modular construction gains the most consideration from projects with tight timelines, or where the on-site duration must be kept to a minimum. The Seventh Street Bridge in Fort Worth Texas, recently completed by Sundt Construction, is one such example. Disrupting traffic on a major thoroughfare is never pleasant or desired, so reducing the duration of disturbance is priority. By constructing the bridge modules off site, Sundt was able to reduce the amount of time on site to just over four months, although it took nearly a year and a half to build the modules (Dickson, 2013).

Figure 11. Comparison of project duration between modular and traditional construction methods (Williams Scotsman, 2013. Reprinted with permission).

Many builders who use modular construction cite the predictability of the process as one of the deciding factors for using modular (Jackson, 2013). Predictability translates into a more efficient and coherent supply chain. On many site-built projects the builder is in a constant turmoil, torn between receiving the necessary supplies just as they are needed or ordering them early to ensure they are there when needed. The latter decision requires space on-site to store and protect the items from weather and theft (Said & El-Rayes, 2011). With a predictable production schedule, and a facility to properly store and inventory materials, modular builders are able to order materials just in time, and the completion of projects is not delayed because of supply chain hiccups (Smith, 2010).

It can be argued that regardless of the construction method selected, a 10,000 square foot building will require the same amount of hours to construct. A wall that takes an hour to construct on a jobsite will still take an hour in a factory. However, this is not accurate, because it does not account for the concurrent scheduling that can take place in a factory, or the jigs and manufacturing devices available in a factory (Gibb, 1999). Gibb (1999) writes that according to a study performed by Foster Wheeler Energy, the improvements in productivity can be as great as 30% in a factory setting. For example, in a modular facility, workers at one end of the facility will be constructing the floor while workers elsewhere are building the walls and roof (J. Mooring, personal communication, July 23, 2013). Furthermore, in a modular facility there are squaring tables that are elevated to working height, gantry cranes to move components, and a number of other devices to make the work more efficient and streamlined (Figure 12). As such, it is undoubtedly quicker to build in a properly established facility (J. Mooring, personal communication, July 23, 2013). However, the time gains reaped by building in the factory could be offset by the time required to transport the modules to the site, as well as to assemble them (Smith, 2010). It is impossible to speculate what that offset is because every project is different. Some projects are closer to the manufacturing facility than others, and likewise, some buildings are easier to assemble than others (Azari et al., 2013).

Figure 12. Squaring tables and jigs used in the manufacturing of modules (photo by author).

Financial Impacts

By virtue of expediting the project timeline, and delivering the project to the client quicker with modular construction versus site-built construction, there is an immediate cost advantage for modular (Chandler, 2013). If a commercial client is able to utilize a revenue generating facility three months earlier, they effectively gain three extra months of revenue. Likewise, shorter project duration equates to less interest on a construction loan, and less money spent on another facility for operations and maintenance (Construction Industry Institute [CII], 1992). Gibb (1999) proposes that due to the shorter duration of time spent on site, the associated costs for operating a site should decrease. For example, rent for on-site toilet facilities, site storage, security, and possibly living accommodations can be partially eliminated, and these savings can be passed on to the client. However, whether the client actually sees these extra savings is an area that needs more substantiation.

Many critics of modular construction claim higher costs for modular construction versus site-built. The basis for this claim is the cost to transport each module, and the large fees for cranes that are required to move and assemble the modules (Azari et al., 2013). Certainly, a modular project that requires a crane will incur an extra expense for the crane usage when compared to a project that does not require a crane. However, the transportation cost might not be an increase over site-built projects. On a modular project, the transportation expense for each module is a large number, and one that is likely to receive its own line on an invoice. On a site-built project there is a delivery fee to get the materials on site, but aside from that transportation is not likely going to appear on an invoice (Gibb, 1999). The dozen trips that the contractor takes to the lumber yard in the pickup truck and the small fleet of subcontractors who drive to the jobsite day after day are all borne-out as overhead for the contractor (Smith, 2010). Because of factors such as these, it is difficult to compare modular and conventional transportation costs on a level basis, and in all likelihood these costs can differ greatly from project to project (Gibb, 1999). For that reason, modular construction should be assessed on a project-by-project basis to see if the construction cost is better with one method over the other.

There is, of course, the irrefutable cost of a factory included in modular construction. The overhead cost associated with maintaining a factory is not miniscule, and a high volume of sales must justify the existence of the factory (Gibb, 1999). Another possibility, which is regularly pursued with large projects, is to create the factory specifically for a project, as is the case with B2 in Brooklyn, NY (Atlantic Yards, 2013). In such instances, the developer can justify the cost of establishing and operating a factory due to the large volume of modules that will be produced there, and the projected financial savings for each module. With the B2 project, FCS Modular, the subsidiary producing the modules, is able to build— out of the factory door and installed on site— 1,000 square feet of housing for about 15% less than what it traditionally costs to build a comparable apartment in New York City (Carlyle, 2014). The approach has garnered much scrutiny, but if successful it could help usher in a new approach to fast, affordable housing (Carlyle, 2014).

Most modular facilities do not just build one-off modules for small builders. Many manufacturers build customized versions of established house plans for consumers as their primary source of income, which is supplemented by other commercial interests (J. Mooring, personal communication, July 23, 2014). Yet still there are modular manufacturers, such as X-Site modular in New Jersey, that just build commercial modules from steel and concrete (X-Site Modular, 2011). In any case, the economics are the same: a manufacturer must sell a high enough volume to offset the overhead of the factory. This overhead is distributed to each customer who buys a module, or is justified by the productivity gains and economies of scale realized when hundreds of the same module are produced for one project (Gibb, 1999).

Modular construction will cost more with respect to change orders. On a conventional project, moving a wall or sink is an aggravating, but easily accomplished, task. On a modular project, such changes require revised shop drawings, a kink in production, and possibly a whole new module. As such, making changes with a modular project are more costly, and should be avoided once the design is finalized (Smith, 2010).

Collectively, the cost of modular construction is likely more expensive on a per unit basis than site-built construction (Smith, 2010). Intently coordinated design, such as that required with modular construction, is likely to result in more billable hours, even if the design period is unchanged (Azari et al., 2013). Due to the overhead of the factory, a manufacturer will probably charge more than a general contractor for an equivalent amount of work. However, that is not an absolute. For example, the FCS Modular (B2) labor agreement negotiated cheaper work in the factory than in the field (Carlyle, 2014; Smith, 2010). Transportation costs might balance out between the two methods, but that is heavily dependent on the location of the job relative to that of the manufacturing facility (Azari et al., 2013). Therefore, it is critical to determine if there is an additional cost for using modular, and if so, if this cost is offset by the expedited delivery schedule and possible quality improvements (Gibb, 1999; Smith, 2010).

Modular Benefits to Quality

One of the hot-button phrases in the AEC industry in recent times is Integrated Project Delivery (IPD). With IPD, all key stakeholders in a project are brought together during the design phase in a mutually beneficial and collaborative contractual arrangement (American Institute of Architects [AIA], 2007). The intent is that a relationship that encourages frequent communication, shared responsibilities, and collective problem solving will result in a better quality project. When IPD is effectively implemented, the benefits show in the completed project (Gilbane Building Company, 2014). With modular construction, IPD is a necessity that precedes the monumental contractual shift in the AEC industry. If the design team does not effectively communicate with the module manufacturer, the design will not become a reality. With the addition of shared BIM models, modular construction has the ability to seamlessly move between design and construction via shared digital information that precludes the need for shop drawings (Carlyle, 2014). Most of the industry is not at that stage yet, but nonetheless using modular construction will result in greater coordination between the designer and builder, which will usually create a better project (Smith, 2010).

The greatest purported benefit to quality with modular construction is factory conditions. Inside a factory, a builder is not fighting the weather, and the building is not subjected to the environmental conditions (Lawson, Ogden, & Bergin, 2012). This will result in a product that is not deteriorated by weather events, and was built by individuals who were not burdened by their environment. However, this only applies completely if the factory is indeed closed. As seen in Figure 13, many modular factories are open-air facilities that are not climate controlled (J. Mooring, personal communication, July 23, 2013). Although the workers and the building are not directly in the sun, it still gets hot; they are not directly in the rain, but the humidity still gets in; and they are not covered in snow, but it is still cold. All things considered, this is preferable to working out in the elements, but it does raise speculation about the claim of indoor factory assembly.

One unquestionable aspect of factory assembly, however, is the improvement to worker safety. Work on construction sites is typically risky at best and a serious health hazard at worst. Work is often at excessive heights, there may be multiple vehicles roaming the site, and fall hazards are commonplace (Bernstein et al., 2011). In a modular facility, however, work is often performed on the ground, and if it must be elevated, there are permanent scaffolding structures in place to make that possible. As seen in Figure 14, elevated platforms with railings prevent falls, and provide a continuous path around the perimeter of the structure (J. Mooring, personal communication, July 23, 2013). Such measures are routinely cobbled together on a construction site, and the result is not optimal. Without a railing, workers are required to have fall protection on construction sites when working at heights greater than six feet. This is typically a harness worn by the worker and tethered to an anchor on the building. Although this is effective, it can still significantly injure the worker if they fall (R. Riddle, personal communication, June 06, 2013).

Figure 13. Inside of a NC modular manufacturing facility, looking through a large roll-up door that is usually left open throughout the day (photo by author).

Additionally, a factory has routine protocols that can be monitored more easily than on a jobsite. At a manufacturing facility, many workers are employees of the manufacturer, and it is easy to enforce a safety plan (J. Mooring, personal communication, July 23, 2013). On jobsites there are numerous subcontractors, and a lot of people who do not know one another. If there is a safety officer, he or she is typically assigned to multiple jobsites and cannot provide continuous enforcement; therefore, they are not as effective as a manufacturing facility (J. Hunter, personal communication, August 23, 2014).

Figure 14. Permanent scaffolding erected around building modules on a factory floor (photo by author).

As previously mentioned, modular construction provides a high degree of stability and predictability to a construction schedule. The predictability does not just affect time and cost, but it also improves quality as well (Jackson, 2013). Take bath pods, for example, when dozens or hundreds of the same unit are manufactured and serviced by the major trades in a coordinated and ground-level workflow; the result is one of consistent quality (Smith, 2010). The plumber does not have to change his or her pipe runs due to altered ductwork, and the electrician does not have to pull wires through a hundred feet of conduit. Everyone is doing the same thing multiple times to produce a steady stream of high quality units that are ready to be plugged in and connected to the whole.

Relevant Modular Projects

Many colleges and universities have embraced modular construction for new residence halls. Figures 15 through 19 illustrate some relevant examples of projects from around the US that used modular successfully.

Figure 15. One of the dorms constructed by NRB at Bryn Athyn College (NRB Inc., 2010. Reprinted with permission).

Project Name: Bryn Athyn College

Location: Willow Grove, PA

Manufacturer: NRB Incorporated

Construction Duration: 9 Months

Building Size: (3) at 8,114 square feet each

Profile: Three new dormitories were needed on a short timeline, and had to be completed before another fall semester at Bryn Athyn College. NRB was contracted to build the structural steel modules and precast concrete floors. The building's traditional façade was applied on site to contextually blend in with the other campus buildings (NRB Inc., 2010).

Figure 16. Evans-Kimmell Hall designed by Design Collaborative (Whitley Manufacturing, 2013. Reprinted with permission).

Project Name: Evans-Kimmel Hall

Location: Fort Wayne, IN

Manufacturer: Whitley Manufacturing

Construction Duration: 4 Months

Building Size: Not Listed

Profile: Indiana Institute of Technology contacted Whitley Manufacturing to build, set, and finish the four-story dormitory during the summer recess. The building features a modern design, and open concept common areas, as well as semi-private suit style living (Whitley Manufacturing, 2013).

Figure 17. Coal Yard Apartments near the campus of Cornell University (Crandall, 2012. Reprinted with permission).

Project Name: Coal Yard Apartments

Location: Ithaca, NY

Manufacturer: New Era Homes

Construction Duration: 13 months

Building Size: 27,800 square feet

Profile: This private development near Cornell University was designed to coordinate with existing site-built apartment buildings located on the same lot. A total of 32 modules make up the building, and were set in four days. The apartments are marketed to graduate students and the entry-level demographic (Modular Building Institute, 2013a).

Figure 18. La Almenara is a low-income apartment-home development (Clayton Homes, 2014. Reprinted with permission).

Project Name: La Almenara

Location: Pittsburg, CA

Manufacturer: Clayton Building Solutions

Construction Duration: 9 months

Building Size: 24,580 square feet

Profile: This housing project was built by the City of Pittsburg, CA to support the needs of the low-income population. Modular construction was selected because of the perceived benefits to time, cost, and quality. The City of Pittsburg reports that the project was less expensive than a concurrent site-built project (Modular Building Institute, 2013a).

Figure 19. The Modules at Templetown is a solution to urban student housing (Templetown Realty, 2013. Reprinted with permission).

Project Name: The Modules at Templetown

Location: Philadelphia, PA

Manufacturer: Excel Homes

Construction Duration: 9 months

Building Size: 80,000 square feet

Profile: This five-story development adjacent to the campus of Temple University combines student housing, urban living, a parking garage, and sustainable design. The building is pursuing LEED for Homes certification, and is designed to change the way that student housing is perceived in the US (Templetown Realty, 2013).

Conclusion

Modular construction is a method of building that has been around for many decades. From the Hilton hotel in San Antonio built in 1968 to the modern modules that grace the pages of *Prefab,* modular construction has proven to be a viable solution for many projects. Modular construction is prefabrication to the highest degree. A module signifies a volumetric component that can be up to 95% complete when it arrives on site (Smith, 2010). Modular construction is not appropriate for all project types or for all situations, but when the circumstance supports it modular construction can provide benefits to a project in terms of time, cost and quality.

The time-cost-quality triangle is the classic model for success in construction projects. If two legs of the triangle benefit, the overall success of the project is augmented (Gibb, 1999). Modular construction has generally been proven to be a faster method of building when compared to site-built construction because there are factory efficiency increases, and off-site fabrication results in construction tasks that can occur simultaneously (Hutchings, 1996). As such, when site work happens on site, modules are being built in the factory. The shorter construction duration can result in lower costs to the owner. However, logistical costs that a modular project incurs, and the factory overhead that a module must support, may result in a higher cost per unit (Jackson, 2013). For that reason, cost must be assessed for each project to determine if modular is a cost-effective solution. The factory environment in which modules are produced can result in a higher quality product. Keeping materials and workers out of harsh weather will have a positive effect on the project. The indoor conditions also result in a safer work environment at the jobsite, because risky tasks are moved to the factory floor (Gibb, 1999; Smith, 2010).

CHAPTER 3: RESEARCH METHODOLOGY

This study was broken down into three interdependent parts. *Part I: Identifying the Status of Modular Construction on UNC Campuses,* focused on assessing how many residence halls on UNC campuses have been constructed using modular construction. Furthermore, it examined which campuses had considered modular construction, which had not, and what the reasoning was for each consideration. *Part II: Campus Considerations and Experiences with Modular Construction*, further investigated the modular process throughout the UNC system by deriving a sample from Part I and conducting interviews with individuals identified for that sample. *Part III: Comparison of Time, Cost, and Quality Metrics of Modular Residence Halls*, utilized a case-study approach to analyze in-depth two similar university residence halls constructed on the same campus at the same time. One was built using modular construction, and the other was built using conventional construction.

Part I: Identifying the Status of Modular Construction on UNC Campuses

Sample

The sample for Part I of this study used a purposive sample designed to answer the following research question:

1. What is the current status of modular construction for university housing projects across the sixteen campuses of the UNC System?

It was necessary to contact the decision makers at each university campus who are involved in determining whether to use modular construction methods for university housing.

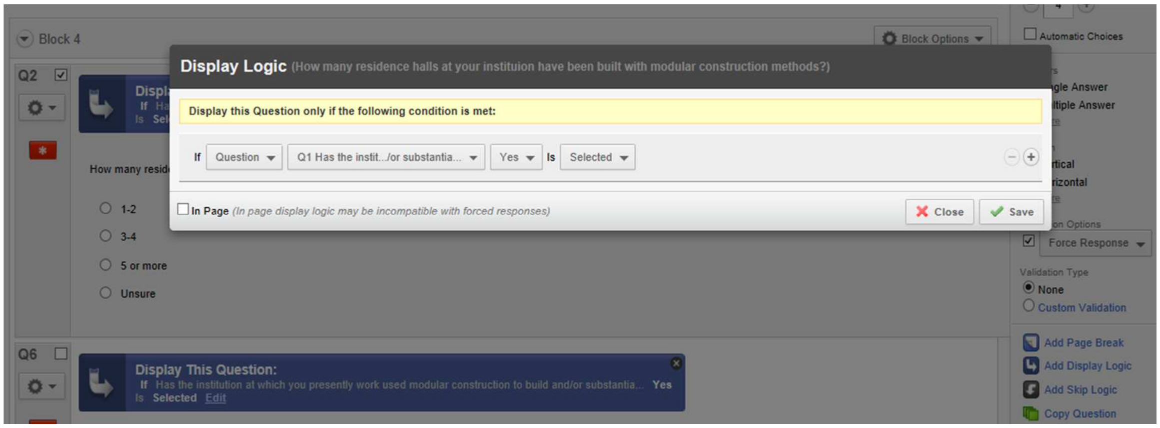
These subjects formed the population for Part I of the study. The population potentially included the Vice Chancellor for Facilities, Director of Physical Plant, Director of University Housing, and Director of Design and Construction at each UNC institution. However, not all of these individuals were available or knowledgeable about the status of modular construction on their campuses, so the individuals selected for each campus varied from one location to the next.

From the available UNC population, a sample of 59 individuals was selected. This averaged over three representatives per UNC institution, with some institutions having as many as five representatives. The reason for this spread throughout institutions was due to uncertain nomenclature and varying hierarchical structures at each campus. For instance, at some institutions the Physical Plant Director is responsible for all aspects of building design and maintenance. However, at many campuses there is an Associate Vice Chancellor who serves in that capacity, and a Physical Plant Director who is more involved in the operations and maintenance of facilities. As such, identifying the correct decision makers at each institution was challenging and sometimes ambiguous. In a case where a clear distinction could not be made about who was the best resource, then everyone possible was included in the sample.

Data Collection

Data collection for Part I of the study was done through an online survey hosted at Qualtrics.com. The survey was designed to find out (a) how many residence halls on UNC campuses have been constructed with modular methods, (b) whether and where modular construction has been considered for building residence halls, and (c) why or why not modular construction was considered and/or selected. A copy of the survey can be found in Appendix A.

Before the survey was officially launched a pilot survey was distributed to faculty and staff from Appalachian State University's (ASU) Department of Technology and Environmental Design, as well as to design and construction professionals that the author knew. The pilot survey took respondents through the same procedure as would be experienced during the actual survey. Feedback from the pilot indicated that modular construction needed to be better clarified at the outset, and that technical difficulties would arise as respondents attempted to navigate the online browser. To solve for these problems, more navigational aids and logic displays were added to circumvent any directional problems (Figure 20). Using the display logic function through the Qualtrics survey, respondents were guided through a directed set of questions that built upon previous responses. For instance, if question two was dependent on question one, then a condition had to be satisfied in question one in order for question two to display, otherwise, question two would be skipped.



Display Logic (How many residence halls at your instituion have been built with modular construction methods?)

Display this Question only if the following condition is met:

If Question Q1 Has the instit.../or substantia... Yes Is Selected

☐ In Page (In page display logic may be incompatible with forced responses)

Display This Question:
If Has the institution at which you presently work used modular construction to build and/or substantia... Yes
Is Selected Edit

Figure 20. Qualtrics display logic that allows the survey creator to target potential questions based on previous responses (Qualtrics, 2013).

The survey link was left open for about one month. The survey required a roughly ten-minute time commitment on the part of participants. Each of the targeted officials from the 16 institutions was emailed and telephoned to inform them about the survey, and then emailed a link to the survey. A follow-up email went out to all subjects who had not responded to the original prompt after two weeks. At one month, all remaining non-respondents were telephoned to request their participation one last time. After all survey activity subsided, the results were exported for analysis.

Part II: Campus Considerations and Experiences with Modular Construction

Sample

The sample for Part II of this study was a subset of the sample from Part I, with the addition of individuals with more in-depth knowledge of the modular projects from each institution, and individuals working in the NC State Construction Office (SCO). Furthermore, survey respondents who had considered using modular construction but had not yet done so, and who agreed to participate in an interview, were included in this sample. Eight respondents were selected for interview. These respondents represented five UNC campuses and the SCO.

Data Collection

Data for Part II was collected through personal interviews. Interviewees either had past experience administering the construction of a modular-built residence hall, or they had considered using modular construction for a residence hall project but opted for another method of construction. Interviews were conducted by phone or face-to-face to answer the research question:

2. On UNC campuses with modularly constructed residence halls, what has been the experience with respect to time, cost, and quality for each of these projects?

The interview format was dependent on the location and availability of the interviewee, but most were conducted via telephone. Each interview took an hour or less to complete, and was semi-structured. Questions for each interview were specifically derived from answers given in the survey. If the interview participant had not completed a survey, then the interview questions were based on the person's role in university housing projects. At a minimum notes were taken during each interview, and if possible, the interview was recorded electronically using a Sony ICD-PX333 recorder. After each interview, the data was electronically archived and then analyzed. Following the initial analysis, follow-up questions were asked of necessary participants. Once all data was processed it was coded into different categorical bins. The bins are time, cost, quality, regulatory issues, and other.

Part III: Case Study

Part III is a detailed case study comparison between Mountaineer Hall, and Summit Hall, two residence halls on the campus of ASU. Mountaineer is a modular building, and Summit is a traditional, site-built structure; both buildings began construction in 2010, and finished in June 2011, and July 2012 respectively. Mountaineer was built for $16.5 million, and Summit cost $31 million. A detailed methodology for the case study portion is included in Chapter 6: Case Study.

CHAPTER 4: RESEARCH FINDINGS, PART I AND II

Part I: Survey Findings

The survey, while informative on its own merit, was used primarily as tool to make headway into the UNC System. The survey was the first contact with many of the interview contributors, and thus, recruited participants for the interview while collecting preliminary information about modular construction throughout the University of North Carolina (UNC) System. Nonetheless, survey responses were valuable even if they did not result in an interview. While many of the survey responses required interpretation, once sorted, they laid the foundation for many themes that recurred throughout all phases of the study.

The survey went out to 59 upper-level employees working in housing, design and construction, and operations and maintenance throughout the UNC System. The survey had a response rate of 32%, and of the 19 respondents, 32% were from housing operations, 26% worked in design and construction, and 37% were from the facilities and operations or executive fields; one respondent worked in university finance. Eighty-nine percent of the respondents had been in their respective fields for over 15 years, with over 60% working in their current position for over six years. Almost 75% of the respondents had no prior experience working with modular construction, which means that almost a quarter of the respondents were from the only institution that has used modular construction, Appalachian State University (ASU).

Of the respondents that had not used modular construction, but had considered using modular, 47% opted to use a traditional, site-built construction process. One respondent from the University of North Carolina at Charlotte (UNCC) considered using modular construction but instead elected to use a prefabricated, metal panel approach. The predominant reason for electing to use a method of construction other than modular was quality, with 32% of respondents indicating that they anticipated a lower-quality building if they used modular. The other main reason for choosing a method of construction other than modular centered on perceived regulatory restrictions.

According to North Carolina General Statute (NCGS) 143-341, all capital improvement projects in excess of $2 million on University of North Carolina (UNC) campuses, on state lands, or owned by UNC institutions must be administered through the North Carolina State Construction Office (SCO) (North Carolina State Construction Office, 2006). Additionally NCGS 116-40.6 provides that all UNC projects of $2 million dollars or less shall be administered by the UNC Board of Governors (North Carolina State Construction Office, 2006). However, the monetary value of any UNC project does not relieve it from, at minimum, being given a cursory review of building plans and specifications by the SCO (G. Driver, personal communication, January 8, 2014).

Accordingly, due to the statutory mandates related to UNC construction projects, many survey participants involved in such endeavors find the SCO administrative process rife with delay and frustration. That is to say, in the experience of respondents projects administered by the SCO are perceived to take an inordinate amount of time and effort in comparison to private development. Further details about the timeline and bidding requirements for SCO-administered projects will be provided in Chapter 5, Discussion. For these reasons, respondents to the survey cited anticipated regulatory hurdles as reason for not pursuing modular construction.

As mentioned, all of the respondents who had used modular construction were from ASU, the only institution in the UNC system that had used modular construction. All of the respondents who had used modular construction reported that both time and cost were their reasons for selecting modular; quality was not selected as their reason for choosing modular.

Of all respondents, 16% reported that they would consider using modular construction for a project within the next two years. The reasons for not considering modular construction for immediate future projects ranged from quality concerns to no plans for new development within two years. As an example, one respondent noted, “we tend to focus on buildings that have a longer shelf life,” indicating that they see modular buildings as less durable than conventional buildings. Additionally, one respondent replied “the only way we would consider it is in one community where we are focused on a developer quality to meet our financial goals and offer newer housing options. In this case, developer quality is synonymous with lower quality, at a discount rate. More detailed information on consideration of modular construction for future projects will be provided in Chapter 5, Discussion.

Part II: Interview Responses

Interview responses were analyzed for content and patterns, and categorized into thematic bins that denote the overall gist of a particular phrase, idea, or conversation. The categorical bins are *project duration, financial implications, quality assurance, regulatory concerns*, and *other*. These categories were used because each represents a major consideration that emerged as a decision factor for new residence halls at UNC institutions. Each significant data point derived from an interview was treated independently, and placed into the categorical bin that best matched the key idea presented. For example, a response to a prompt regarding the cost of modular construction might primarily fit in the financial implications category, but might also address quality assurance or project duration because the level of finish is a function of cost and time. This approach to analyzing qualitative data is a way of providing order and building a framework that presents the data in a logical manner. As Leedy and Ormrod (2010) wrote, qualitative interview studies generate such large volumes of information that wading through the information and distilling it into smaller themes is an essential process of data analysis.

The findings for this section of the study are presented in a hybrid narrative / question and answer format. Each thematic category is introduced with a brief overview of its content and context. The data contributing to that theme are then outlined in a question and answer arrangement, with a prompt from the researcher eliciting responses from interviewees.

Project Duration

When a UNC institution decides that it needs to build a new facility, one of the most important considerations is how long it will take to get the building built and occupied. Academic schedules are quite predictable, and follow similar patterns from one year to the next. At universities this means that new facility opening schedules often coincide with the academic schedule at that institution. If the building does not open on schedule, this results in a displacement of students and activities slated for that new facility. For the university housing office this is as much a financial concern as it is an academic one, because failure to achieve occupancy could result in a substantial financial loss for the department, in addition to inconveniencing students.

Accordingly, when planning for a new housing facility, the officials making the decisions must weigh each of these variables and set a course that will satisfy both their programmatic space needs as well as their need to have habitable space by a specific deadline. Extenuating campus circumstances such as replacing an existing building with a new one, or the impending closure of an occupied building due to regulatory pressure, often complicate these decisions. In light of these challenges, universities are constantly searching for solutions to circumvent anticipated scheduling problems. As evidenced in the answers below, attempting to cut time from a project's duration is as commonplace as it is contentious.

According to many individuals interviewed, the process of proceeding through traditional UNC channels with a new residence hall is usually a two year minimum commitment. As one housing director describes:

> It can be three to four years from the time you actually move into the building from the time you said "I want to do this." You spend your first six months hiring an architect; you spend the next year designing the building; then State Construction has to review what it is you propose, and make all of their changes, and if everything went perfect, they could do that in 60-90 days. If they don't like what it is they can send it back and that can take six months or a year, and that was pretty much the perception we had when we were looking at modular. Initially with State Construction, they were like "ehhhh, you'd be better off just building a traditional building because we know how that works." And at that time we needed some beds pretty quick. (Housing Director, personal communication, December 11, 2013)

The above answer refers to a modular project that was initially proposed through the traditional channels of the State Construction Office (SCO). That is, the project was presented to SCO to begin the planning process that would eventually result in design, contract, and construction. However, that particular project did not get built through traditional UNC means. Instead, the project utilized an unconventional, albeit completely legal, contractual arrangement whereby a building is funded by a private entity (such as the Wolfpack Foundation) and then leased to a university. A basic understanding of this process is germane to understanding other answers.

On the SCO website, there are a handful of resources describing the obligations UNC institutions have if they build a project that is not owned by the state. Basically, there are three options available to a UNC institution when it comes to building a housing facility:

1. Build a state-owned building on state land.
2. Build a building that is not owned by the state on state land.
3. Build a building that is not owned by the state and is not on state land.

Although the last option may seem unusual, it is actually a viable option where the UNC institution leases a building and property, and this lease holding is primarily for state (UNC) use. Usually the leaseholder is a non-profit foundation that is closely allied with the university, if not directly managed by the university, but this is not a requirement.

The second option, however, is the one that gets the most attention in this paper. In this method, a university will act through its foundation to build a project that is not owned by the university, but is constructed on university land. The foundation will own the building and will lease the facility to the university for a predetermined amount of time. Then, sometime in the future after the building is paid for, ownership of the building will transition to the university and it will become a part of the facility inventory on that campus. This practice is commonly referred to as “privatized building,” and the practice has generated tension between the SCO and the UNC system because it can be seen as intentionally bypassing the SCO and the legislative mandates within which it operates in order to build a project that is not of the same standard as other institutional buildings.

According to one university architect interviewed, since 2002 all of that campus's residential projects—four total—had been built using the privatized approach. These projects ranged from wooden, stick-built multi-plexes to low-rise apartments constructed with light-gauge steel framing. One such project, a stick-built apartment style building, was built in ten months from design to occupancy. The question was asked:

Q. Why were those projects privatized?

> It's mainly to get the buildings built in time for our needs. State Construction takes a long process [sic]. Our biggest problem here, and anywhere on a campus where you have students, is getting it done on time for the semester to start, and one month of bad weather can mess you up, so that's why having modular would be a consideration..... When we do our next residence hall that's something I may suggest, if it comes about in my time, now that maybe the state's receptive to it possibly. (University Architect, personal communication, December 18, 2013)

Other responses that dealt with project delivery time touched on the issue of privatized construction, but often they focused on the financial aspects of privatized development. However, there was sufficient mention of privatized construction throughout the survey sample to warrant a question on this topic to a representative from the SCO. Part of that individual's response addressed the theme of project duration.

Q: Many of the people I have been speaking to mention that it takes a long time to build a project going through SCO. So they often go through their foundations to build a

privatized project in order to save time. Have you had discussions with people about this issue?

> Yeah, they still do privatized construction. It's not the review that takes the time, what takes the time is the bidding laws. You know we don't write the laws, we just enforce them. So the bidding laws takes quite a bit of time to publicly bid, whereas privatized companies go out and hire somebody immediately. That can easily cut off several months in construction from bid time, several months in design, designer selection also. So those are two big areas that can benefit by going privatized. (SCO Representative, personal communication, January 07, 2014)

Financial Concerns

As the familiar saying goes, time is money. This homily rings true for UNC housing projects as well, and for a number of reasons. As described in the project duration section, many UNC institutions choose to use privatized construction on selected residence halls because it is assumed that the projects will get completed in less time. This shortened construction duration translates into lower financing costs and quicker income for the university. However, the durability and anticipated life-cycle of that building is also a contributing cost.

On one hand, there is the cost to operate and maintain the building throughout its life-cycle. The National Institute of Building Sciences (NIBS) reports that the cost to maintain a facility throughout its life can be as high as 95-97% of the building's total life-cycle cost (National Institute of Building Sciences [NIBS], 2014). With operating costs representing such a significant portion of the cost, it is logical that the UNC would want the highest quality, most durable, and most efficient buildings possible. However, there is the challenge of paying for this superlative building. Many UNC institutions simply have a hard time covering the initial investment, and the problem of future operating costs is somewhat dwarfed by the mountain of debt necessary to start the project.

Another challenge for housing departments at UNC campuses is that they operate as competitors with local property rental companies. Unlike most other university units, housing departments are generally revenue neutral, in that they generate the money they will use to operate and do not typically take from the university coffers. Accordingly, housing departments are trying to fill their beds, and in doing so must beat out private competitors also vying for student tenants. Of course, housing departments have some inherent advantages in that the university can stipulate that certain classes of students, such as freshmen, must stay in university accommodations for some period of their academic career.

Nonetheless, housing departments are still competing for non-mandated student renters while also trying to comfortably accommodate students and court future students to their respective campuses. Doing all of this means that the housing facilities must be up to date with modern amenities and space arrangements that suit their customer's desires. Offering communal bathrooms and multi-occupancy shared bedrooms is not favorable to the students who are checking into housing these days. Instead, they want suite-style and apartment accommodations typical of off-campus housing. The cost of these modern arrangements is added to what is already an expensive building, but forgoing this expense can result in lost revenue.

In the face of such challenges, housing departments are often compelled to choose what they perceive as the lesser of many evils. As the proliferation of privatized housing projects demonstrates, the choice usually trends toward a cheaper up-front cost; albeit a cost that includes the seemingly necessary amenities required to fill vacancies. However, the SCO does not seem convinced that this decision is always a prudent one.

> … the argument's always been about they do it cheaper and faster, and they do it cheaper, we (chuckle) I mean it, you pay, you get what you pay for. UNC, uh North Carolina Central, we built two dorms at the same time, one's called Eagles Landing, built on private land, private built. We built one exactly right beside it, state land, state built, they tried to sell it back to the state for in excess of $20M for a dorm that should have been built for $13-14M. We built the same number of rooms, a lot better construction, faster, for about $13-14m in that case, at the same time frame. So I'm not sure that argument holds much water, at least on that example. (SCO Representative, personal communication, January 07, 2014)

As referenced in the above comment from a SCO representative, the Eagles Landing project was a private housing endeavor that did not go well. In a series of articles published in 2006 and 2007, the *Raleigh News and Observer* reported on several code violations and building durability concerns voiced by the SCO after inspecting the facility (Blythe, 2006; Ferreri, 2007). Despite SCO concerns, however, NCCU officials still recommended purchasing the facility, and ultimately the university did.

With such deviation from SCO recommendations, the question lingers:

Q: What does it cost to build a UNC dorm, and why is it often so much more expensive than a privatized facility?

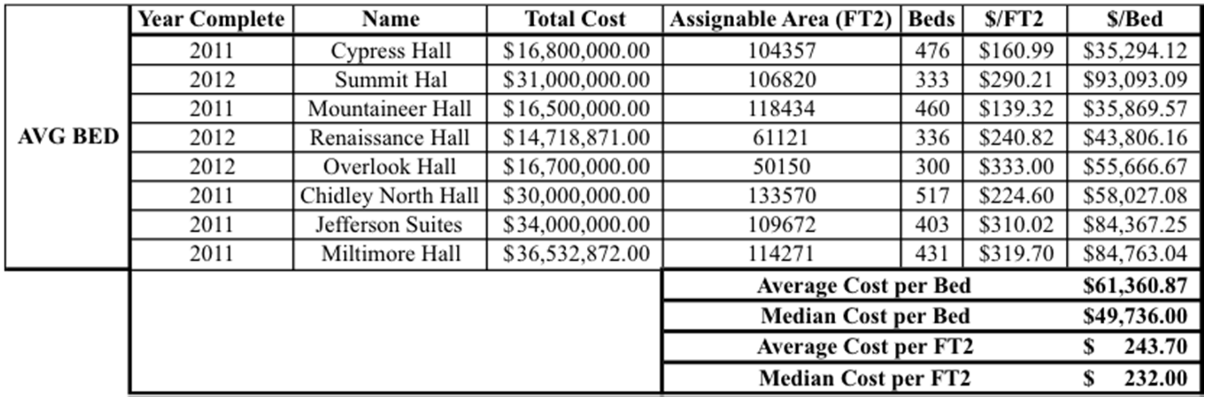
> A good example is things that we have to do that private communities do not. In a state owned facility—dorm type facility—we have to provide elevators, the code requires it. On a private community you do not. That's a huge cost that the residence

> people have to absorb. There's things in there like that that people overlook. That why's it costing so much? Again we have to obey what the code is, and that's a good example. (SCO Representative, personal communication, January 07, 2014)

This SCO representative's comment answers part of the question, but does not address the question of typical costs. According to the UNC Facilities Inventory, there were eight residence halls completed during 2011-2012 (data for more current years was not available). The costs for those projects are summarized in Table 2 (UNC, 2013).

As the data in Table 2 show, the range of costs varies greatly, and there are two extreme cases on each end of the spectrum. The Jefferson Suites dormitory at UNC Greensboro, Miltimore Hall at UNC Charlotte, and Summit Hall at ASU cost in excess of $84,000 per bed, while both Cypress Hall at UNC Pembroke and Mountaineer Hall at ASU each cost less than $36,000 per bed. The average cost per bed for dormitories built during this time was just above $61,000, and around $240 per square foot of assignable area.

Table 2. *UNC Housing Projects Completed in 2011 and 2012.*



	Year Complete	**Name**	**Total Cost**	**Assignable Area (FT2)**	**Beds**	**$/FT2**	**$/Bed**
AVG BED	2011	Cypress Hall	$16,800,000.00	104357	476	$160.99	$35,294.12
	2012	Summit Hal	$31,000,000.00	106820	333	$290.21	$93,093.09
	2011	Mountaineer Hall	$16,500,000.00	118434	460	$139.32	$35,869.57
	2012	Renaissance Hall	$14,718,871.00	61121	336	$240.82	$43,806.16
	2012	Overlook Hall	$16,700,000.00	50150	300	$333.00	$55,666.67
	2011	Chidley North Hall	$30,000,000.00	133570	517	$224.60	$58,027.08
	2011	Jefferson Suites	$34,000,000.00	109672	403	$310.02	$84,367.25
	2011	Miltimore Hall	$36,532,872.00	114271	431	$319.70	$84,763.04
				Average Cost per Bed			**$61,360.87**
				Median Cost per Bed			**$49,736.00**
				Average Cost per FT2			**$ 243.70**
				Median Cost per FT2			**$ 232.00**

Regardless of the construction method used or the per-unit cost, the total cost of these new housing facilities was substantial, and by no account has it become cheaper since 2012. Most of these projects were traditional UNC dormitory construction concrete and steel with a brick veneer, built to last 50-100 years, and adhering to the strict state and campus design standards guiding their creation. As one campus business officer described the institutional design paradigm:

> So I think that we've got this idea, I think a lot of campuses do, that we want to build the most durable product, but the reality is we can't afford what we want. So we're our own worst enemy. (Business Officer, personal communication, January 23, 2014)

This spokesperson went on to say:

> The interesting part is that we often get dictates that never have funding, and so as a department that's an auxiliary we have to figure out how to make that work financially. So we've taken on significant debt burden in order to meet those very high standards. (Business Officer, personal communication, January 23, 2014)

What this commenter describes is the persistent on-campus struggle between physical reality and financial reality. As mentioned, operational costs, longevity, and cohesive campus appearance are key indicators driving campus decisions. Universities want to have the most efficient facilities that last a long time and look similar to the other buildings on campus, creating an overall appearance of solidity and fidelity that provides reassurance as to the value of the institution. However, as the previous comments indicate, paying for those things is creating a fortress of debt as imposing as the campus is welcoming.

As one campus housing director describes, this balancing act is lopsided because the debt incurred by constructing traditional buildings exceeds the revenue they generate. This conundrum is influencing his office to seriously consider alternative construction methods, although this is met with resistance from other departments on campus and from potential designers.

> But I look at it as if it’s something that’s durable and workable and definitely more affordable, then that’s what it comes down to is being able to fund a project where right now the cost of construction exceeds the revenue that we could get out of it. Particularly if you're shooting towards single bedroom apartments or super-suite style; you make up for it if you're doing double rooms, but we're not doing double rooms. (Housing Director, personal communication, December 04, 2013)

Furthermore, he described how the department has been paying for housing facilities with respect to the life-cycle of the buildings.

> And we're paying for most of them with 30-year bond debt, so we're trying to run the life cycle a little bit beyond when the building was actually paid off, and then leave the future people the option if they need to tear it down, and build something totally different. Leave them that option, but don't build some steel and concrete behemoth that will be impossible to get rid of, but build something that's going to be sturdy in the meantime. (Housing Director, personal communication, December 04, 2013)

One university architect extended that line of reasoning beyond lifespan, to also examine the population of students housed in the buildings:

> Well that’s part of the reason our privatized housing is a 30-year construction, because it’s going to be turned over to the state at that point or does it come down? If

> the cost of it allows us, it may be cheaper to come down, and put a new one up, that's sort of the thought process we have. We couldn't afford to build a privatized housing to the 50-100 year. But every time we build one, we change how it's laid out because the students' needs are different; at least they think they are. The generations impact how we do business. (University Architect, personal communication, December 18, 2013)

The following comment laces several of the aforementioned arguments together in an effort to describe how, when all is said and done, it is the students who bear the brunt of the institutional financial woes, but the students are also inadvertently driving up costs.

> Honestly, my challenge, since I'm an auxiliary, [is] how much building can I build? For example, if I'm going to build a $33M dollar building, that means every student on campus has to pay $300-$400 more in rent so I can pay the debt on that building. If I can build a building for half that cost, and get that many beds out, that means I'm going to have to raise rent $150-$200 for every student on campus. You're looking at long-term versus short-term, but you have to be aware of the current dollar value of how much can you raise rent before you hurt yourself with the competitive market that you're in, and sure, for $400 what could I build? But the problem is, I'm not sure I'm building anything nicer, I'm just building something a whole lot harder and more durable for that. On the other hand if I can take that $400 and build a wood structure, steel frame, drywall, and I can put a swimming pool, and exercise rooms, and all of the things that the amenities that they're building off campus into the project, but on the other hand, why do I need that stuff when it's already on campus? Do I need a climbing wall in a residence hall when they have a

> pretty nice one sitting over in UREC? On the other hand if you're off campus, maybe a climbing wall is a good thing to have ‘cause you're trying to get people to live in your complex. So, what makes sense to build? What do these students need versus what do these students want, especially if they had to pay for it? (Housing Director, personal communication, December 11, 2013)

Adding to the argument that the initial cost of new residence halls is prohibitive, a representative from NCSU extolled the benefits of building a load-bearing concrete and steel shell with reprogrammable space in the center of the building, but lamented the debt accrued from such a decision.

> So we can modify that space pretty easily if we choose to do that without major problems with the structural integrity or anything like that, but it’s still going to cost us a bundle. If we chose that with our Wolf Village complex finished in 2005, we're going to have debt service on that building to 2028. So if I’m going to make a decision…. we’re going to be stacking debt upon debt, so that’s another consideration. So these battleships of buildings can be really expensive and [it’s] difficult to make those types of decisions because of the initial cost. (Business Officer, personal communication, January 23, 2014)

Further expounding upon the idea of reprogramming and renovating existing residence halls, or any other academic structure for that matter, this spokesperson from ASU described one instance in which the cost to renovate was prohibitive.

> What we've learned is it’s expensive to renovate and convert, we've found that in Broyhill when we made the decision that we were going to take it from being a hotel to a residence hall. For those 150 beds it was going to cost a fortune, because the

> building was built under 1960 hotel codes, and we were going to have to use it as a 2012 residence hall. All of the doors were too narrow; the bathrooms would have to be gutted because the doors in the bathroom wouldn't have been big enough. All the code changes that would have to be done, it would have just been easier to demolish the building and build a new building, for the hotel portion. (Housing Director, personal communication, December 11, 2013)

Continuing with this reasoning, the spokesperson drew upon other renovation projects to illustrate how renovations can be complicated by the fact that partitions were constructed with masonry walls in past decades, and the challenge this poses in terms of the cost and difficulty of installing new services through masonry versus drywall and framed walls.

> Let's think about what was designed 40 years ago. We've had to go in and knock out walls and renovate and do things to make them, put more public space in buildings, change how the bathrooms are done, change the plumbing, we've had to install sprinklers, we've had to do all that. Think about the cost of doing that in a building full of cinder block and concrete. Think about if you want to change the wall structure, where the walls are in a building that's drywall, how much easier that is to do that. So, the changing of the building design purpose in 10-15 years, you want to convert something or make rooms bigger or do something, it's a whole lot easier to do something with drywall than it is to do something with the block wall. (Housing Director, personal communication, December 11, 2013)

The needs of many of the operators in facilities management run counter to this approach of making UNC buildings more malleable. That is not to say that facilities managers are opposed to easier renovations and more flexible spaces, but rather that they are interested in low maintenance, a characteristic that is often lacking in lower-grade materials and finishes. As the SCO representative stated, there must be a balance between what is affordable and what will last through student use and abuse.

> A lot of things a university does on each campus is tailored toward how their maintenance department runs also. So many times housing, they have their need, they have their need of, “I need 400 beds in the fall extra,” but the…facilities management side has to look at, “I've got to maintain these things for the next 20 years,” you know. There’s certain things I have to have in there ‘cause it’s not cost effective to be, to put small single heat pump units in every room ‘cause that’s, its cheap up front, but the cost to run them and the cost for replacement is high, so you've got to get this happy medium in there. (SCO Representative, personal communication, January 07, 2014)

As the representative from NCSU points out, at least the reluctance on behalf of maintenance staff to use different materials and techniques can lead to a productive dialogue for making decisions.

> Or worst case they'll say “look, if you want to do this, this is the money you might save now, but over the course of ten years this is how much more you'll be spending.” So we can at least make a good decision as an end user. I think our campus has moved more in that direction over the last five years where our B, M, and O [Building Maintenance and Operations Staff] and our facilities folks are giving the end user more information in order to make a logical, wise decision versus a mandate. (Business Officer, personal communication, January 23, 2014)

One principal factor behind each of previous opinions was the balance between making the best use of money over the longer term, and making the best decision for current circumstances, both of which hinge on having access to funding. In 2013, the North Carolina Legislature passed House Bill 857 (HB 857) to provide some relief in that area. HB 857 is not solely intended to be a catalyst for providing alternative means of funding for projects, but rather is a means to provide NC public projects with progressive contract structures that were previously not available. One of the additional contracting methods legalized by HB 857 is the Public-Private Partnership (P3). P3s have been successfully used around the world for several years, and come in many arrangements, with a central focus on easing financial pressure on public agencies. Some P3s are development contracts that allow a private developer to provide partial or total funding for a public project in exchange for some form of compensation that may come from operating the facility, exacting fees from the facility's use, or some other method that allows the developer to recoup their investment and earn a reasonable return (National Council for Public-Private Partnerships [NCPPP], 2014).

HB 857 has provisions for development arrangements through P3s and allows NC public agencies to enter into contracts with private developers in order to fund new public projects. Conceivably, this new arrangement could benefit UNC housing offices and assuage their concerns regarding up-front costs for new residence halls. However, as a representative from NCSU points out, if their university is relying on a developer to front the cost for a project, then the university is bound not only by UNC and campus design standards, but also by the developer's need to make a profit.

> There's a constant tug between what <u>should</u> the state be allowed to dictate, and really who is the primary beneficiary of these decisions? So, if the goal is for us to replace buildings on the dollars of the developer, well that's fine, but realize if the developer

> is carrying my cost, it's going to be more expensive and I'm probably not going to get the product that I ultimately wanted. So if we were to go out to a developer on a typical residence hall there is no way that a developer would accept, nor could we afford to build at, the standards that we've been building for the last 25 years. We need to make that a less durable construction in order to make that all work, to make the numbers work, because the developer's going to get paid, and the P3 is one of those pieces where someone else might help us fund this but it's still our obligation. It's still on the books, and we might have a product that's a little more challenging to manage. (Business Officer, personal communication, January 23, 2014)

As this representative illustrates, innovative funding streams could just as easily introduce new layers of complication that add to the complexity of building a project that is acceptable to all parties involved. During the same conversation the representative also highlighted how university housing departments generally have greater flexibility in pursuing innovative or alternative technologies and practices because their funds do not come from UNC General Administration (UNCGA) appropriations. Due to this financial independence, housing departments do not receive as much scrutiny because they are not spending taxpayer dollars.

> It helps when you actually have money. If I were managing a state-appropriated building project, I think I'd lose a lot of the flexibility to try new things because there's a higher standard of care. Folks will say, you know, "these are state funds, how can you consider something that's cutting edge and not tried and true?" With a housing project, I think we have a little more flexibility just because of the flavor of our money. Our auxiliary funds are a lot easier to spend on really anything. (Business

> Officer, personal communication, January 23, 2014)

On the matter of finance, perhaps one of the most illuminating, although simple, comments came from a representative from WCU:

> Anything that’s appropriated dollars, you need to last as long as you can get it to ‘cause you don't know if you'll ever get another penny. It’s tied to where the source of money comes from. Privatized, all our self-liquidating, non-appropriated dollars, they go out and borrow money, or they pay it back with student fees and all that kind of stuff. State-appropriated projects you may not get anything [more] in 100 years. (University Architect, personal communication, December 18, 2013)

Quality Assurance

> There’s kind of a paradigm push back, because people think of modular and they kind of cringe…’cause it’s something they're not used to. (Housing Director, personal communication, December 04, 2013)

From all of the data gathered via the interviews in Part II of this study, one resounding constant is skepticism about the quality of modular construction. Despite the pervasiveness of this attitude, most subjects conceded that they have no experience with modular, and that their exposure to it is limited to the modular housing industry that they have observed from a distance. Interestingly, opinions about the poor quality of modular construction are held alongside a disdain for the slow, traditional process of state construction and the burdensome challenge of financing institutional buildings. To sum this contradiction up, modular construction is perceived as low-budget, substandard quality, and institutional buildings are perceived as overly-expensive, over-built behemoths. Common ground between these two perceptions exists, but not everyone knows how to get there or what it looks like.

Many of the excerpts selected for this section speak to the perceived quality of modular construction, but many more are concerned with building maintenance, and what challenges might result from different material choices. There is also concern about changing the paradigm of UNC or campus-specific construction so the inclusion of modular or some other alternative construction technique is not challenged from the administrative side. Ultimately, the constant throughout this section is uncertainty. Uncertainty about what something that is not tried and true will look like, how it will perform, and if students will like it. Uncertainty about getting the project approved, and whether the university will be able to promote the project as a point of pride; and ultimately, uncertainty about design and construction.

When speaking with one campus representative, it was asked whether modular construction had been considered for residence halls. The negative response was accompanied by the following rationale:

> Our standard up until probably this year has been to build a structure that is a 80-100 year, you know, encasement there. So if we're looking at that type of duration or durability then for us it's very much been block and steel. The other part was that our campus standards didn't really reflect the ability to use that type of design. We've got a very involved office of university architect and a master plan that kind of dictates what is expected or what has been expected…the other reason that we haven't considered modular is that we're a little concerned about the quality of that construction, and you know honestly the only experience that we've seen is very

> much on the residential side, but often modular homes look a little too cookie-cutter and a little too, I guess, boring for us, and we didn't really see the value in that. I know App has done one, and I haven't really heard how that project has rolled out after opening. I know that initially Tom Kane was very excited about it, but I had also heard that State Construction wasn't terribly excited about it. So we don't like to put ourselves in a situation where we get more oversight from state construction than we absolutely have to. (Business Officer, personal communication, January 23, 2014)

These remarks are fairly indicative of the opinion of modular throughout the UNC system: UNC builds higher-quality buildings that last 100 years; modular design is not congruent with campus design standards; modular is of lower quality; modular is not compatible with the SCO standards.

When describing the challenges affecting a proposed new housing development at UNCCH, a spokesperson from the campus questioned the mandated standards of today's UNC buildings, while also boasting about the oldest public university building in the US.

> Because this one's coming kind of in the middle of campus we've been trying to change the paradigm at the state level that every building needs to last forever. They call it "institutional construction;" I call it industrial strength, 'cause I think they kind of over play it. Keep in mind that our oldest residence hall is now officially 225 years old. (Housing Director, personal communication, December 04, 2013)

The 225 year old building referenced by the speaker is Old East Hall (Figure 21), the first UNC building, which was finished in 1795. The building is a brick structure with other wooden framing, and has been modified innumerable times in the two centuries it has adorned the UNCCH campus. Old East Hall still houses students, although it is as much an artifact as it is a functioning residence hall. Nonetheless, Old East is proof that buildings can last for over a century if built well and cared for properly. However, as one individual points out, the model of building and maintaining facilities for decades or a century is not always practiced as well as it's written:

> On our campus we've got one building that was built in 1901 and we've modified that building significantly but it's still got some historic features that we really like, but it was built really well in the 1900s. We have other buildings that were built in the [19]50s and [19]60s and we've found obvious—well I don't know if it's obvious but painful—that those buildings were not built as well, and we have more issues with those buildings than we do with our old block buildings. (Housing Director, personal communication, December 04, 2013)

Figure 21. Old East Hall at UNC Chapel Hill (UNC Chapel Hill, 2014. Reprinted with permission).

Consistent maintenance is a basic requirement for the longevity of any building, and it must be considered before the building is built as well as while it is operating. The SCO contends that durable materials and finishes must be specified for UNC projects if the building is to last for the desired length of time. Despite this policy, the SCO has also reduced its quality standards for some materials and systems used in privately funded UNC residence halls. Table 3 contains the refined SCO standards applicable in these instances. A representative from SCO described these choices, and the decision for making them:

> Because they were having so many problems, with us going out and inspecting, and finding so much not built to code, what we do now is they actually meet up front before they start building a project, we look over what they've got, we do a full review, a full inspection like we would any other project, ‘cause typically it’s rare it’s not built on state land. So we're doing a full-blown review, full blown inspection. We’re not building it quite to what we would, we're reducing some of our requirements. An example is we would use cast iron piping, they want to use PVC [Polyvinyl Chloride]. We use EMT [Electrical Metal Tubing, for wiring], they want to use MC [Metal Clad wire], we won't let them go AC [Armored Cable wire], just ‘cause the ground’s too small. It doesn't give them the flexibility in the future for their buildings, but what it does provide them is a good quality building that is still built above code standards, and it’s still a very nice facility for the students to use, and it gets within their budget, which, because they're competing against private individuals around for the students living quarters. We work a lot closer now than we used to, more as a team, and that's happened over the last 5-6 years. (SCO Representative, personal communication, January 07, 2014)

Table 3. *SCO Relaxed Design Standards for Privatized UNC Housing Projects.*

COMPONENTS	BASE	POSSIBLE UPGRADE	NOTES
Structural Framing Systems	Steel with exterior metal studs and wood interior framing	Steel with metal studs	Careful consideration should be observed about the use of Masonry shafts due to incompability
Exterior Cladding	Brick veneer with cast stone trim	NA	
Exterior Cladding	Reduce Curtainwall to storefront/steel frame.		Main entrance only
Roofing System Slope	30 Year ashpalt shingle	Metal/Slate	
Roofing System Low Slope	20 Year Single Ply	30 Year Buildt-Up Roof	
Interior Wall Systems	Regular 5/8” drywall	Impact Resistance Drywall	
Doors and Frames	Closet doors only six panel residential. All others solid core	Solid core wood doors at entrances and bedrooms Closet & bathroom doors solid core / six panel residential	
Windows	Vinyl	Aluminum	
Cabinetry	Residential Grade	Finish	
Fireproofing	To be per NCBC, no exceptions		
Fire Sprinkler System	NFPA 13R (up to 4 story building)	NFPA 13 Light Hazard	Must use NFPA 13 in all common use areas
Waste Piping	PVC pipe	Cast Iron	Must use cast iron on all waste verticals & under building elbows/horizontals

Table 4. *SCO Relaxed Design Standards for Privatized UNC Housing Projects.*

COMPONENTS	BASE	POSSIBLE UPGRADE	NOTES
Site Waste Piping	PVC pipe	NA	Must use cast iron or steel sleeves under vehicle traffic area
Water Distribution	CPVC or PEX	Copper	PVC not allowed
Toilet Type	Tank Type	Power assisted flush	
Hot Water Distribution	Individual Electric water heaters	NA	Must meet the 30% energy mandate for whole building
Mechanical Systems	PTAC	Four Pipe Fan Coil	
Telecom & Low-voltage wiring	Plenum rated wiring		Where plenum ceiling exists only, supported in accordance w/ NEC
Electrical Wiring	MC Cable, 1/2", up to #12 AWG Solid copper w/ ground	EMT	Must use EMT in all common use areas
Fire Alarm	Plenum rated wiring	Red MC Cable	Can use as specified in University Guidelines
Service Feeders	Aluminum Feeders > #1 AWG	Copper	
Main Distribution Panel	Load-center Panels	Copper Bus, Bolt-on Breakers	
Transformers	Aluminum Feeders	Copper	

Note: Apply only to Privately Funded UNC System Dormitory buildings, Chancellors' residences and Park Rangers residences. All others must acquire SCO approval

The SCO representative contended that the lesser standards do not compromise on items required for safety and that they specify a certain standard of durability that must be maintained in order to please new students and concerned parents.

> Which is why we have the lesser standards, that's the whole nexus of that trying to take care of their needs but also keeping in mind that maintenance is a huge cost. I was a student at one time and sometimes students are about the same mentality of prisoners, they tear things up. So if you build it cheaply, you will repair it more expensively. You got to make it a little more stout if you want it to last any time at all… and you know it may look good for four or five years, that's one group of students who have gone through it. But seven, eight years down the road you got to think paint's not gonna cover everything. When momma and daddy brings their students there to look at their new housing, they want it to look nice. And if you build it to minimum code they're not going to like that. It's not gonna fly 'cause it's gonna be tore up by then. (SCO Representative, personal communication, January 07, 2014)

As with any other aspect of a project, there must be a balance here as well. As a housing director illustrated, a concrete block wall may be ideal for maintenance because students cannot easily put holes in it and it is easy to paint and clean. However, block walls do not bode well for curb appeal, and new generations of students want soft, comforting surfaces in their rooms, so painted drywall is becoming the standard.

> Anyplace you put drywall you're going to have more maintenance than you do cinder block. But obviously cinder block is institutional in appearance, students don't like it, and it's more expensive than drywall. I mean, you're hiring a mason and buying the

> materials, it takes more time, it costs more money than putting metal studs or wood studs up in a building, and drilling drywall to it (Housing Director, personal communication, December 11, 2013)

Concerning maintenance for a modular residence hall, below is an account from an individual who is closely associated with the operation of Mountaineer Hall at ASU (further detail of this project will be provided in Part III).

> Here's the things we learned from Mountaineer. Obviously it's noisy, noisier than we thought it would be. Even though there is space from one floor to the other because each box is its own frame and all that, that plywood, even with carpeting on it, and in rooms the vinyl flooring, people below can hear the noises. We knew it wouldn't be soundproof, but we didn't know it would be so prominent. So we would be looking at probably putting in some gypsum board or some additional layer on the floor to try to create some additional sound deadening in the buildings, but that is probably, the noise is probably the only thing. And I tell you the texture on the walls, we're using, we call it an orange peel… it's hard to match when there's damage. So we need to figure out what should we use in its place. But what would be the plaster finish we would use that would be easier to match on that? The mere fact that it's drywall, and there's students living in there, there's damage, not like cinder block that people can bang their heads on, they can punch it, they can kick a ball into it and nothing happens to it. Drywall, even if you get hardened drywall, if you hit it hard enough you can make a hole in it. And so, if you put something on it, even these Command strips from 3M that they say you can take them off …we find it takes the finish off,

> sometimes even the paper on the drywall (Housing Director, personal communication, December 11, 2013)

Regarding the overall quality of modular construction, the following was said about Mountaineer Hall:

> I think that there's a general assumption that you say to a company that I want to do modular, and we think modular homes. That it's substandard lumber, that it'll rot. They're using the cheapest windows, the cheapest light fixtures, the cheapest toilet fixtures and all of that. When we did our project we went and looked at a mock-up, we picked the windows that we wanted, we worked with them to pick the A/C units that we wanted. We looked at the light fixtures, we stood in the shower, two of us, to make sure the floor didn't flex in that shower, because everybody knows, if a guy and a girl get in there together, and it pops that floor down, and that drains now not connected, you've got flooding. We monitored what we got, and I'm pretty satisfied that the stuff in [Mountaineer Hall] is of equal quality to anything we have anywhere else. And they used some products that we typically wouldn't be allowed to use: they used PEX for the water, where we have to use metal; there's nothing wrong with PEX. (Housing Director, personal communication, December 11, 2013)
>
> I think people have been surprised that [Mountaineer Hall] looks as nice as it does. When we've taken people in to look at it, you have to describe to them how the modular thing works, cause they're "this looks just like a regular building." They expect something different. I mean, it's kind of funny when you sit there and say this was on the back of a truck, and they say where, and you say imagine a tractor trailer, imagine there's a long thing, imagine there's a wall here, and a wall there, and this is

> what was put into place. And then once they visualize it they say “well, that makes all the sense in the world.” (Housing Director, personal communication, December 11, 2013)

Regulatory Concerns

> To be honest with you, the lawmakers of the state are the most detrimental thing that we have in our operation. They are destroying us [to] where we can't do our job. They'll come up with a law, but they'll mark no resources to comply with it. It’s all they seem to be doing, and they've been doing that for as long as I can remember. (University Architect, personal communication, December 18, 2013)

If that introductory comment seems a bit jaded, that is because it came from a true veteran of UNC design and construction who was ready to retire after many decades in the business, and he is indeed jaded. However, the comment is somewhat suggestive of the sentiment towards regulators that I found throughout the UNC system. On one side of the argument you have the design and construction operators at each UNC campus who are frustrated with the SCO and the NC Legislature. On the other side is the SCO, which is firmly planted in the “we just enforce the laws, we don’t write them” rhetoric, all the while trying to appease both the lawmakers and the UNC institutions who are their customers.

The SCO inevitably takes most of the criticism for the way that UNC construction projects flow, and for the implementation, or lack thereof, of new and innovative processes and procedures. Whether that blame is rightly placed or not is not for this paper to adjudicate. However, to the extent that the battle-weary employee responsible for the introductory comment has insights into this argument, he contends that the SCO does a fine job, and that they are not solely to blame for inefficiencies or ineffectualness.

> They're changing, but not at a real quick pace because of resources. But they see where things can be improved. My hats off to them there. I don't see the resistance to want to change, I'm seeing more resistance of how do we get there from here and still keep serving everyone? (University Architect, personal communication, December 18, 2013)

The general regulatory climate governing UNC construction projects is lamented for a number of reasons, but the main complaints are slow processing and excessive bureaucracy. The processing time for projects has already been addressed, and the bureaucratic aspect has been touched on by different participants. The procedures required to work on government projects are tedious, but the general intent is to provide fair competition in the marketplace and to ensure that state resources are effectively utilized. However, the laws governing the letting of public contracts can at times be counter-productive, as was demonstrated by the following comment:

> You don't get prices on the design, all you do is qualification-based selection. There's not a fee [restriction] that's not a law, [it is] only on contractors that we have to take the low bid. We're able to prequalify the contractors, but we use the state's formula and format, and it's a little less restrictive than mine, but we have to use theirs in order to be protected. Even when you prequalify, the only thing you're knocking out are the ones who aren't a contractor, it doesn't really tell how good they are, you can still get burned. (University Architect, personal communication, December 18, 2013)

That comment referred to the practice of selecting designers for public projects based solely on the appeal and merit of their proposal, with no provision for selection based on the cost of design services. Nonetheless, design fees are well-established percentages that are levied fairly for all design services rendered, and it would be incorrect to suggest that design firms are able to charge any fee that they want. However, it still holds true that contractors or subcontractors, the companies that will actually perform the work, are selected solely on the basis of cost. In NC public projects, the lowest bidder always gets the contract (North Carolina State Construction Office, 2006). Although contractors can be prequalified, this is essentially an entry-level, nominal qualification that precludes firms that do not have the financial wherewithal to handle large, complex projects. Thus, prequalified contractors with the lowest bid are awarded the contract for their proposed scope of work regardless of whether a more qualified firm was vying for the same contract. To summarize, universities can hire the designer that they prefer, but must take the cheapest contractor that submits a bid.

Despite that fact, there are contracting methods that allow for the selection of a construction manager on a qualification basis. In one of several variations of this arrangement, the construction manager acts as the general contractor for the project, and is a professional partner acting on behalf of the owner through the design and construction phases of a project. One method of this variety that is common on UNC projects is the Construction Manager At-Risk contract that was described by a UNCC representative:

> So far everything we've done for big projects has been CM At-Risk, which is a little different from Design-Build if you're not familiar with it. Basically you hire an architect and a big construction firm, but they sort of act like a GC, so you bring them in early and you do a preconstruction period where you design the building together for three months, and then you put together a package, you divide the building up into packages, and you go out and bid it. So you get blind bids on bid day and whoever is

> the low bidder wins the package, so the challenge is the contractor doesn’t get to pick his subs, he’s stuck with whoever is the low bidder and those are his subs, and he has to provide a guaranteed maximum price. The advantage is that they have some contingency and some other things that they allot for because you negotiate their fee up front so you don't get change ordered to death and all those things. So it ends up that with the preconstruction period having that time to figure out, to have them on board when you're pricing the building, and having the time to plan through, and think about what you’re doing, and sequence the steps before you ever break ground, or even bid it has been hugely valuable to us. We've looked at hard bidding a few things because we probably pay a little bit of a premium for CM At-Risk, but we feel like we’re getting what we pay for. (Housing Coordinator, personal communication, December 13, 2013)

In addition to CM At-Risk and Design-Build (DB) there is an Integrated Project Delivery (IPD) arrangement. It is outside of the scope of this report to go into detail about each of these contracting methods, but they do warrant a concise explanation. In a DB or IPD contract, the common practice is to hire one professional firm, usually a large construction firm, and this firm has the only contract with the building’s owner. This firm then contracts with designers and subcontractors for their respective scopes of work. DB and IPD contracts are usually regarded as more progressive contracting methods that result in higher quality and more successful projects due to the early involvement of all key stakeholders. With the recent addition of HB 857, NC law allows DB and other contracting methods that were previously unavailable.

> It just passed, in July, actually August 8th, August 18th, I forget the exact date as the

> effective date. Design-Bid, Design-Build, Design-Build Bridging, and Public-Private Partnerships....it’s HB 857….Representative Dean Arp, he's kind of the one who pushed it, done a good job. As in any legislation, everybody doesn’t get everything they want, but it’s a good start. He dealt with municipalities, state agencies, universities, designers, construction contractors, so he had a good collaborative effort to write that bill. (SCO Representative, personal communication, January 07, 2014)

A representative from NCSU also regards the new legislation as a positive sign that NC lawmakers are enacting laws that make public projects easier to build:

> In our current environment, there seems to be more openness to, say, a developer approach. I know that we've just recently had legislation on P3 so the encouragement to get external entities to assist us in building and ultimately managing projects, so that's been one direct example where I think things have loosened up a bit. (Business Officer, personal communication, January 23, 2014)

On the topic of modular construction within the confines of NC regulations, a representative from UNCCH sees the modular process as incompatible with existing procedures:

> Because you're getting the modular unit including your wiring conduit and all that already ingrained and in the walls and stuff and the normal paradigm is build the wall, inspect, run the conduit, inspect, pull the wiring, inspect, and so it’s a different way of them looking at things. And I think they didn't have systems in place to do that when App State was in the game, and so they struggled with that a little bit (Housing Director, personal communication, December 04, 2013)

That interviewee was referring to the typical building and inspection process on UNC projects, and how that process differs from the procedure used with modular buildings. This topic was breached with a representative from the SCO, and in his opinion the SCO had not been approached on this topic, and would not be opposed to an unusual inspection schedule as long as it was preceded with appropriate planning:

> Its never been asked that I know of, it may have been assumed that we wouldn't [approve a different inspection schedule], and I'm not sure that we would. I don't know where the factory is going to be at; we obviously aren't going to go out of state to inspect a factory unless I have more manpower. On the electrical side I only five electrical inspectors that cover the entire state, so, it, um, they're very busy, and it just depends on, I would say it's project specific, which is what's true on most projects. It's not a cookie-cutter, construction's not cookie-cutter typically, so, um, I'm not sure we've ever been asked that question. I'm pretty sure we could probably work it out, it's just planning would probably solve that problem. (SCO Representative, personal communication, January 07, 2014)

Regarding modular construction in general, the SCO representative claimed that the building simply needs to meet the same requirements as other state buildings:

> As long as it meets the building code. I tell you it has to meet the building code, but our standards are a little higher than the building code. Building code's obviously the minimum, we don't build to the building code. So if it can meet our standards and the building's construction can last for, you know, a full service of, what we consider the full service of the building, I don't know if we would be opposed to it. We don't typically tell people what they can't build; we review what they submit to us and inspect what's on the plans. Now if it's just, if it won't work, we will tell them it

> won't work. (SCO Representative, personal communication, January 07, 2014)

A representative from ASU who had been in part responsible for the construction of the modular Mountaineer Hall (which was not built through regular state construction) had been contemplating another modular project, this time with steel modules, and had some initial conversations with the SCO regarding this new proposition. He recalled a recent conversation with representatives of the SCO, and reported that it seemed as if the SCO was more receptive to the idea of a modular project than he remembered from the past:

> We know that a modular construction building is not a 100-year building, and typically we've been required to build concrete, and steel, and hard, and typically the building will last, go through two renovations, after initially opening, maybe as many as three before you could think about demolishing it. By acknowledging that we could use steel frame construction, they're basically saying we'd be okay with a 40-year building, with the understanding that at the end of 40 years we probably will not need this building any longer. So the fact that state construction has impressed that opinion upon us, that's a big change. (Housing Director, December 11, 2013)

The idea that getting the SCO on board with a project is the major hurdle seems to permeate the UNC system, and the SCO is sometimes incorrectly substituted for NC law in all issues related to state construction. Although in reality the SCO is an administrative office that serves as somewhat of a liaison between the NC government and the governmental agencies building the projects, it is sometimes viewed as the sole arbiter that will bless or condemn a new project. One university architect clarified the position of the SCO, specifically with reference to modular:

> They're subject to the legislature, and laws and regulations, and they're doing what

> they're told to do or asked to do with regard to the regulations and their liability. That's why if I was in their shoes I'd want to do the same thing. It's just how to expedite it more, and they've improved drastically in their process, but they have limitations on what they can do. The problem that I see with modular and the SCO is they want to see it. It's all built in a factory, and they can't inspect every detail of it. I think that's probably the biggest [problem], the inspection process more than anything else. I don't know where they stand with modular [in] regard to building codes, state building codes. (University Architect, personal communication, December 18, 2013)

He continued:

> If we go privatized we have more flexibility, but we still have to comply with the SCO standards and requirements, and that's the main reason we haven't investigated it because I'm not sure they're on board with it or not. That would be my only reason. That's always with self-liquidating, non-appropriated funds to build it, but if we go through the state to get approval per se, and bid it like we normally do, then we would have to comply with their regulations for sure, and I don't know where they are with regard to modular construction. (University Architect, personal communication, December 18, 2013)

Other Comments

Interview excerpts in this category are varied and cover content closely related to the other categories. There were comments about the SCO; people lambasted the requirements for state buildings; and there were generalizations about the habits and expectations of current college students, and how this should have greater influence over the design of student housing. However, there was also deep insight into the current status of the construction industry, and some praise of modular construction. Ultimately, these data do not fit neatly within the other categorical bins, but the content is so rich that this report would be incomplete without their inclusion.

> I can build the most modern building for housing in the world today, but I can pretty well bet that 18 year-olds 30 years from now won't like it. So what good is it? I mean, it really becomes an issue of how many, education is changing, the world is changing, at what point, and I don't think I'll see it in my lifetime, but we talk about online education, will there be housing here in, say, 50 years? Will students even come to the campus? Will this whole campus be obsolete in 50 years because we do it a whole different way? I don't know. But I do know that saying I'm going to build a residence hall that's going to last for 100 years is pretty impractical. (Housing Director, personal communication, December 11, 2013)

As that comment suggests, the American educational model that has existed for over a century is changing. Online educational opportunities are expanding, and there is an increasing reliance on electronic resources. There are buildings from the 1970s that were designed for 80 to 100 years that have been demolished after only 40 years. The building model that was established during that time is now being tested as institutions are deciding to renovate buildings that are out of date, or demolish them.

> It's that need to have to build everything to last forever, and in reality, buildings, residence halls in particular, shouldn't be built to last any more than I would say 30 or 40 years; they lose their effective usefulness at that point. As an example …we have family housing that was converted… to undergraduate apartments, and they're small

> buildings, they could be bomb shelters, because they're all brick and mortar and all. But they lost their useful life probably 10, 15, 20 years ago, and these are the ones we're closing down now. They're about, I'd say, 50 years old…, and they need to have sprinklers installed in order to keep them open, that's obviously a UNCGA mandate. It's cost prohibitive and, well, it's just a stupid waste of money to put sprinklers in these buildings because they're too small and cramped, and they don't have, we have wireless in there, for example, because we can't pull actual data connections because of asbestos…so, the useful life of a residence hall is fairly limited compared to some of these other buildings they want to stand forever, and that's a challenge that we find ourselves in. (Business Officer, personal communication, January 23, 2014)

Talking about new projects on the campus of UNCC, one representative reported that they have constructed 50-year buildings that seem to be a happy medium between traditional state construction and developer-quality apartments.

> The lifespans are designed for, they're 50-year buildings. You could probably squeeze a little more out of them if you had to. They're certainly not like stick built wooden construction that you see in most garden apartment complexes, it's going to last longer than that, but you're not going to get 100 years out of it, like the state construction office usually wants. We've got four high-rises on UNCC's campus that were built from [19]68-[19]72 that are 100-year buildings; they're poured-in-place concrete high-rises that in 1970 were state of the art, they had A/C that nobody had ever heard of. Now, they're so outdated 40 years later that we're having to completely gut them, what we need to do is tear them down, but to try to build a 100-year

> building is completely ludicrous. Who knows what the building is going to be, what a campus will look like, in 50 years? (Housing Coordinator, personal communication, December 13, 2013)

The 50-year buildings in question were built with steel panelized walls with a metal deck and concrete slab at each level, steel-trussed shingle roofs, and brick veneer. These buildings are quite stout, and the idea that they will last any less time than the earlier cast-in-place concrete structures is one that will have be tested by time (Figure 22). One drawback to the panelized approach used on these newer buildings, and to any innovative, unpracticed method, is finding the appropriate contractors to do the job.

Figure 22. Residence hall phase XIII at UNCC during construction, October 2014 (photo by author).

> One of your constraints... you've got to find people here who know how to do it, and you've got to have a local contractor who understands the system, that's built one, and you don't want to be their laboratory; you don't want to be their learning curve. We've had that with the panelized guys, several companies will tell you "yeah, we know how to do it," and we found one that really, really didn't, and we had to ask them to take a hike and brought on a company that did. (Housing Coordinator, personal communication, December 13, 2013)

Figure 23. Holshouser Hall at UNCC, one of the cast-in-place concrete buildings from 1972 currently being fully renovated (UNCC, 2014. Reprinted with permission).

On the topic of finding the right people for the job, a representative from WCU noted the particular challenges that his campus has faced due to geographical isolation, and a general shift in construction management techniques:

> Our labor force is limited and contractors, if they're not familiar with our region, will come in not listening to us because they need to be aware of that. Then they come down to the wire [and] they have to bring people in that don't know the area, and that's usually our biggest [problem], the labor force can be bad. Deliveries used to be a challenge, it’s not as bad as it was. People know where western NC is now, but those two factors, deliveries and labor force. The other challenge is if you get a contractor who really doesn't understand mountainous regions and construction, and the site can impact. And our weather, it impacts this time of year, it’s very unpredictable how much rain and snow we get, and it can delay us if they don't get started at the right time. I'll be honest with you, part of our biggest problem, not necessarily the region, is that contractors more and more have less ability to manage the projects. The ones we seem to be getting, they let the subs run the job rather than the contractor, superintendent, project manager run the job. It's not across the board, but we're seeing that more and more. I don't know if it’s due to a lack of education and understanding of how projects are to be handled, or what it is, the trades of course are just not taught like they used to be in my early days. They were taught how to do mechanical, now they just have people working and they've no idea about the systems they're putting together. The head guy may know, but the workers aren't all trained as they should be, they're learning on the job. (University Architect, personal communication, December 18, 2013)

Regarding innovation at the UNC and state level when it comes to trying new things, one representative from NCSU claimed that the state is paying more in the long term simply because there is a dearth of resources at present. In his opinion, if UNC and the SCO were allocated more human resources, and support for those resources, then NC would benefit from more innovative and efficient processes.

> There's a challenge that we have in that there's not enough staffing to really do things right. Like, the state inspectors are only a handful for the entire state, so they want to keep things as simple and consistent as possible, and when you throw a project in that you have to look at from different points of view, a different perspective, and a different process, that just complicates their lives, and so they want to stay away from those because they don't have the staffing and the resources to actually do things right. I think frankly if there was enough folks behind the operation to actually explore these alternatives, I think the state in the long term would save money. Everything is really into this inspection process that's been there forever. And I don't dis [respect] state construction [SCO], I think they've got a pretty tough job, and there's some good people over there, it's just that the processes that are in play, and with that said, they don't have enough opportunities. It's almost just like if we had the resources we would be looking at things in a different way, but we don't, so long term it may cost the state. If you use this in an aggregate sense, it would cost the state some money simply because they don't have the resources to venture out and try something different. (Business Officer, personal communication, January 23, 2014)

Along those lines, a representative from ASU who worked on Mountaineer Hall claimed to have had an experience with the SCO that is consistent with the previous remark:

> Because no one had done a modular project previously, SCO was pretty well telling us they were going to move slowly with reviewing, and thinking about it, and looking

> at code issues. Whenever you're the first at something it takes longer, and so, in that particular case we were looking to move as quickly as we could, and obviously there's a natural conflict between us and what SCO wants to do. (Housing Director, personal communication, December 11, 2013)

Lastly, this comment about modular construction is not necessarily an endorsement of the system, but it demonstrates that some people in the UNC system who have not used modular at least understand some of its merits.

> There's some advantage to it because you can build in a factory somewhere, dry, your conditions are favorable at all times. Shipping it would be an issue. Sometimes designers don't want to use it because it might mess up the look of their building, but I've see some pretty good looking modular construction. (SCO Representative, personal communication, January 07, 2014)

CHAPTER 5: DISCUSSION

Part I: Discussion of Survey Findings

The quantitative data provided by the survey begin to answer the research question:

1. What is the current status of modular construction for university housing projects across the sixteen campuses of the UNC System?

However, interpretation of the accompanying qualitative data is necessary to get at the root of the issue. For example, judging solely by the responses to survey question four (which directly asked if the respondent's employing institution has used modular construction; see Appendix A for further detail) it appears that four campuses throughout the University of North Carolina (UNC) system have utilized modular construction (Table 5). However, answers to subsequent questions revealed inconsistencies that suggested a misunderstanding on the part of the respondent. Question four is the line of demarcation in the survey between modular users and non-users. After question four, survey participants were asked different questions based on their answer to number four. The questions that delved deeper into modular use at each institution revealed that some respondents had misconceptions about what modular construction is.

To illustrate this point, one respondent from the University of North Carolina at Charlotte (UNCC) gave the answers in Table 6 (questions are simplified for brevity, see Appendix A for further detail):

Table 5. *Abbreviated Survey Questions and Answers, see Appendix A for Full Text.*

Number of Responses			**19**
Q#	**Qusestion / Answer**	**Responses**	**Rate**
Q1	**Occupational Title**		
	housing	6	32%
	D+C	5	26%
	facilities	7	37%
	business	1	5%
Q2	**Time in current position**		
	<1	0	0%
	1 to 3	2	11%
	4 to 6	5	26%
	> 6	12	63%
Q3	**Time in the professional field**		
	1 to 9	2	11%
	10 to 15	0	0%
	>15	17	89%
Q4	**Have used modular construction**		
	yes	5	26%
	no	14	74%
Q5	**Number of modular projects**		
	1 to 2	4	80%
	3 to 4	1	20%
	> 5	0	0%
Q6	**Decisions to use modular**		
	time	5	100%
	cost	5	100%
	quality	0	0%
	other	0	0%
	not sure	0	0%
Q7	**Have considered using modular**		
	yes	2	14%
	no	12	86%
Q8	**Reasons for choosing another system over modular**		
	time	1	5%
	cost	2	11%
	quality	6	32%
	other	13	68%
Q9	**Other methods of construction used**		
	conventional site built	7	47%
	other prefab system	1	7%
	not considered	3	20%
	modular	3	20%
Q10	**Will consider using modular on projects that develop in the next 2 years**		
	yes	3	16%
	no	16	84%

Table 6. *Selected Survey Data.*

Question Number	Question	Response
4	Used modular?	Yes
5	Number of projects that used modular?	3 to 4
6	Reasons for using modular?	Time and Cost
8	Reason for using a method other than modular?	Cost
9	What method other than modular was selected?	Steel vs panelized system, we used steel because we hears it was faster, it wasn't so we panelized everything wkde *[sic]*
10	Consider modular within the next 2 years?	We use light gauge steel panels not modular like app st did *[sic]*

As indicated by the answers, the respondent clearly understood the difference between modular and other modes of prefabrication; however, the respondent answered yes to using modular. Through the descriptive answers and a subsequent interview any ambiguity was removed, and it was possible to utilize this data without questioning what the respondent actually meant.

Other descriptive answers provided similarly revealing evidence about the status of modular construction at UNC institutions, notably with respect to quality concerns. One respondent from the University of North Carolina at Chapel Hill (UNCCH) reported: “I was looking at it for cost and speed of construction. Received pushback from designers.” Other respondents specifically questioned modular construction’s durability: “… we tend to focus on buildings that have a longer shelf life.” Similarly, a respondent from the University of North Carolina School of the Arts (UNCSA) reported: “[we] prefer traditional construction due to the reliability and less risk.” A representative from North Carolina State University (NCSU) stated: “The only way we would consider it is in one community where we are focused on a developer quality to meet our financial goals and offer newer housing options." The idea being that a developer-quality project is of lesser quality when compared to a traditional institutional project.

Piecing all of these bits of data together creates a profile of the UNC System at large with regard to perceptions of modular construction and what is accepted as an institutional standard. The profile indicates that modular construction is not congruent with state standards of construction; it is a paradigm shift that will result in sub-optimal buildings at a greater risk to UNC. Examining this profile within the context of the sample and the population, this point of view seems logical. Traditional UNC buildings are site-built concrete and steel constructions with anticipated lifespans of 80 to 100 years, with one or two major renovations throughout that period (T. Kane, personal communication, July 23, 2013). Sixty-three percent of respondents had been doing their current jobs for over six years, and 89% had been in their field for over 15 years. Such tenure is sure to bind decision makers to an approach that is well vetted and accepted throughout their industry.

The data also raise some interesting questions about university housing. As the respondent from NCSU noted, they would consider modular construction to meet financial goals and to offer newer housing options. University housing is one of the few operations on a UNC campus that is required to be financially self-supporting. The revenue generated by housing leases is in turn used to operate facilities and sets the budget for housing operations. The UNC Board of Governors does allot funds to university housing projects, as it does to other academic needs; however, university housing is a business that must compete with other community developers to rent residences in their facilities (T. Kane, personal communication, July 23, 2013). When viewed in this light, it makes sense that the respondents who wanted to pursue modular with the greatest vigor were representatives from housing.

The other major issue raised by the descriptive survey responses was that of regulatory concerns. The "main issue to determine if will work is for compliance with the NC State Construction Office *[sic]*." This respondent from Western Carolina University (WCU) noted that they are unsure if modular construction is compatible with standard operating procedures at the North Carolina State Construction Office (SCO). The key thing to understand about the SCO is that it is an organization created by the North Carolina General Statutes (NCGS), and tasked with enforcing NC law with reference to state-owned buildings. It is not the SCO's position to create laws or standards, and the SCO is not the ultimate steward of UNC-owned property. The UNC institution is the owner and the decision maker, and SCO is there to provide administrative and industry-specific professional council (G. Driver, personal communication, January 8, 2014).

Nonetheless, respondents raised concerns that the SCO will disrupt a UNC institution's plans to pursue an unconventional project. One respondent specifically cited state regulations as a reason to choose another method of construction over modular. Obviously, there is a conflicting view over the purpose and benefit of the SCO. With respect to these UNC representatives' trepidations about the SCO, there is an added layer of bureaucracy inherent in a state construction project. As previously stated in Chapter 4, all UNC projects must go through the SCO in some capacity, whether a full review and administration or simply review and advisement. When a UNC project of over $2 million dollars is administered by the SCO, it must go through a comprehensive contract document review, bidding procedure, and inspection process (North Carolina State Construction Office, 2006).

The SCO review process involves five stages that correspond to the different design phases of a project. According to the *North Carolina State Construction Manual* (2006) the maximum review time can be up to five months long. That is not five consecutive months, but is broken down as follows in Table 7:

Table 7. *Selected Survey Data.*

Stage	Duration (days)
Advance Planning	15
Schematic Design	30
Design Development	30
Construction Documents	30
Final Approval	15

These review times are applicable to all projects under $40 million, and note, these are the maximum anticipated times, not absolute (North Carolina State Construction Office, 2006). It is unknown how much this review process might impact the overall project schedule, but gauging by survey responses it can be significant enough to warrant alternative considerations.

Aside from the review process, the SCO also conducts periodic inspections of each project. These inspections correspond to traditional code compliance inspections that are common throughout the construction industry. However, SCO-inspected buildings are held to a higher standard than those inspected by municipal authorities. According to Greg Driver, Director of the SCO, his inspectors and reviewers are better trained and educated than most municipal inspectors, and they have experience with large, complex projects that far exceeds the capabilities of municipal departments (G. Driver, personal communication, January 8, 2013). In addition to the rigor of the inspection process, the buildings are built with more industrial-grade materials, all in accordance with NC law. Electrical Metal Tubing (EMT) is used to sheath all electrical wires, as opposed to Metal Clad (MC) wires. Iron pipe is used for plumbing waste lines and for fire protection instead of plastic, and there are no compromises on safety (G. Driver, personal communication, January 8, 2013).

Of course, buildings are constructed throughout the US every day according to the accepted and more conventional International Building Code (IBC) without any noticeable violations of health, safety, or welfare of the public.

The other contentious issue surrounding SCO and NC public construction projects is the bidding process. Depending on the contract method selected, there are specific bidding requirements that must be satisfied. There are a number of contracting methods available to public projects, including those on UNC campuses, and it is outside of the scope of this report to detail what each of those methods entails. However, it is important to note that, regardless of the contracting method selected, certain procedures must occur according to law. The significance of these bidding procedures as they impact a decision to use modular construction is that a modular approach is enhanced by a contracting method that encourages early involvement of the general contractor and modular producer. Additionally, any duration added to the project schedule as a result of bidding laws will equally affect a modular or conventional approach. However, the flow of a modular production schedule could be disrupted by a contracting and bidding structure that places restraint on the amount of early collaboration between designers and builders. For details about NC public construction project contracting methods, see NCGS Chapter143, Article 8.

The last salient aspect of the survey that has not been touched on is the fact that it did not include responses for all campuses within the UNC system. Formal survey responses were received from 14 of the 16 institutions. However, informal responses were received via email from representatives at the other two institutions. These informal responses corroborated the data collected, and confirmed that there are no modular projects other than the aforementioned project at Appalachian State University.

Part II: Discussion of Interview Findings

Several key themes recurred throughout the interview data collected. Many times similar lines of questioning between multiple interviews would bring about similar responses; however, oftentimes, there were resounding commonalities that resulted without prompting. For instance, on the topic of NC State Construction, or SCO, many interviewees commented on their disdain for the process required by SCO. Nonetheless, the majority of these people also praised how SCO had transformed within the last decade, and is now more of an ally than an adversary of campuses. Representatives from all UNC business units—housing, design and construction, operations—and from SCO echoed this sentiment. Additionally, many claims and opinions asserted during the interviews were substantiated by written documentation from other outlets such as print and online media, and from survey responses from Part I of this study. This triangulation of data reflects good internal validity for the study, and indicates that the results can be relied upon with some certainty.

However, there were some statements made during the interviews that could not be substantiated. The representative from SCO made the comment that the SCO review process is not what takes time and adds to the project duration, but that it is the bidding laws that take time (this comment is specific to design-bid-build work). As alluded to in the discussion of Part I, bidding laws differ for varying contract types, but there are certain constants throughout each contracting method. A thorough review of resources available on the SCO website, in the *NC State Construction Manual*, and in Article 8, Chapter 143 of the NCGS, which governs public contracts, revealed that not much is written about the duration of the public bidding process. The only reference to a bidding timeline that the author was able to find comes from Paragraph "B", Section 129, Chapter 143 of the NCGS:

> The advertisements for bidders required by this section shall appear at a time where at least seven full days shall lapse between the date on which the notice appears and the date of the opening of bids. The advertisement shall: (i) state the time and place where plans and specifications of proposed work or a complete description of the apparatus, supplies, materials, or equipment may be had; (ii) state the time and place for opening of the proposals; and (iii) reserve to the board or governing body the right to reject any or all proposals. (143 NCGS § 129, 1931)

As this legislation states, a notice to bidders must exist for at least seven days before the public opening of bids. Seven days is not an amount of time significant enough to impact a project that lasts for at least a year. The review times for projects administered through the SCO, up to five months, are significant enough to impact the overall project duration (see Table 7 in Chapter 5). Furthermore, as referred to by several interview participants—and quoted in Chapter 4—the inspection schedule for SCO work can be tedious and time consuming, requiring frequent inspections from a small staff of inspectors. Thus, evidence suggests that it is indeed the review and inspection process that takes significantly longer on UNC projects. However, the bidding process could exacerbate this problem if not enough bids are received and the work has to be rebid, or if through rebidding the estimates exceed the budget available for the work, and significant value engineering must take place.

Difficult to Dispose of the Building	Difficult to Modify	Egregious First Cost
Institutional in Appearance	Excessive Building Lifespan	Takes Too Long to Build
Cost Exceeds Revenue	Out of Style in One Generation	Increased Reliance on Privatization

Figure 24. Interview themes that relate to the designed lifespan of UNC buildings.

Another constant that emerged from the interview data was the perception that UNC housing facilities are overbuilt. Representatives from each business unit throughout the state staked this claim. Many times this opinion was expressed as a response to a question regarding the longevity of campus buildings, and from there evolved into a diatribe on the materials of the building, or the generational differences between classes of students, or the cost of building the facility. As Figure 24 depicts, regardless of what the individual objection was it tended to emerge from the argument that UNC residence halls are designed and built for an unrealistic lifespan.

UNC facilities are built of durable materials, and are intended to last at least 50 years (Appalachian State University & Lawrence Group Architects, 2009). The American Institute of Architects (AIA), in its 2010 *AIA Guide to Building Life Cycle Assessment in Practice,* notes that while there are some general assumptions that building designers and practitioners use in assessing the service life of a building, there is no standardized approach to establish what an actual service life will be (Bayer, Gamble, Gentry, & Joshi, 2010). Indeed, O'Connor (2004) notes that although there are assumptions about how long a building's structural systems may last, these assumptions may be irrelevant because buildings are usually demolished or removed from service before their assumed physical life is exhausted (see Figures 25 and 26). Through a study of Minneapolis, MN demolition permits issued between 2000 and 2003, O'Connor and her research team studied 257 buildings that were demolished during that time. The study concluded that "although the wood buildings in our sample lasted the longest, our overriding conclusion is that no meaningful relationship exists between structural material and average service life, and that most buildings are demolished for reasons that have nothing to do with the physical state of the structural systems" (O'Connor, 2004, pp. 3-4).

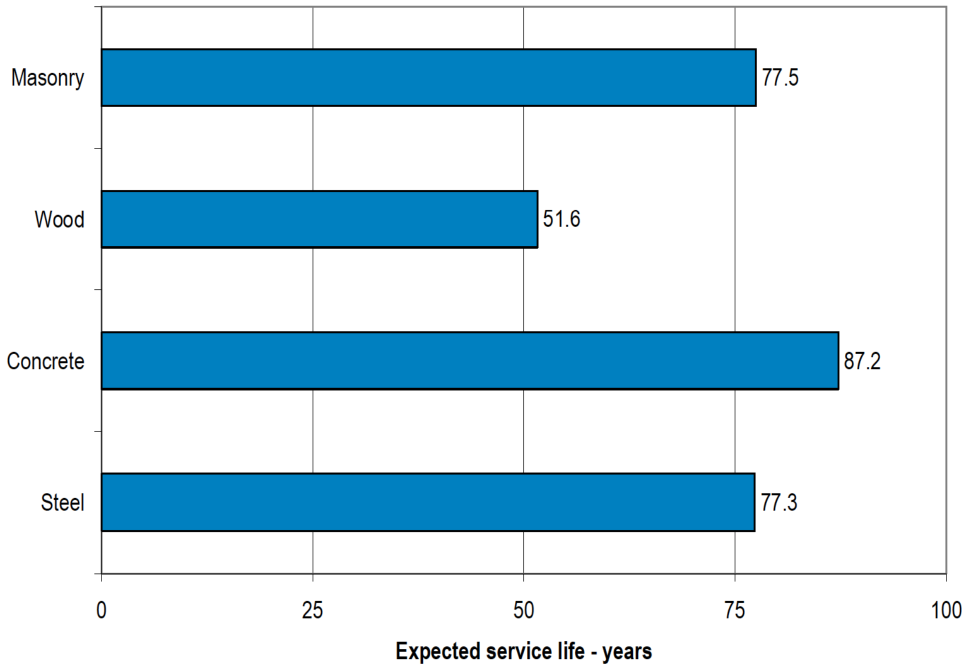


Figure 25. Average expected service life for non-residential buildings by primary structural material. From surveys of architects, structural engineers, builders and developers in the United States and Canada, N=683 (O'Connor, 2004, p. 5).

Continuing this string of logic, when explored holistically, many UNC buildings are just beginning to test the hypothesis of a 50-year minimum lifespan. "In 1997 and 1998, the North Carolina General Assembly mandated that the Board of Governors of The University of North Carolina conduct a *Study of Capital Equity and Adequacy* and prepare a *10-Year Capital Plan*—to identify capital needs of each institution for all categories of facilities" (Board of Governors of the University of North Carolina, & Eva Klein and Associates, 1999, preface). For each campus, a separate profile was created which, in broad terms, defined the current facilities inventory, and plans for future expansion through 2008. Of course, these reports are now over a decade old, but they are the most current, concise collections of facilities data that the author was able to find, and they provide a good accounting of what buildings existed in 1999. Through a review of each of these reports, it was determined that in 1999 the UNC system owned 2184 buildings (not differentiating between residential and academic). Of these 2184 buildings, only 2% were older than 50 years at the time of the accounting. However, over 50% were built before 1970, which means that those 1119 buildings are now a few years away from, or have surpassed, the half-century mark if they are still in service.

This reckoning does not take into account anything that was built in the last 15 years, but nonetheless it creates a picture of what existed in 1999, and how much of that building stock is likely approaching a critical point today. Simply put, most of the UNC buildings that have been designed for 50 years are just now approaching the age where that distinction can be made.

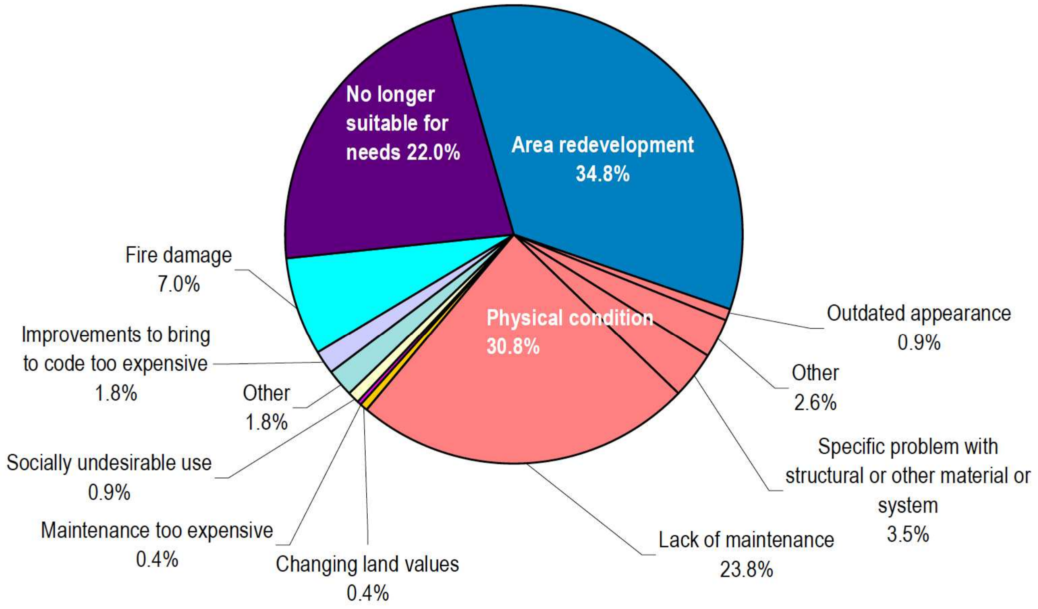


Figure 26. Of the 227 buildings demolished in O'Connor's study, the above reasons were given for demolishment (O'Connor, 2004, p. 8).

As an example, one residence hall on the ASU campus was recently demolished before it reached age 50. Winkler Hall, built in 1974, was an 11-story high-rise dormitory that housed 132 students (Wood, 2014). The structure was typical of UNC residence halls of its age, concrete and steel, and was composed of four-student apartment-style dorms (Figure 27). It was demolished because the cost to renovate the building exceeded funds available, and because it did not house an effective number of students per area of the building (T. Kane, personal communication, July, 27, 2013). ASU University Housing went through an entire design phase to renovate the building, and contracted and paid an architectural firm for the redesign. However, when the bids from contractors came back on the design, the lowest bid exceeded the designers' estimate by 50%. University Housing simply did not have the budget to proceed with the work, and value engineering yielded a building devoid of any features that students find appealing. In the end, this left the university financially responsible for design services and demolition, a combined cost of almost $2 million, with no building to use (T. Kane, personal communication, July 27, 2013).

Figure 27. Winkler Hall on the campus of ASU, circa 1974 (ASU Special Collections, 1974. Reprinted with permission).

From the interview data, the other constant that grounded many divergent comments was the cost—first cost, operational cost, and how to pay for those costs. Of course, opinions and facts on this point were addressed under the Financial Concerns section of Chapter 4, just as the other salient discussion points were addressed in their respective sections of Chapter 4. However, what may not be apparent is the connection between these comments and the Time-Cost-Quality model of construction. As seen in Figure 28, when all three factors are pursued equally, then each parameter will suffer to some degree. Likewise, if two of the factors are the priority, then the third factor will undoubtedly diminish. On UNC housing projects that proceed through the official channels of the SCO, time is the variable that usually seems to suffer because the SCO places a priority on monitoring cost and delivering high quality. To the chagrin of SCO, when UNC institutions pursue a privatized approach, time and cost receive the priority while quality may not receive as much favor. However, simply viewing quality in terms of the perceived durability of materials and finishes does not give that parameter full consideration. As O'Connor (2004) illustrated, the durability of a structure may not be indicative of the structural system used. Likewise, using metal pipes versus plastic pipes may seem to be a quality upgrade, but there are dorms in the UNC system that are having metal pipes replaced with plastic pipes because they are leaking after 25 years (T. Kane, personal communication, July, 27, 2014). As such, one person's opinion of quality and durability is shaped by his or her experiences and can be at odds with another person's.

The problem is that quality is a subjective trait that is hard to agree on and equally hard to gauge. As SCO is apt to point out, if a UNC housing facility is built to minimum building code it is not likely to last very long because students can be destructive. Contrarily, UNC housing officials are quick to point out that it does not make sense to build indestructible buildings when they probably will not see more than 30 to 40 years of use, as was the case with Winkler Hall. At the same time, that argument is easily countered with the fact that some dorms have lasted for more than 50 years, and have been renovated during their tenure. This elicits the remark that those renovations are too expensive, universities cannot afford them, and the buildings still lack the flexibility and amenities demanded by today's students. The list can go on, as it does in the previous chapter, but what do all of these arguments mean? Who is right, and is this an absolute? The case study between

Mountaineer Hall and Summit Hall provides some insight into this matter, while also exploring what bearing modular construction has on the outcome.

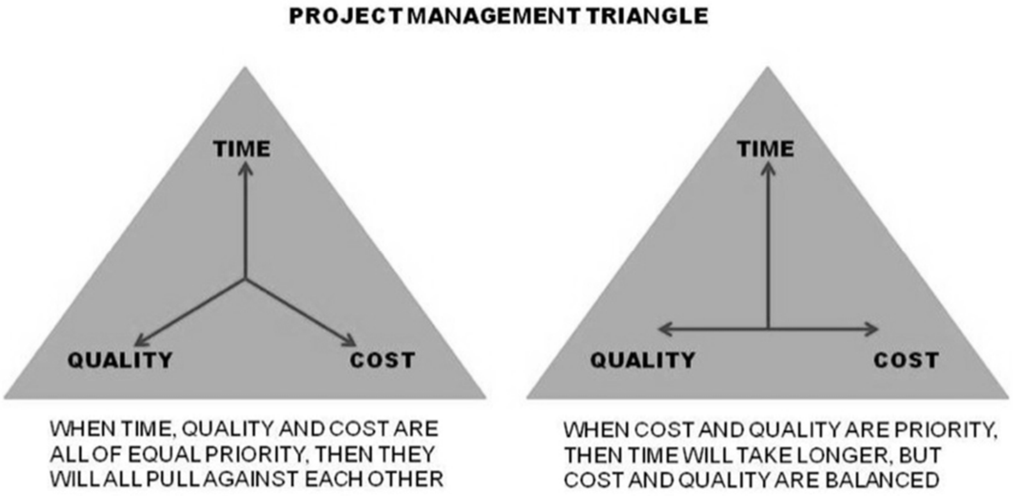


Figure 28. The conflicting nature of time, cost, and quality on a construction project (O'Leary, & Sludds, 2011).

CHAPTER 6: CASE STUDY

This case study was a comparison between a residence hall built using modular construction, and a residence hall constructed using conventional, site-built techniques. Both residence halls are located on the campus of Appalachian State University (ASU) in Boone, NC, and they were both constructed during the same time. The modular facility is Mountaineer Hall, and the conventional facility is Summit Hall.

Figure 29. Mountaineer Hall entrance (center right of photo) with bus stop (Clayton Building Solutions, 2014. Reprinted with permission).

Mountaineer Hall (Figure 29) is a 118, 434 square feet, 460-bed facility constructed of light-wood-frame modules clad in brick veneer. The building has a basement and crawlspace foundation of block and reinforced concrete with spread footings. Mountaineer has a combination low-slope and steep-slope roof with standing-seam metal roofing covering the steep-slope portions. It has standard interior finishes for an institutional residence hall that include hard tile, resilient flooring, carpet, and painted drywall with the addition of orange peel texture on wall surfaces. Mountaineer also has some communal spaces with real stonework and premium finishes. Each individual dwelling unit has its own Packaged Terminal Air Conditioner (PTAC) heat pump for heating and cooling, and the other portions of the building are conditioned by independent split-system heat pumps. Hot water is provided through a boiler and the ASU steam system, and is supplemented with solar thermal water heating. The building is certified LEED (Leadership in Energy and Environmental Design) Gold by the United States Green Building Council (USGBC). LEED Gold is the third tier of four levels of certification (the levels are certified, silver, gold, and platinum), and is recognized as a standard for green building in the US and North America. Students first occupied Mountaineer in the Fall 2011 semester.

Summit Hall is a 106, 820 square feet, 333-bed facility constructed of a reinforced concrete superstructure, with curtain wall glazing and brick cladding; the building has a flat roof with a penthouse. Summit has deep micro-pile concrete foundations with pile caps and grade beams, and sits atop an underground steam tunnel that is linked to Cone Hall and Plemmons Student Union. It has standard interior finishes for an institutional residence hall that include hard tile, resilient flooring, carpet, painted drywall, and acoustical ceiling tiles. Summit also has some designer spaces with wood paneling, real stonework, and premium fixtures. Summit has an industrial mechanical system made of a four-pipe chiller and independent fan-coil cooling system, and a steam-driven boiler for heating and hot water; the building has supplemental solar thermal water heating. Summit is pursuing LEED Silver certification, but this has not been finalized to date. Students first occupied the building during the Fall 2012 semester.

Further details about each building and its systems are provided later in the report.

Figure 30. Summit Hall (right) beside the Plemmons Student Union addition (Perkins and Will Architecture, & Grassal, A. [Photographer], 2014. Reprinted with permission).

Case Study Methodology

These two buildings were selected for the case study for one reason. Mountaineer is the only modular project throughout the University of North Carolina (UNC) system, and Summit was built on the same campus at the same time, making the two project ideal for a one-to-one comparison. During the planning stages for this study the idea was to collect as much time-cost-quality data from existing modular projects throughout the UNC system as possible, and to compare this data to comparable data from site-built projects similar in scope, and proximal to the modular projects. However, during Part's I and II it was determined that Mountaineer is the only modular project in the UNC System, so that limited the case study to focus on this dyad of residence halls at Appalachian State University that me the selection criteria.

Data Collection

Each project was evaluated for time-cost-quality through qualitative and quantitative data. The first step in evaluating each of these characteristics was contacting an authority with ASU familiar with each project. These initial conversations identified key stakeholders for each project and provided basic project descriptions and details. Stakeholders identified included architects, contractors, project managers, consultants, and other key personnel who were responsible for the planning, design, construction, and operation of each facility. Interviews with each stakeholder were conducted in a manner consistent with that described in Part II, and focused on the interviewee's knowledge of each respective project from time-cost-quality perspectives.

Data related to the timeline and duration of each project were extracted through a number of methods. Primarily, these data were collected through interviews with stakeholders and corroborated with documented evidence from press and other media. Additionally, the ASU Office of Design and Construction had initial project schedules and logs of project activities. Combined, these data sources provided a good, collective overview of how long each project took to design and build.

Cost data for each project were derived through interviews, records available through the NC State Construction Office (SCO), the UNC General Administration (UNCGA), and ASU. Similar to time records, there are inconsistencies throughout costing data; however, the general price ranges reported are consistent despite their errors. For the most part, cost data derived through interviews was given as a final price, or what the interviewee recollected to be a lump-sum price for services. The same is true for data retrieved through the UNCGA: the price is given as a total cost for design and construction. Data from the SCO, however, are more specific because the cost reports are composed of estimates received for the specific project. For this reason, SCO costing data give aggregate unit costs for the major construction trades (general, plumbing, HVAC, electrical) and some main tertiary trades (conveying systems, fire suppression), as well as associated fees (design, commissioning, planning, contingencies).

To assess the quality of Mountaineer and Summit interview data, project contract documents and building energy use data were collected. Additionally, project site visits were conducted at each facility to gauge the quality of workmanship, building functioning, and comfort conditions.

Contract documents include drawings and specifications for the construction of a project. Given a building that is already built, the drawings should be Record Drawings that incorporate as-built changes that occurred during the construction. For Summit, a complete set of Record Drawings and specifications were provided by ASU. For Mountaineer, the only contract documents available from ASU were a partial set of drawings issued for construction thus any changes that occurred during construction were not made in the drawing set. Additionally, without the specifications, it is not possible to determine if all specified products were installed or if there were deviations from the initial scope of work for each division.

Building energy use data for Mountaineer and Summit was collected through the ASU Physical Plant. These data included all reportable utility usage from initial occupancy through March 2014. The data includes total usage for electricity, steam, natural gas, water, and sewer reported monthly. These values were analyzed on an area and student basis to provide a per unit measure of energy intensity. Cost of utilities is also reported in this data to reflect monthly, annual, and total energy expenditures for each building.

Work order claims for each facility were collected through the ASU Physical Plant. The Physical Plant operates using an automated work order system. Work orders are submitted by the property users, processed, and assigned to the maintenance unit responsible for that area of campus. Work orders are classified according to building, category, and problem code, and a number of other variables. Given that the two buildings were differentiated in the raw work order data, problem code was the only indicator that provided information about what the work order related to. The problem code is not very detailed, but it does indicate whether the problem is electrical, HVAC, appliances, and so on.

Site visits to Mountaineer and Summit were conducted with the assistance of a housing representative. Each facility was toured and photographed as necessary to document any significant evidence of poor workmanship or lessened quality due to durability. A portion of each building was observed to include main entryways, horizontal and vertical circulation corridors, individual dwelling units, mechanical and electrical rooms, rooftop surfaces, utility spaces, and exterior elements. Not all spaces and floors were observed as access and time were limited, but effort was made to see a representative sample of each building.

Data Analysis

Data related to the time of completion for each project were triangulated between information sources to check validity, and were compared with other typical project timelines to assess how Mountaineer and Summit fared with respect to other projects that have been built throughout the UNC system. There were some inconsistencies throughout and between documents and statements. These differences were typically not significant, and were usually a matter of days or a few weeks. Ultimately, all accounts of each project were accurate to the month, and correctly identified the start date and end date.

Analysis of cost data for Mountaineer and Summit ranged from basic comparison to future projections based on the values reported for these projects. At the basic level, costs per bed, costs per square foot, and total costs were compared for the projects. In reality, those simple metrics are what really matter to a university or any property owner when it comes to making a financial decision about a future building. In addition to those figures, property owners like to know, and need to know, what it will cost to operate the building. For this reason (and for assessment of quality) energy and operating costs for each project were also collected and compared.

Using a Life Cycle Cost Assessment (LCCA) the operating costs and total cost for each project were calculated for a 100-year lifespan. The LCCA's used standard accounting methods and procedures prescribed by the NC Department of Administration manual *Life Cycle Cost Analysis for State Facilities* (Brinkley & Stanford, 2001). Each LCCA included initial capital investments, annual recurring costs, non-annual recurring costs such as planned maintenance, and replacement and renovation costs dependent on the facility type. Details of the LCCAs such as inflation and discount rates used are provided in Appendix C.

Using data from a 1999 NC General Assembly *Study of Capital Equity and Adequacy 10-year Capital Plan* (Board of Governors of the University of North Carolina, & Eva Klein and Associates, 1999), the residential housing needs of each UNC institution through 2008 were estimated. Using these projected needs, the LCCA values from Mountaineer and Summit, and cost data from other conventional UNC dorms, financial projections for the housing needs of the entire UNC system were calculated. These projections compared the life cycle costs incurred by the UNC system if modular or conventional construction were used on all new dorms. These projections were used to partially answer research question three: Considering the housing needs incurred by the UNC System, and the scheduled rebuilding plans, how could time, cost, and quality for future student housing projects be affected by adopting modular construction for new residence halls?

Data related to the quality of Mountaineer and Summit were analyzed on a continual basis within the context of each project. The contract documents were perused for quality-related mandates, and were compared to as-built conditions, energy consumption data, and interview responses in an effort to determine if there were design details that resulted in higher or lower quality. Likewise, these comparisons extended to potential deviations from the contract documents which may provide some indication of construction quality in the execution of the design.

Energy use data was compared between projects on a per unit basis for each type of energy. These comparisons also included cost of each type of energy to examine total economic impact based on energy use. Comparisons were conducted on an annual and monthly basis, and included degree days. Degree days are a temperature-based design criterion that provide a baseline measure of heating or cooling intensity based on the mean outdoor temperature (United States Energy Information Administration [USEIA], 2014). If the mean outdoor temperature is above 65°F then you have Heating Degree Days (HDD); if the mean outdoor temperature is below 65°F then you have Cooling Degree Days (CDD). For example, if the high temperature one day in August is 95°F and the low temperature is 75°F then there are 105 CDD for that day (95+75 / 2 =170). Comparing energy use within the context of degree days provides insight into how well the building performs in different seasons, and could point to deficiencies in mechanical efficiency, insulation levels and detailing, solar orientation, or any number of building system failures.

For example, if building "A" consumes 25,000 kWh in a summer period with 300 CDD, and building "B" that is exactly the same consumes 15,000 kWh during the same period then there are several explanations for this difference. Maybe building "B" does not have air conditioning, or it has a different type of occupancy, or maybe the thermostat set point is higher in building "B.". There could be many reasons for the difference in energy consumption. However, in the case of two residence halls on the same campus each with air conditioning with the same temperature set-point, it becomes easier to drill down to the aggravating circumstances. Although it is nearly impossible to specifically pinpoint one variable that could be causing such a difference, over time, with monitoring and evaluation it is possible to shorten the list of potential suspects, and to make adjustments to systems and behavior that may be exacerbating the situation.

Work orders were analyzed for overall number, number by facility, frequency of a particular problem code, and frequency by date. Evaluating the work orders by number provides the basic understanding of which building has the most recorded maintenance. This value was taken one step further to examine the total number of work orders by year to study whether there were an inordinate amount of work orders based on facility start-up. The number of work orders was also examined on a per student basis, to understand how many work orders each building had on a per capita basis. Delving into the problem code provided some insight into the type of problems experienced at each facility, be that electrical, mechanical, or lost keys. However, there was not enough descriptive data associated with each work order to make any assumptions beyond a high, categorical level. For example, a problem code of appliances is obvious, but it does not state whether the appliance is the dishwasher every time, or if all of the appliances share in the maintenance burden equally.

Pictures from site visits were analyzed alongside contract documents to note any deviations from the design. Additionally, they were examined with respect to interview testimonials to assess how accounts from stakeholders compare to what is actually built. Site visits also allowed the opportunity to examine how work orders could be the result of a particular finish, fixture, or appliance within a building. Ultimately, the site visits provided a well-rounded context for analyzing, validating, and reporting the other data collected.

Case Study Results

Similar to other sections of this report, this results section is segmented into the categories of time-cost-quality. However there are certain project details that do not fit neatly within these categories. For this reason, details of the project such as construction process or project management that are necessary to understanding the overall category are included in each. Because there is so much overlap between data analysis and interpretation, this provides the best format for presenting the findings of each particular segment while keeping perspective of the whole. Before delving into the particulars of each category, however, it is necessary to understand more macro-level details of each project as provided through personal interviews and documents collected through those interviews.

Dr. Tom Kane is the Housing Director at ASU, and has been in this role since before Mountaineer Hall and Summit Hall were built. Kane was my initial contact during the planning stages of this study, and provided many of the basic details and future contacts for both projects. He is a champion of modular construction, and any other way of building that may save his organization time and money. Having previously worked in university housing throughout Florida, Kane saw many unique ways to build and deliver a project that were statutorily forbidden in NC. As such, when he received a mandate from the ASU Board of Trustees to increase his housing stock by 1000 beds in a relatively short amount of time, he immediately looked to modular construction due to its reputation for quick project delivery. Mountaineer Hall is one building that resulted.

Concurrently, there was interest on the ASU campus in expanding the Honors College and making a living-learning environment, as well as in expanding the Plemmons Student Union. All of these projects were lumped together, along with the renovation of Cone Hall, and were tackled as one large project in the center of campus. David Sweet is the University Architect at ASU, and he was the project manager for this large multi-phase development. The Plemmons addition and the Honors College Living-Learning Center (LLC) became one project with three phases plus an alternate add-on. The project was delivered as a Construction Manager at Risk (CM at Risk) contracting venture (the first of its kind at ASU) and it resulted in Summit Hall, the Plemmons addition, the Regional Utility Building (RUB), and the Academic Wing of the Honors College LLC. Sweet contends that all of these projects were pursued as one, with one primary construction manager because they are co-located in the heart of campus and the university wanted to minimize on-campus disruptions.

Summit Hall is a 10-story, 333-bed facility that is built to last at least 50 years with at least one major renovation occurring during its lifetime. Summit is the outgrowth of the Honors College LLC expansion, and was part of the original plan to develop that program. All of the buildings bundled together in this one project (Summit, Plemmons, the Academic Wing, and the RUB) were designed by the Charlotte, NC office of the architecture firm Perkins and Will. The Charlotte, NC office of Balfour Beatty Construction was the CM at Risk for the entire project.

Mountaineer Hall is a four-story, 460-bed facility that is built to last 30 years. Mountaineer Hall is owned by the Appalachian Student Housing Corporation (ASHC) and was built as a privatized venture. The building is on ASU owned land, and is leased to ASU by ASHC. In 2016, after all debt is paid on the building, ownership will transfer to ASU. The project was designed by CJMW architecture in Winston Salem, NC. John S Clark, from Mt. Airy, NC, was the general contractor and the contract holder with the owner for this design-build venture (note: John S Clark is no longer in business). The modular manufacturer was Clayton Building Solutions from Bean Station, TN.

With both buildings, demolition and rough site work was necessary to ready the sites for new construction. In the case of Mountaineer, there was an existing housing community located on the site called Mountaineer Apartments. These apartments were derelicts from the 1970s and served as the housing accommodations for non-traditional students with families. Mountaineer Apartments would have needed significant renovations to remain viable, and were seen as an inefficient use of the land. To make room for Summit two existing buildings, Coffey Hall and the College of Fine Arts Administration Building, were demolished. Coffey was a 1950s era, four-story steel and concrete structure that was previously part of the Honors College. The College of Fine Arts Administration Building was a two-story former residential house that had been converted for University use.

Time

Mountaineer Hall took approximately two years from initial conceptual design through completion. Figure 31 shows a timeline of the project duration with major milestones. As mentioned, this project was a design-build arrangement where one contract existed between the owner and the design-builder, in this case John S. Clark, who then contracted with the architect CJMW. The modular structure is made of approximately 127 modules ("approximately" because the reported range is from 125-129, with 127 being the most consistent). In the case of Mountaineer, a typical module consists of two dorm rooms and two bathrooms separated by a corridor (see Figure 32). The modules were constructed by Clayton in Tennessee, and trucked to Boone for installation.

Figure 31. Timeline of Mountaineer Hall.

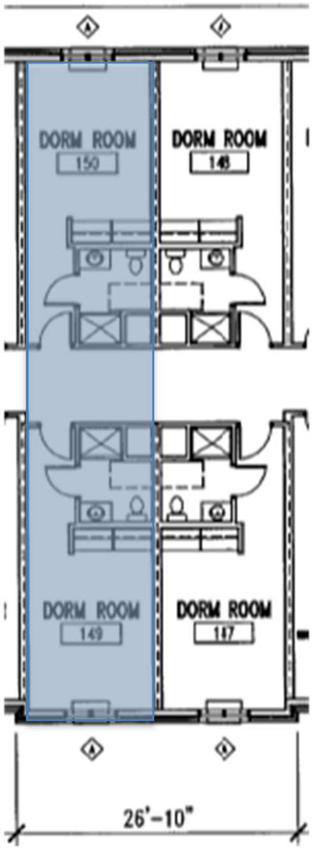


Figure 32. One module of Mountaineer Hall is highlighted in blue.

According to Jeffrey Emmons, who was the Project Manager for John S. Clark, each module came from the factory with all systems and finishes intact. This included all structural framing; Mechanical, Electrical, and Plumbing (MEP) rough-in and fixtures; windows and doors; and floor, wall, and ceiling finishes. The exterior brick cladding was installed on site. Each module from the factory arrived at an off-site staging area located about two miles away wrapped in a weather barrier and ready for installation. The modules were trucked from the staging area to the job site as needed by the module-setting contractor Hunter-Saak Modular.

Figure 33. Mountaineer Hall during construction on November 30th, 2010. All modules are set and brick is being laid on the first floor (Hunter-Saak, 2014. Reprinted with permission).

Hunter-Saak installed the modules in less than 30 days, tiering each level of the structure to provide rigidity as the building was under construction, and to provide weather protection (Figure 33). Emmons reported that the each module on the fourth floor had a factory installed EPDM rubber membrane on the roof that provided an instant waterproof covering once the top layer was set. Every day, the final module to be set was on the top. In this way, once the top module was set, a temporary roof existed before the other modules were set, and before the roof trusses were set and the building was dried-in.

Due to the absolute need for new beds at the start of the Fall 2011 semester, the harsh winters that exist in Boone, and the projected schedule for finishing the building, there was a contractual stipulation that charged the contractor liquidated-damages of $2500 per day if all of the modules were not set, and the structure not dried-in by December 1, 2010. All modules were set by November, 2010 and the masonry contractor, Gates Construction, was able to begin installing the brick veneer that month.

With the modules of Mountaineer set, it would seem that everything after this point would be typical for any construction project. However, it is important to recall that the modules arrived with finishes intact, so a lot of the finish work was already complete aside from some instances where finishing became tear-out and re-work, thus setting the schedule back. Andy McDonald, the project coordinator for ASU University Housing, reported that when the modules were set during the Fall of 2010, they were not conditioned for the winter. When the temperature dropped below freezing that winter, most of the flooring installed in the modules contracted and was permanently damaged. Once the building was completely dry and climate controlled, the flooring in the modules was replaced.

Additionally, Emmons revealed some flaws inherent in the temporary weather protection of each module. Although the modules came from the factory with weather protection, and the top floor had a temporary roof, this temporary roof was not infallible. When it came time to install the roof trusses a wood plate was installed around the perimeter of the top modules. This plate was screwed into the framing of the modules, and was used as an attachment point for the trusses when they were set. However, in the time between installing the plates, installing the trusses, and decking and drying-in the roof, rain accumulated on the top of the modules, and leaked into the building through the penetrations made by the screws fastening the plates to the modules. The project team tried to prevent this by wrapping the plates in felt paper and sealing the penetrations, but a hole is a hole, and water will get into a hole. The water that leaked into the building ruined the finished drywall on some of the ceilings in the modules, and had to be replaced later in the project.

Figure 34. Mountaineer Hall during construction on August 24th, 2010. Some footings have been dug, and reinforcing steel placed, while others are currently being dug (Hunter-Saak, 2014. Reprinted with permission).

Despite these setbacks, the building was complete before the required occupancy date. By July 2011, everything was complete barring a few punch-list items. Given the construction start date of June 2010 that is right at 12 months for completion of the building. Including the bulk of the design work, most of the project occurred in less than 18 months, as design development wrapped up in February 2010. As Figure 34 depicts, retaining walls were in place, but foundations did not start going in until August 24, 2010. From this perspective, aside from site work, the building itself was built in less than ten months (Figure 35).

Assigning a project duration to Summit Hall is infinitely more complicated. From the timeline in Figure 36, one could easily, and erroneously, assume that the project took five years. However, as previously mentioned, Summit was part of a large expansion project in the center of campus, and this tied the timeline of Summit to those of the adjacent buildings. Although there was a feasibility study complete during November 2007, schematic design for all phases was not complete until November 2009. Couple that date with the date for selecting the CM at Risk and a reasonable start period of Fall 2009 can be assumed. Jeff Yelton with Perkins and Will was the project manager for the design team, and he estimated the design period to be about 12 months for this project, which he contended is standard for most UNC project. Yelton is the manager responsible for all Higher Education and Institutional work at his firm, so his estimation of a reasonable design period is as sound as any.

Figure 35. Mountaineer Hall during construction on June 13th, 2011. The building is complete (Hunter-Saak, 2014. Reprinted with permission).

The timeline in Figure 36 was constructed from data provided by David Sweet that he logged as it occurred during the project. Examining the timeline shows that construction documents (CDs) for Phase III (the final phase) were submitted to the SCO around September, 2010. CDs are produced after schematic design, and it is the design step that immediately proceeds actual construction. So if Phase III CDs were finished in September 2010, Yelton contends that the design duration was fairly standard, and a CM at Risk firm was submitting proposals for preconstruction during the Summer of 2009, then assuming a start date of Fall 2009 for Summit is reasonable. Thus, Summit had a project duration of approximately three years.

However, there is another caveat, the projects were not built one after another. Summit was designed and constructed at the same time as the other four buildings. As Sweet contends:

> It appears that the size and complexity of the total scope of work of the Center for Student Leadership project [including the PSU Addition, Appalachian Hall, and the Regional Utility Building] caused both the design time and the construction time for Summit Hall to be extended beyond what I would expect if Summit had been a stand-alone project that was not related to the other simultaneous work on all sides. (D. Sweet, personal communication, May 19, 2014)

For these reasons, it is difficult to specify an absolute timeline for Summit, which makes a comparison with any other timeline equally confounded. However, there is enough detail to make a worthwhile estimate, even if an objective comparison is unreasonable.

SUMMIT HALL

TIMELINE

Figure 36. Summit Hall Timeline.

SUMMIT HALL

TIMELINE

Figure 36 (continued). Summit Hall Timeline.

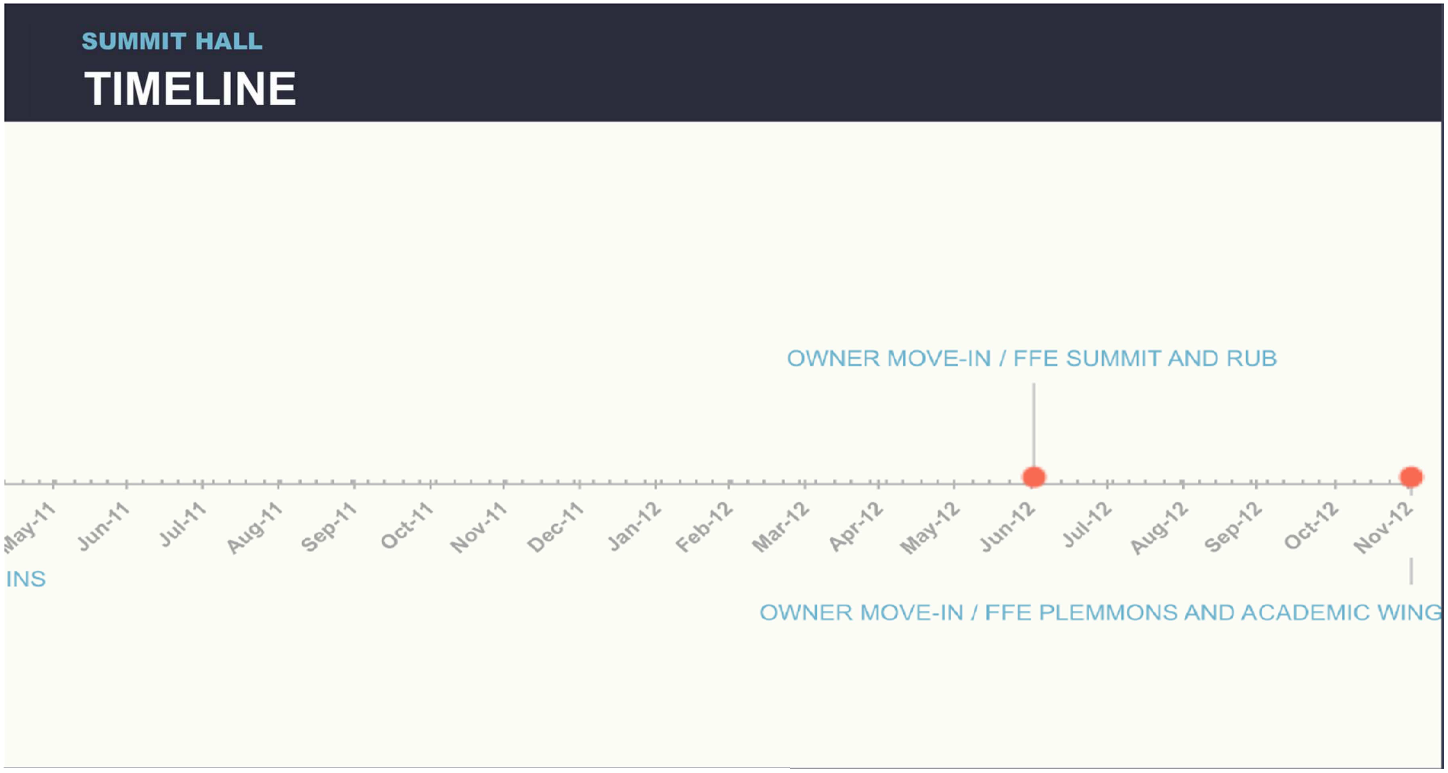


Figure 36 (continued). Summit Hall Timeline.

Summit and the overall Center for Student Leadership project were broken down into three phases. Phase I consisted of erosion control, hazardous material abatement, and the aforementioned demolition. Phase II was mass excavation, deep foundations, and site utilities. Phase III was the superstructure, exterior envelope, and interior upfit of each building. John Schlobohm was on the project management team for Balfour Beatty Construction (BBC) and he recalls that construction for Summit lasted approximately 24 months, from Summer 2010 through Summer 2012. According to the timeline, Phase I work began around May 2010 and the project was completed July 2012. Schlobohm admits that he was not on the project from the inception, and that his involvement was primarily from August 2010 until completion. Piecing those bits of information together, it is reasonable to assume that the construction duration for Summit was approximately 24 months. The construction duration for the Plemmons Student Union addition and the new academic wing extended to November 2012.

The timeline also indicates that Phase III work began in March 2011. Phase III included the bulk of construction for the actual building that is Summit. This means that the 10-story tower from concrete frame through finishes was built in about 16 months not including the foundation. The foundation, which was a part of Phase II, began construction in December 2010, so including this phase in the overall schedule puts the construction duration at around 19 months. Regardless of how long Summit took in relation to the ongoing work at the surrounding buildings, for Schlobohm and the team from BBC, the most important thing to focus on is that they finished the project on schedule, and in time for the Fall 2011 semester.

Similar to Mountaineer, Summit also had an array of challenges that tugged at the project schedule. These circumstances will be covered in more detail in the quality section.

Cost

For both Mountaineer and Summit stating an absolute cost is difficult. Records from the SCO give an estimated cost and budget for each project before construction. Accounts from project representatives at ASU give slightly different figures, and these are different between people. Likewise, there are different numbers recounted from members of the project teams who worked on the buildings. However, the differences are not grave enough to cause any significant misunderstandings. For simplicity, the budgets retrieved from SCO are used as a starting point in this report, and exceptions are noted.

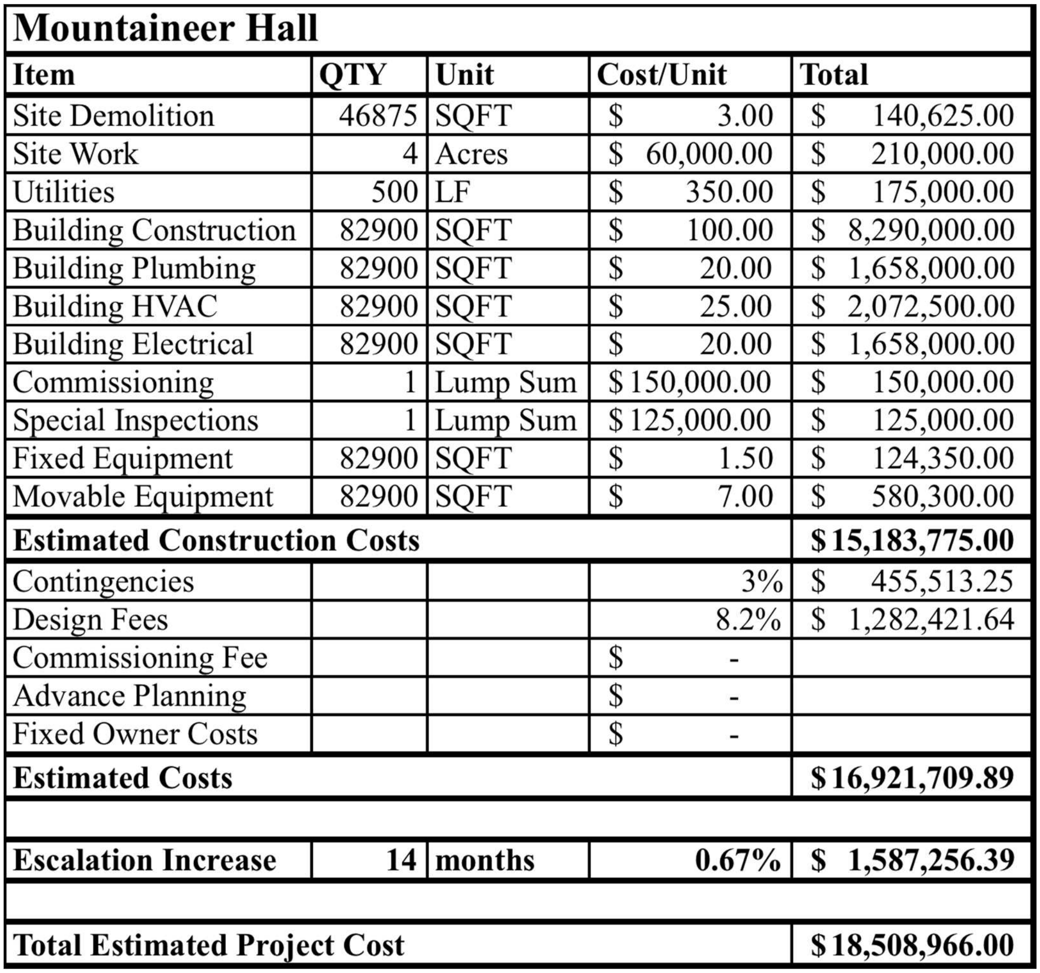
As reported in Table 8, Mountaineer had an estimated construction cost of \$15,183,775. Combined with design services and other contingencies this came to a total project cost of \$16,921,709. SCO included an escalation factor based on the duration of the project, but according to other accounts, the project cost was closer to the \$16 million amount. John S. Clark reported that the total construction cost for the project was \$15,892,168 including all site work. Without site work, the building cost was \$13,490,009, or \$113.90 per square foot at 118,434 square feet. With 460 beds, the John S. Clark price is \$29,326 per bed excluding the cost of the site. This brings up a notable exception. The SCO estimate is for a building that is 82,900 square feet, yet the estimate is remarkably close to what is reported by the general contractor as the actual expense.

Based on the discrepancies between what was in the SCO estimate, and what the contractor reported, it helps to have another source of data. Bob Fide was an official with

ASHC (the owner of Mountaineer) and he reported that the cost data from John S. Clark was correct, and in addition to the reported costs, the following costs were also incurred:

- Demolition: $450,000
- Furnishings: $743,885

Table 8. *Project Cost Estimate for Mountaineer Hall as given by the SCO.*



Mountaineer Hall

Item	QTY	Unit	Cost/Unit	Total
Site Demolition	46875	SQFT	$ 3.00	$ 140,625.00
Site Work	4	Acres	$ 60,000.00	$ 210,000.00
Utilities	500	LF	$ 350.00	$ 175,000.00
Building Construction	82900	SQFT	$ 100.00	$ 8,290,000.00
Building Plumbing	82900	SQFT	$ 20.00	$ 1,658,000.00
Building HVAC	82900	SQFT	$ 25.00	$ 2,072,500.00
Building Electrical	82900	SQFT	$ 20.00	$ 1,658,000.00
Commissioning	1	Lump Sum	$ 150,000.00	$ 150,000.00
Special Inspections	1	Lump Sum	$ 125,000.00	$ 125,000.00
Fixed Equipment	82900	SQFT	$ 1.50	$ 124,350.00
Movable Equipment	82900	SQFT	$ 7.00	$ 580,300.00
Estimated Construction Costs				**$ 15,183,775.00**
Contingencies			3%	$ 455,513.25
Design Fees			8.2%	$ 1,282,421.64
Commissioning Fee			$ -	
Advance Planning			$ -	
Fixed Owner Costs			$ -	
Estimated Costs				**$ 16,921,709.89**
Escalation Increase	**14**	**months**	**0.67%**	**$ 1,587,256.39**
Total Estimated Project Cost				**$ 18,508,966.00**

- Exterior Lighting and Bus Stop: $61,232

Adding all of those costs together with the value reported by the contractor yields a figure of $17,147,285, all-inclusive. Fide also claimed that the project was financed in part through a Build America Bond in the amount of $16,500,000. This bond has a variable interest rate of LIBOR plus .85% and is for a six-and-a-half year period. Being a federally subsidized bond, the US government is paying 35% of the interest paid by ASU.

So what did Mountaineer cost? The number that is tossed about by ASU staff is consistently $16.5 million, which is the amount of the Build America Bond. However, examining final costs submitted by the contractor and supplemented by Fide's account puts the final cost above the $16.5 million mark. Yet the UNC General Administration also placed the project cost squarely at $16.5 million. Ultimately, even with all of the variations between sources, the cost is generally consistent. It is uncertain if the bus stop, exterior lighting, and furnishings were partially or totally included in the construction contract, but demolition was not. A point could be made that the demolition costs should be included in the project costs, because Mountaineer would not exist if its predecessor had not been demolished. Likewise, the other ancillary costs are incumbent upon the project becoming a habitable space. However, for simplicity the value used in this report will be $16.5 million.

It was difficult to place a timeline on Summit, and it is also difficult to report an actual price. As with Mountaineer, the SCO had an initial project budget as given in Table 9. The first discrepancy in this figure is the value given for estimated construction costs. The sum of the total values for site work through building electrical comes to $23,205,000. However, the value given by the SCO is $24,025,000 (Table 9), a difference of $820,000. It is unclear why this discrepancy exists, but all other calculations and figures are based off of the higher value. As such, the SCO reports an estimated project cost of $26,725,410 without an escalation factor.

Sweet, the ASU project manager for Summit, reported the following costs:

- Construction: $27,643,880
- Other (commissioning, testing, preconstruction, other minor work): $755,207
- Design: $2,587,38

The total value for these combined costs is $30,986,474. Reports from the housing department at ASU give a lump sum of $33 million. To reconcile these differences, the costs reported from BBC were collected as best as possible through the SCO records.

Table 9. *Project Cost Estimate for Summit Hall as given by SCO.*

Summit Hall				
Item	**QTY**	**Unit**	**Cost/Unit**	**Total**
Site Work	1	Acres	$ 75,000.00	$ 75,000.00
Utilities	400	LF	$ 75.00	$ 30,000.00
Building Construction	110000	SQFT	$ 135.00	$ 14,850,000.00
Building Plumbing	110000	SQFT	$ 20.00	$ 2,200,000.00
Building HVAC	110000	SQFT	$ 35.00	$ 3,850,000.00
Building Electrical	110000	SQFT	$ 20.00	$ 2,200,000.00
Estimated Construction Costs				**$ 23,205,000.00**
			(value given by SCO)	**$ 24,025,000.00**
Contingencies			3%	$ 720,750.00
Design Fees			8.0%	$ 1,979,660.00
Commissioning Fee			$ -	
Advance Planning			$ -	
Fixed Owner Costs			$ -	
Estimated Costs				**$ 26,725,410.00**
Escalation Increase	**24**	**months**	**0.67%**	**$ 4,297,445.93**
Total Estimated Project Cost				**$ 31,022,856.00**

Table 10. *Center for Student Leadership Construction Costs Based on GMP Proposals and Change Orders.*

Center for Student Leadership Change Orders

Action	CO #	Days	Amount	Received	Last Status	Status	Contractor
OPEN	1	0	$ 169,893.29	2010-09-20 10:42	2010-09-27 16:00	Approved	Balfour Beatty Construction, LLC
OPEN	**2**	**154**	**$ 4,982,810.00**	**2010-09-20 14:36**	**2010-10-18 15:42**	**Approved**	**Balfour Beatty Construction, LLC**
OPEN	3	0	$ -	2010-10-25 09:26	2010-10-28 08:09	Approved	Balfour Beatty Construction, LLC
OPEN	4	0	$ (238,571.56)	2010-10-28 14:03	2010-11-05 16:15	Approved	Balfour Beatty Construction, LLC
OPEN	**5**	**565**	**$ 42,263,523.25**	**2010-12-02 14:43**	**2010-12-09 07:56**	**Approved**	**Balfour Beatty Construction, LLC**
OPEN	6	0	$ 6,323.81	2011-02-22 12:17	2011-03-25 16:21	Approved	Balfour Beatty Construction, LLC
OPEN	7	14	$ 7,878,107.00	2011-04-22 10:42	2011-04-29 09:09	Approved	Balfour Beatty Construction, LLC
OPEN	8	0	$ 1,361,298.81	2011-06-23 11:06	2011-07-22 09:42	Approved	Balfour Beatty Construction, LLC
OPEN	9	0	$ 20,074.72	2011-08-15 11:54	2011-09-14 08:13	Approved	Balfour Beatty Construction, LLC
OPEN	10	0	$ (1,214,224.01)	2011-10-28 11:05	2011-11-01 11:59	Approved	Balfour Beatty Construction, LLC
OPEN	11	0	$ (15,249.78)	2012-01-09 11:46	2012-02-01 22:21	Approved	Balfour Beatty Construction, LLC
OPEN	12	0	$ (11,060.57)	2012-02-27 14:56	2012-03-19 00:28	Approved	Balfour Beatty Construction, LLC
OPEN	13	0	$ (220,266.78)	2012-03-19 14:43	2012-04-09 16:35	Approved	Balfour Beatty Construction, LLC
OPEN	14	0	$ 213,077.61	2012-04-30 16:50	2012-08-15 15:55	Approved	Balfour Beatty Construction, LLC
OPEN	15	0	$ 16,284.79	2012-08-01 10:19	2012-09-03 23:15	Approved	Balfour Beatty Construction, LLC
OPEN	16	0	$ 135,262.11	2012-09-20 11:56	2012-10-24 05:54	Approved	Balfour Beatty Construction, LLC
OPEN	17	0	$ 111,961.61	2012-10-12 13:55	2012-11-14 15:36	Approved	Balfour Beatty Construction, LLC
OPEN	18	0	$ 166,197.09	2012-11-30 08:54	2013-01-23 13:42	Approved	Balfour Beatty Construction, LLC
OPEN	19	0	$ 124,931.71	2013-01-03 11:14	2013-02-04 17:34	Approved	Balfour Beatty Construction, LLC
OPEN	20	0	$ 169,349.98	2013-03-01 13:31	2013-04-22 17:14	Approved	Balfour Beatty Construction, LLC
OPEN	21	0	$ (74,160.14)	2013-09-10 11:18	2013-09-18 13:16	Approved	Balfour Beatty Construction, LLC

Phase One Estimate	**$ 860,821.00**
Phase One CO	**$ 169,893.29**
Phase Two CO	**$ (238,571.56)**
Phase Two Cost GMP	**$ 4,982,810.00**
Phase Three FGMP	**$ 42,263,523.25**
Change Order Totals after FGMP	**$ 8,667,907.96**
Total Cost	**$ 56,706,383.94**

According to the final pay application submitted by BBC the total cost of construction for all buildings was $56,706,383.94. Documented change orders, and the Final Guaranteed Maximum Price (FGMP) that BBC proposed for each phase (Table 10) corroborate this figure. It is unclear what the final design fee was because that figure changed with preliminary prices, and is not reported within the scope of the final price. However, that value was initially expressed as 8.2% of construction costs, and preliminary design fees are congruent with that percentage. Thus, if the design fee was 8.2% of some $56.7 million, then that puts the total project cost at $61,694,028 excluding any additional costs for commissioning or other related items..

Of course, the aggregate cost for the Center for Student Leadership (CSL) does not specify the total cost for just Summit. Starting with the FGMP Proposal for Phase III, Summit is explicitly valued at $23,257,239 (excluding the costs of the first two phases). The costs for these preliminary phases were parsed out between the buildings to arrive at a cost of $26,380,100 for Summit alone. After this FGMP was proposed, there was an additional $8.6 million of change orders expensed to the collective project. Adding the cost of site utilities, contingencies and fees, and an allocation for the RUB, this price could be justified at $28,134,511. Adding 8.5% for design fees produces a sum of $30,525,944 without additional change orders.

There were over 300 documented change orders for the CSL project, with 277 affecting the overall cost. Of those 277, Summit Hall was involved in about 100 of them, but it is hard to definitively state the exact number, because some of the change orders are ambiguously described. The total cost for these changes amounted to about $340,000. When this change order amount is added to the previous sum of $30,525,944 this equals

$30,865,944. Sweet reported a cost of $30,986,474 as the total project cost for Summit. Given that this study has attempted to verify costs based off of historical documents and personal memories, and that Sweet was part of the daily administration for Summit, the similarities between figures suggests that Sweet's number is reliable, and it will be used as the total project cost.

Quality

Data related to the quality of Mountaineer and Summit come from personal interviews, a review of contract documents, energy use for each facility, work orders generated by each building, and site visits to each project. While objective quantitative data such as energy use and work orders provide comparable metrics to compare the two projects, the richness of qualitative data provides deeper insight into how each building is perceived by the people who operate it on a daily basis, and into how each project was built and managed.

Perceptions of quality from project stakeholders.

Kane, the Housing Director at ASU, contends that Mountaineer is as quality a facility as any building on campus, but he was not overly concerned with quality when he set out to build a modular project. Andy Sykes was the Project Architect and Design Manager for CJMW, the firm that designed Mountaineer. Sykes reports that CJMW, through the design-build relationship with John S. Clark, won the award of Mountaineer through a competitive bidding process that required modular designs. Modular was the preferred method solely because of the ability to deliver a project quickly, and without concern for winter delays. Sykes claims that many construction systems were considered in the preliminary design phases, including stick-built construction, but the owner demanded modular because of reservations that winter weather would disrupt construction progress. As such, design teams were required to form a design-build partnership that included a modular manufacturer from early in the process.

This early collaboration allowed the design team to formulate a solution that incorporated best practices in modular construction while meeting the spatial and budgetary needs of the owner. This arrangement also resulted in an optimal workflow that allowed the designers to design with modular in mind, preventing the need to retroactively impose a strict modular framework to an existing plan. Although this was the first modular project for everyone on the project team, Sykes reported that the process was not onerous due to the early involvement of all construction stakeholders.

Sykes also applauded the modular construction process, citing a controlled work environment and manufacturing aids as quality control measures that are lacking in traditional construction. He contended that most one-off construction projects are unique, whereas the modules produced for Mountaineer were repetitively produced to a consistent standard. However, there were drawbacks to working with modules. For one, there are redundant structural systems throughout the building. Each module was produced as a stand-alone entity that had to be transported intact, which resulted in double walls and floors where one module adjoins another. If the project had been stick-built there would be only one wall separating different apartments, and the floor system would be one structural member thick.

Additionally, Emmons from John S. Clark stated that even though the modules were produced in a factory, there were inevitable variations between each module, sometimes up to an inch difference. Because each module fluctuated in size, the errors compounded as each module was set. Luckily, in the case of Mountaineer, there was a brick veneer to take up some of those differences. If the design had been to install a cladding material directly to the structure, then the variations would have necessitated a significant amount of furring to keep the exterior plane consistent. However, with brick veneer there is an air space—usually one to two inches—between the brick and the outer plane of the wall structure. While laying the brick around some areas of the building, Emmons claimed “We were going up on the basement wall, that’s a four story unit right there, on top of that one I think it was the place closest to the common areas, we had a six-inch air space.”

The six-inch air space was necessary to keep the brick plane true while also maintaining an air space where the deviations were smaller. Further compounding that condition was flashing around openings with such large gaps. Where a two inch gap is the norm, trying to accommodate a six inch gap without sacrificing aesthetics or protection can be tricky. To compensate for such misgivings, John S. Clark hired outside waterproofing consultants to detail all of the flashing, and also paid a premium to hire Gates Construction for the masonry. Emmons asserted that Gates is one of the top masonry contractors in the state, and that his company hired them for their quality, despite that they cost about $300-$400 thousand more than their closest competitor.

Aside from the joint condition between modules, the aforementioned trouble keeping the modules dry, and having to repair flooring due to temperature fluctuations, Emmons thinks that the job went smoothly and that it is a quality project. He said “At the end of the day I think it was a successful project for everybody involved. As far as all the subs go, it was a financially successful project, and modular-wise it was successful, and the number one thing is everybody is happy with it.”

As a project manager who has worked on other state projects, Emmons is realistic about the quality of the building. He believes that it will last 30-40 years, and he thinks that it is higher quality than stick-built, but less than reinforced concrete. However, he is skeptical about how long a concrete and steel building will actually be used. He has submitted many bids for renovations and new work on UNC campuses, so he has witnessed how long buildings are being utilized. His company had the lowest bid for the renovation of Winkler Hall at ASU, but that amount was still too much to justify the cost of the renovation, and it was demolished. As a builder, Emmons is happy to build another modular project that lasts 30 years if that means he gets to build it again when its time is up.

McDonald, the Project Coordinator for University Housing at ASU, also thinks that Mountaineer is a sound project and a worthwhile investment. During initial conversations, McDonald voiced all of the problems with Mountaineer that were later disclosed by Emmons, and he was an active owners' representative during the construction process. He did note that there were a few issues around window seals that were fixed during the warranty period—possibly the result of the six-inch air space—but other than that, he noted no problems with the building. McDonald was previously in charge of maintenance for University Housing, and he is in-tune with ongoing maintenance demands at each facility. He notes—as previously mentioned by Kane—that Mountaineer is unexpectedly noisier than other facilities, and that sound travels through floors. He begrudges the orange peel texture on the wall surfaces because it is difficult to match after repairs. Drywall repairs have been a consistent hassle for the facility, so Housing contracts with a drywall contractor to perform multi-unit repairs on a yearly basis.

Summit, being a project that went through the traditional channels of state construction, was conceived, designed, and built strictly to NC regulations. ASU University Architect Sweet notes that the project is much more complex than a stand-alone dorm, as it was a part of the larger CLS project. To this point, he adds that the entire project, including Summit, was thought about as a potentially disrupting endeavor because it is located right in the heart of campus. Around this central tenet, many of the project's details unfurled. One designer and one contractor were selected for the entire scope to provide greater continuity to the different buildings and phases. ASU elected to use a CM at Risk contract for the first time on this project, and there were some growing pains associated with the new method.

For one, Sweet notes that with CM at Risk contracts (at least for this contract) there is less predictability. With a CM at Risk contract, the contractor gives the owner a GMP to deliver the project as it is designed and specified, and by a certain date. If the contractor completes this task, they are rewarded with a negotiated fee for performance; if they fail in one aspect or another, the amount of the failure is usually deducted from this fee, or there might be liquidated damages based on a stipulated arrangement with the owner. With Summit, the GMP that was originally proposed was increased before the start of Phase III: as noted, there were hundreds of change orders during the project, and Sweet contends there was an onerous amount of legitimate paperwork. Because many of these problems were occurring while Phase III was beginning there was considerable tension between the interested parties.

Sweet, who was a career Naval Officer and later worked in facilities management at the University of Virginia, is well versed in public construction projects, and prefers the assurance provided by the stipulated sum of a Single-Prime contract. With Single-Prime contracts, Sweet believes that the accuracy of the contractor's bid is increased because they start with a well-developed set of plans and specifications for a fully designed building. In the case of Summit, it was built and designed in phases, with work starting in one phase before the design was complete for the next. Additionally, there were owner-initiated changes, such as building the Academic Wing that occurred well into the construction process (the Academic Wing was added April 2011, and Phase III began March 2011). These and other problems were in part responsible for the concern voiced below by SCO administrators in construction notes for the project:

> KGREEN attended MC#8 held WED23FEB11. Phase I of this project completed ahead of schedule in OCT'11. Phase II is over 80% complete and due to complete prior to required APR'11 date. Issues exist with the cost and schedule of the PH III project completion. The CM's bidding in Jan'll got low participation and bids recieved came in over estimate by approximately $2MM. Also, due to the need to re-bid, the CM is requesting additional schedule time. Since no float existing in an excellerated schedule (which all ready calls for 54 hour work weeks), and the ASU requires the 10 story dormitory building to be completed by late July'12, SCHEDULE IS A MAJOR CONCERN even 17 months out. Also the overage on the bids for the ~$40MM PH III portion has led to a potential dispute between the CM and Owners/DSGNR as to who is responsible. The CM is claiming scope creep. The parties are discussing possible cost reduction options. KGREEN has offered to provide an informal dispute resolution on the time extension request by the CM which the DSGNRs have denied. Parties agreed to attempt to work out the time extension request issue amoungst themselves first. KGREEN to monitor situation.

KGREEN attended the WED23MAR11 MC. Continuing concerns with the management of the project were discussed. These include BBC's request for in excess of a week of time for alleged delay by designers on Addendum dwg issue for bid. On this issue, KGREEN pointed out that request for time related to the completion of the 10 story dormitory facilty was a moot point because all parties had agreed from project inception that this was a hard date without recource to revision due to the owner's need to occupy not later than the contractual date of late July/early Aug 2012. Also, CM's transfer of responsibility to other parties is a major concern by the ASU and SCO -- such as the imposition of schedule update requirements to sub-contractors in the CM bidding documents -- was discussed. KGREEN pointed out that deflection of work all ready contained in the CM's fee structure to other parties is a serious problem. TPEYTON of BBC responded that saving are being given back for that item. KGREEN pointed out that this in not savings ; this is improper deflection of responsibility and resulting double cost to the owner. This is a fiduciary concern. ASU has identified accelerated billing for General Conditions work far beyond the proportional value with respect to construction in place. The amount involved is $100K's. TPEYTON responded that these costs had been incurred. ASU's position is that only proportional billing is premitted by the contract terms. This is a fiduciary concern. A Special Meeting for MON4APR11 was arranged to explore the owner's concerns with the above listed management issues of the project by the CM. This project is being transitioned to Ross Wood as SCO project monitor. Ross has been kept aprised of the issues on this project. He was not able to attend the Mar'll MC but

> will attend the SM 4APR11 as well as the APRIL11 MC's for ASU projects. (North Carolina State Construction Office Project Notes, 2011).

There are many things addressed in the SCO notes, but the primary point of contention concerns the additional $2 million in cost uncovered through the bidding of Phase III. Schlobohm of BBC contends that the problem, from the contractor's perspective, was the late issue of new drawings, as mentioned in the SCO notes. According to Schlobohm, many new drawing sheets and revisions to sheets were issued a few short weeks before the receipt of bids from subcontractors. When drawing revisions are made to an existing sheet set, the standard practice is to make a revision cloud around the area of concern, so that those viewing the new edition know where to look for changes. Schlobohm asserts that most changes were not inside of revision clouds, and there was ambiguity about what was new. Additionally, the subcontractors vying for the job had already performed a full unit-cost estimate on a prior revision. It is Schlobohm's opinion that the new drawing revisions forced the subs to either re-estimate the whole scope of work (which they probably did not have the time or resources to do so close to the submittal date), or simply tack on a heavy contingency for new things that might have been added to their scopes of work. Schlobohm thinks that the subs did the later, thus resulting in the extra $2 million.

BBC officially claimed scope-creep as one of the principal reasons for the cost overrun. Scope-creep is a trade term that means the scope of work grew beyond what was called for in the original scope. An example of scope-creep could be as simple as upgrading the paint on the walls, or as complex as updating the entire HVAC system. The scope-creep alleged in this case included both extremes, and ultimately, an arbitration session with the SCO resulted in officially acknowledging over $1.2 million of added scope to the project.

One other problem that was also noted in the SCO monitor's post was the lack of bidders for all bid packages. State Construction requires at least three bidders per bid package, and there is a mandatory number of bid packages required (the principal MEP trades, elevators, fire protection, security, and so on). Schlobohm reported that on bid day Boone received heavy snowfall, and this hampered the number of bidders who were able to deliver their bids to the jobsite. Additionally, he noted that many of BBC's top-tier contractors from the Charlotte region were not willing to travel the distance to Boone, so this limited the pool of subs bidding on the job. Either way, not receiving the required number of bids meant that those bid packages had to be re-issued, thus requiring more time, and potentially delaying the construction schedule.

These conditions resulted in a strained relationship between the owner, architect, and contractor from the beginning. From that point forward, even routine activities could become points of contention, and the job faced an unforgiving schedule. Yelton with Perkins and Will acknowledged the strain of the schedule, and added that contractors are under immense pressure to get projects completed on time and under budget. Although he acknowledged the challenges that existed on the Summit project, he does not give them any particular significance. As a seasoned design professional, Yelton simply saw the issues as routine dealings in the contentious and litigious world that is the modern construction environment.

Nonetheless, the initial squabbles did nothing to alleviate future construction problems. As mentioned, Summit is located in the middle of the ASU campus therefore, it is land-locked by the campus, and the construction site had only one way in and out. This traffic problem was complicated by limited staging and material laydown area. Tacked onto that was the addition of three concurrent building projects, as well as a steam tunnel. Added all together, this resulted in a congested site with limited access, on a campus with restricted hours, and a project with an accelerated schedule.

Furthermore, as Schlobohm reported on the limited number of Charlotte-based subs willing to submit bids for the job, this made for some challenging logistics outside of the job. BBC had trouble keeping a full roster of trades engaged on the site at all times. Initially, the trades would start their portion of the job strong; however, as time progressed, the number of tradespeople would diminish. At other times, it was difficult for the workers to retain temporary lodging around Boone. In some instances, Schlobohm reported, workers would be displaced from their hotel rooms because the hotel staff would claim that the rooms had been let-out in advance for football games. So the workers were made to vacate the rooms for the weekend, and they could re-occupy them the next week. On other occasions, it was reported that rates for hotel rooms would escalate to unreasonable amounts due to tourism demands, and workers would be required to pay those rates or leave. These claims have not been confirmed through other means, and were not expressed by representatives from the Mountaineer project.

There were other complications throughout the Summit building process that were either unpredicted or unplanned for. One such problem was keeping the interior of the structure semi-conditioned so that work could continue during winter. Due to the structural system of the building, the way that the cladding was detailed, and the time which the building was started, cladding could not be installed on the building immediately after the structure was finished. As such, there was a reinforced concrete frame, 10-stories high, but without any protection from the elements. To solve this problem, the management team of

BBC constructed temporary windows throughout the building using wood and polyethylene sheeting (Figure 37). Because certain aspects of the work necessitated moving from inside to outside with materials and equipment, these temporary structures were operable. So each of the 10 stories had temporary, operable, partitions for the duration of the winter, and inside of this, the space was conditioned with propane space heaters; a cost that was estimated at close to $60,000.

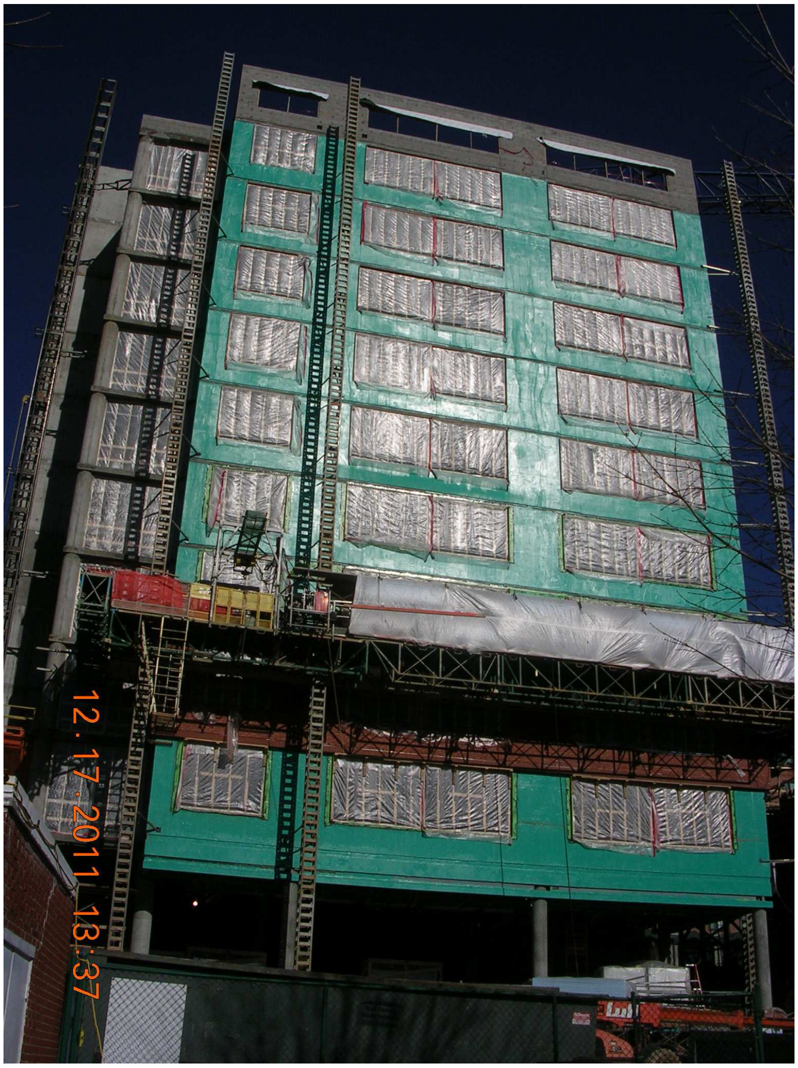


Figure 37. Temporary windows and walls constructed of wood and polyethylene sheeting during the construction of Summit Hall (photo courtesy of John Schlobohm).

11.29.2011 16:51

Figure 38. Sheet metal flashing installed under pre-cast concrete window sills. Notice the steel studs protruding through the flashing that caused the windows to leak after occupancy (photo courtesy of John Schlobohm).

In addition to these logistical concerns, there were also some architectural detailing problems that surfaced during and after construction. The punched-windows for the building were detailed in a manner that required around 35 steps, completed in multiple phases between different trades. There was a concealed lintel system used above each window that was a German product, and new to the US and the project team. Additionally, according to the plans, each window was supposed to install on top of a precast cast-stone sill, which was drawn sitting on top of a steel Hollow Structural Section (HSS) member, with no way to attach the sill to the steel framing. So, scrambling to come up with a suitable solution, the plan was to weld studs to the HSS framing and to drill holes in the precast sill for these studs. The sill would be placed on HSS steel, with the studs recessed in the drilled holes, securing the sill in place (Figure 38).

However, on top of the HSS member was the primary pan flashing that kept the window assembly dry. The steel studs had to penetrate the flashing, and these penetrations were sealed with sealant—not an ideal flashing condition. Nonetheless, the windows were installed in this manner, and all was well for a few months. After the building was turned Over, however, many of the windows began to leak, and they had to be inspected and replaced. The source of the problem was reportedly improper cleaning of the materials prior to installing the sealant; therefore the sealant did not properly adhere to all adjacent materials when it was installed. The affected windows were replaced during the summer of 2013, and there have not been any known problems with them since that time.

Surely there were other problems that flared at times, but those are the only ones of significance noted by the project participants. Ultimately, Yelton and the staff with Perkins and Will are proud of the building and think that it fits well with the style of the university, while also portraying a clean, modern, and green style. Officials with the university are somewhat ambivalent about the project. Sweet is surely happy with the result and what it will provide in the future; however, he has reservations about how the project was managed. Kane and McDonald with University Housing both decry the cost of the project, and do not appreciate some of the aesthetics of the building. Schlobohm and other BBC employees do not think that the project truly reflected the caliber of their company, and as Schlobohm put it "some people with the university are happy, some aren't, I wish the relationship could have been better with ASU."

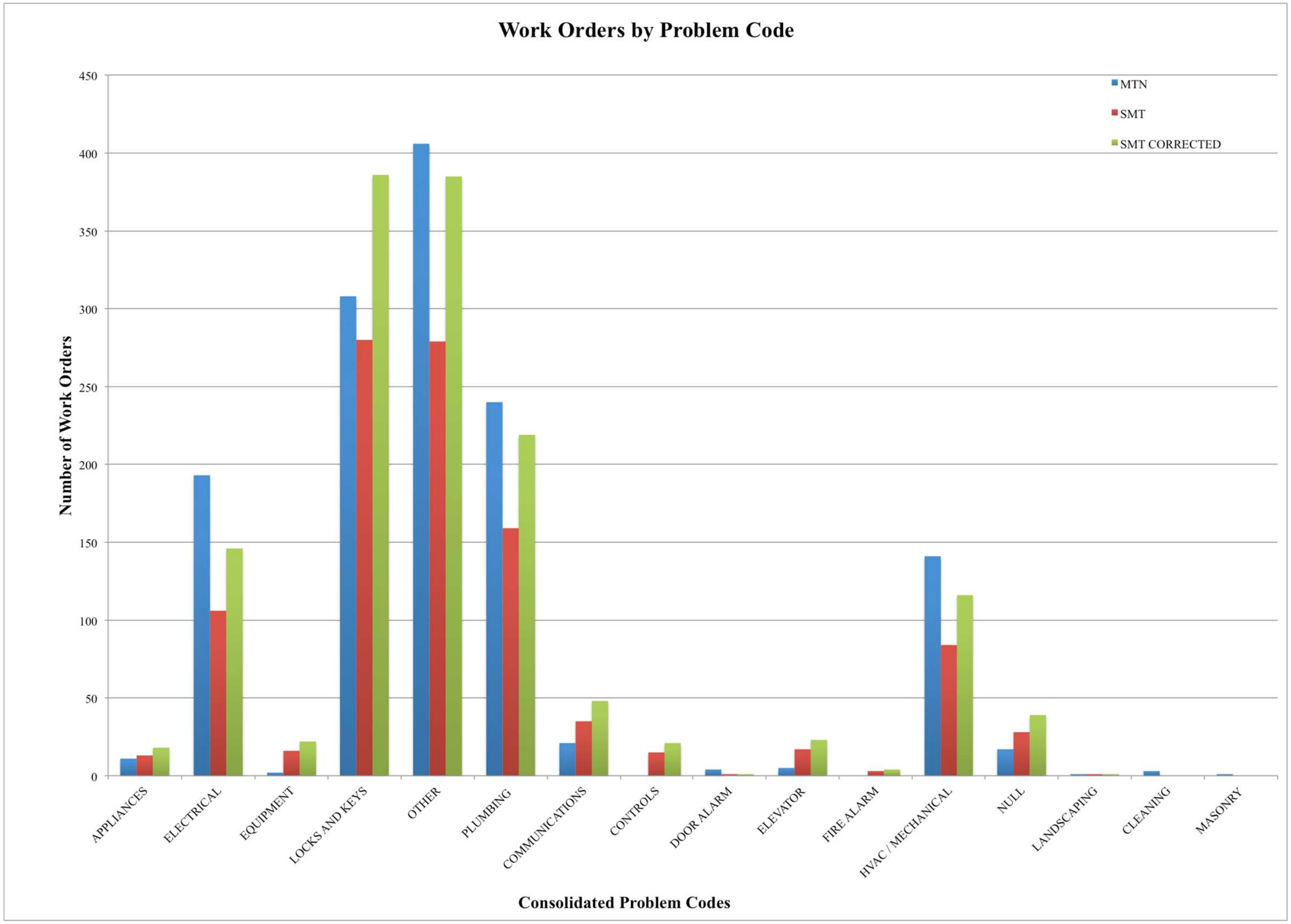


Figure 39. Work orders reported by problem code. The problem codes have been consolidated to eliminate redundancies.

Work orders as evidence of operational quality.

Both Mountaineer and Summit have drywall on the interior wall surfaces. In Summit most of the ceilings are painted concrete—painting the exposed concrete being a design change prompted by the owners during construction finishes—and the flooring is a combination of tile, resilient flooring, carpet, and terrazzo. The finishes in both buildings are typical for institutional residence halls, with the addition of premium finishes on the entry levels and in some common areas. However, it is not possible to track maintenance to interior finish surfaces from the automated work order processing system used by the ASU Physical Plant. This system logs work orders according to a generic problem code that corresponds to most of the major maintenance areas. Drywall and paint are not categories, but they each may be covered by the “other” category. As seen in Figure 39, aside from locked doors, and broken or lost keys, “other” dominates the number of work orders for both buildings.

No further explanation is given for the other category, but ASU Physical Plant staff members indicate that it can mean just that. Figure 39 also displays the other leading work order categories, those being plumbing, electrical, and HVAC respectively at both buildings. Of special note is the Summit Corrected value that is displayed in Figure 39, and in other work order graphs. Summit Corrected is a hypothetical number created to normalize the size disparity between Mountaineer and Summit, and to provide an indication of how many work orders might be expected if the two had the same number of beds and occupants. Summit Hall, with 333 beds, has 38% fewer residents than Mountaineer, which has 460 beds. As such, Summit Corrected multiplies each of the categorical fields by 38% to adjust the number of work orders per student. By no means is it proven that the number of work orders would increase in this linear manner, but this was a reasonable attempt to provide a more accurate comparison between the number of residents and the number of work orders.

Mountaineer leads in the number of work orders for each of the two complete years of data represented in this study. Removing locks and keys, and null claims from the mix, Mountaineer still holds the lead, netting a total of 1045 work orders compared to 758 at Summit. As seen in Figure 40, Mountaineer saw 565 works orders reported in its first year of operation, as compared to 361 with Summit. 565 at Mountaineer and 361 at Summit work out to about 1.22 and 1.08 work orders per year per bed, respectively. The second year of data shows a lower rate of work orders at Mountaineer, and a higher number at Summit. Mountaineer had 1.01 work orders per bed, or 464 work orders for the year. Summit had 370 work orders which is about 1.11 work orders per bed. Averaging the ratio of work orders to beds for both years yields almost equal numbers of 1.11 and 1.10 for Mountaineer and Summit.

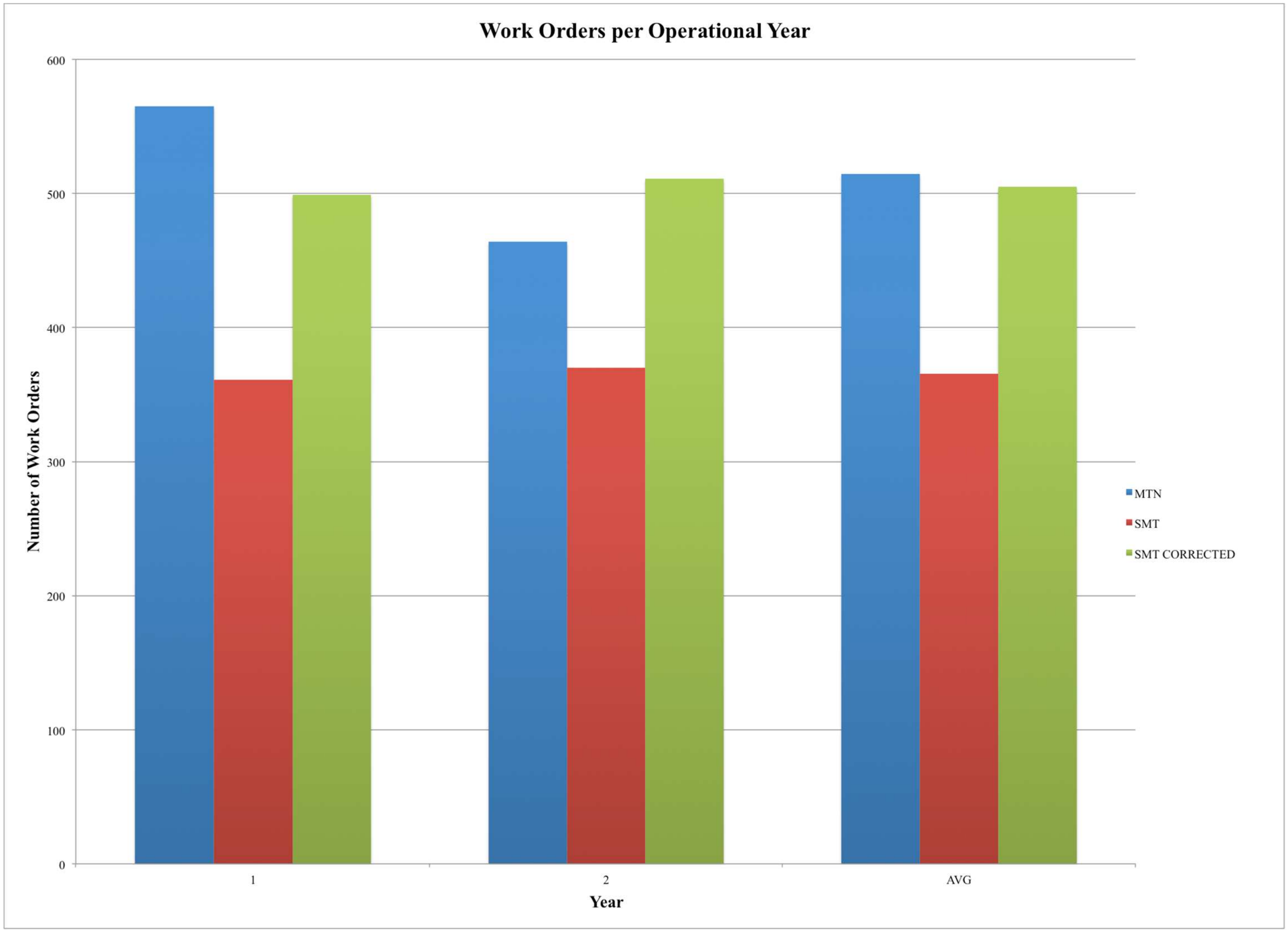


Figure 40. Total number of work orders per year by facility.

Resource consumption as evidence of operational quality.

Examining resource consumption, including energy and water, gives some indication of how well each building is performing. Unfortunately, as with maintenance data, some key inputs are missing in order to gain a comprehensive understanding of each building's energy use intensity. Likewise, there is limited operational data from which to gauge performance over time. For these reasons, outliers and anomalies can be difficult to justify or explain, and patterns have not yet emerged as they will in the next few years. Furthermore, there is limited information to make generalizations from. For instance, Summit has only one complete year of data, therefore, any claim relative to the annual performance of the facility must be considered preliminary.

From the simplest aggregate comparison, Summit consumes more than twice as much total energy as Mountaineer on an annual basis. As Figure 41 illustrates, Summit surpasses Mountaineer in both electricity and steam use. Mountaineer consumed more water and generated more sewage on an annual basis during the years for which data are available. From a per square foot perspective, Mountaineer used 28,600 Btu/SQFT while Summit used 69,400 Btu/SQFT annually; a difference of 40,800 Btu/SQFT per year.

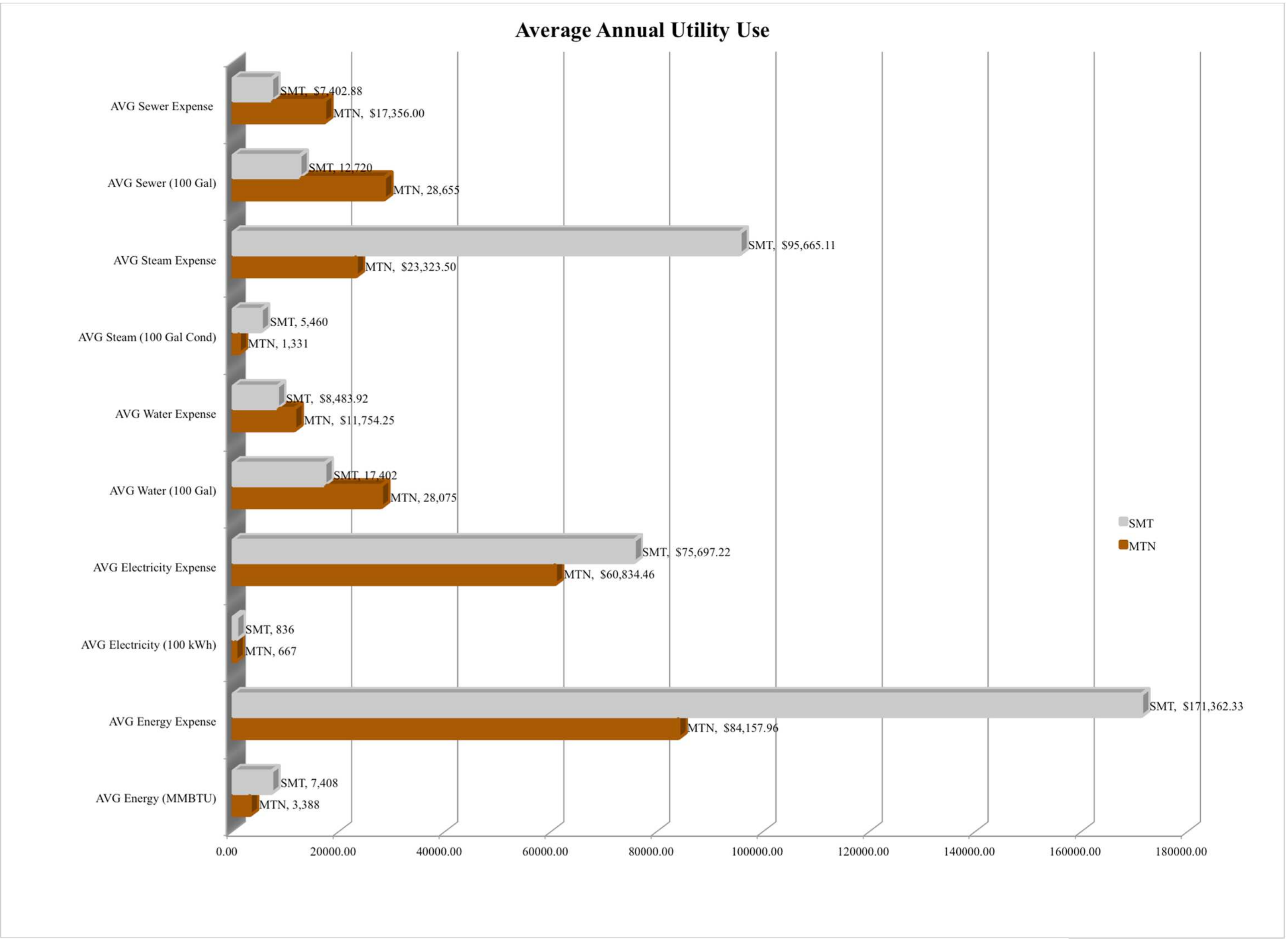


Figure 41. Average annual utility use including energy, water, and sewer.

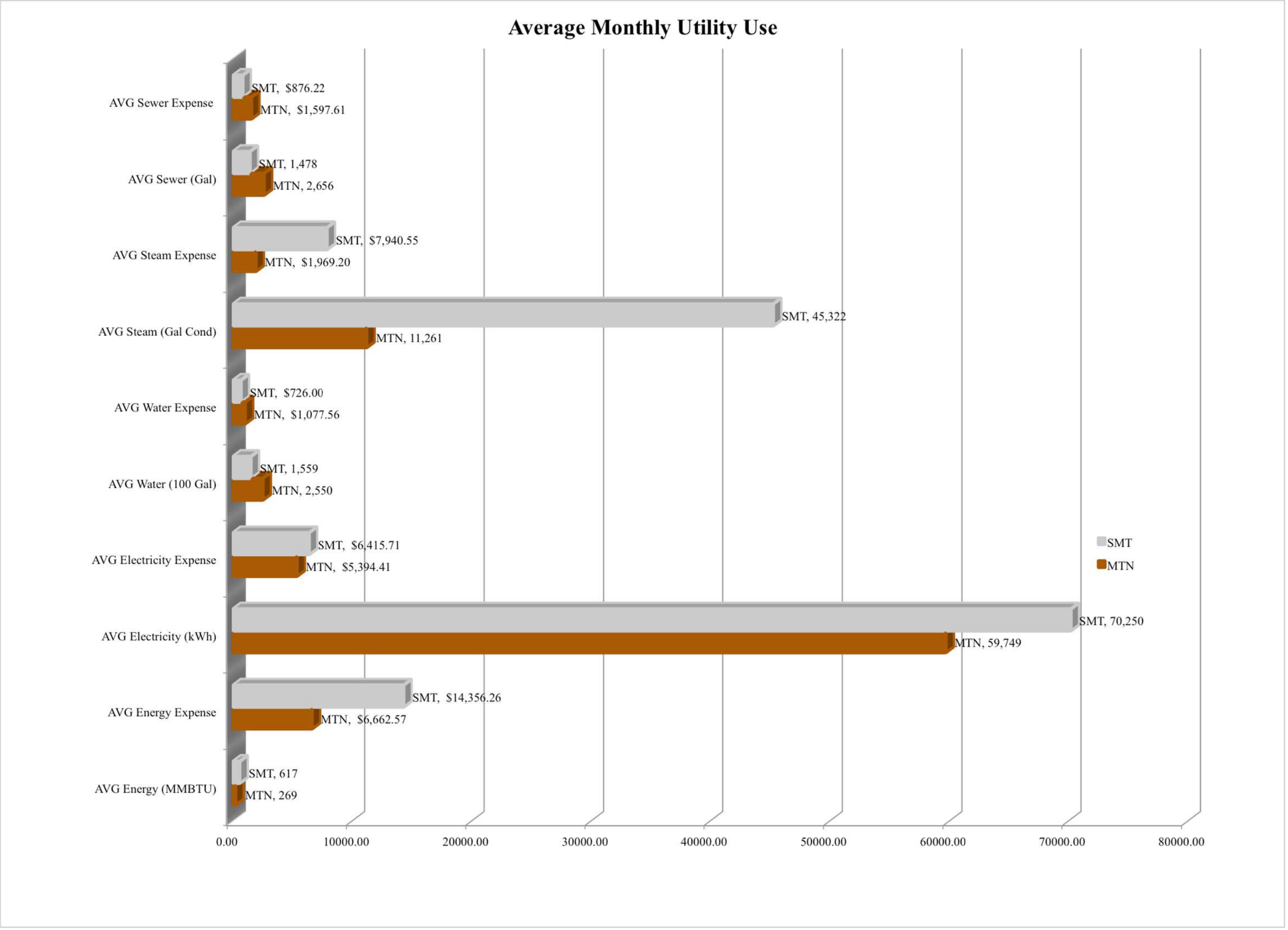


Figure 42. Average monthly utility use including energy, water, and sewer.

Mountaineer contributed over two times the amount of sewage as Summit per year at, 286,550 gal and 127,200 gal, respectively. The disparity between water consumption is not quite as stark with Mountaineer consuming 280,750 gal/year, and Summit taking in 174,020 gal/Year. As seen in the data in Figure 41, Summit greatly exceeded the annual steam consumption of Mountaineer with 546,000 gal cond annually, versus 133,100 gal cond/year for Mountaineer. As Figure 42 demonstrates, the annual trend of resource consumption is reflected on a monthly basis as well. However, the monthly average is better dialed in than the annual average because the data are distributed across more data points. As mentioned, there is only one complete year on which to base annual consumption on for Summit. On a monthly basis, however, there are 20 full months that are taken into account.

The factors contributing to the energy consumption at each building are similar in some ways, and starkly different in others. Mountaineer is wood-framed construction with 2x6 (nominal) walls and, fiberglass-batt filled wall cavities. These cavities have high-density R-21 insulation, and the exterior of the building has a continuous layer of ¾" Extruded Polystyrene (XPS) insulation, which is covered by one to two inch air-space and 4" nominal brick veneer. With all of the combined layers, and not taking into account openings, penetrations, voids, etc., the wall assembly has a U-value of .041. The perimeter of the building slab has 2" of XPS insulation with an R-value of 10. The building has a sealed crawlspace and basement walls with spray foam insulation around the perimeter bands of the crawlspace, and interior R-13 cavity insulation in the basement walls. The vented attic space has R-38 batt insulation at the ceiling plane, and the flat-roofed portions have a minimum of R-20 tapered polyisocyanurate. The windows of Mountaineer have a U-factor of .35, a Solar Heat Gain Coefficient (SHGC) of .62, and are low-e coated. All said, Mountaineer has a decent thermal envelope that by 2009 standards, before the 2012 NC Energy Code upgrades, was a high-performance enclosure in North Carolina.

Information about the thermal envelope of Summit is not as readily available, but there are some key details in the contract documents. As with everything else concerning Summit, one problem is that much of the information is packaged together into phased documents that often overlap buildings, but adhere to the phase, so there is ambiguity about some information. Summit has a basement with 10” cast-in-place concrete walls, faced with 2” XPS insulation on the exterior. The slab is not insulated. The concrete superstructure is filled with 6” light-gauge steel studs around the exterior perimeter, and these studs are faced with 5/8” gypsum sheathing. The studs are filled with R-19 batt insulation, and there is 2” of XPS continuous insulation around the building. On the outside of the exterior insulation is a 2” airspace and 4” of brick veneer. The U-value of this assembly is .032. There are also walls that are 8” precast concrete, and these too have 2” of continuous insulation. The glazing of the building has a U-value of .27, and a SHGC of .27.

All said, the thermal envelope of Summit is impressive in narrative format. The glazing is top-notch as a U-.27 assembly, and 2” of continuous insulation is still unpracticed on many higher performing buildings. However, there are a few caveats to go along with that. One is the amount of glazing used. The plans identify 32% of the envelope as glazed, which violates code by today’s energy standard. Additionally, a large portion of this is glazing is a west-facing curtain wall, which is not optimal for solar-thermal performance. That said, this study did not include an in-depth energy analysis of either facility, and will not go in-depth into energy performance.

The other main factor affecting energy performance at either facility is the fixtures and equipment inside. No matter where the line is drawn, Summit is infinitely more complex when it comes to the mechanical systems of the buildings. At $2.8 million, the mechanical division of this project was the most expensive portion of work. The building is equipped with a steam-to-water heat exchanger for building heat and domestic hot water. There is a supplementary solar thermal water heating system located on the roof. The building has a four-pipe HVAC system with individual vertical fan-coil units in each room, and a distribution system that includes Variable Frequency Drive (VFD) motors and Variable Air Volume (VAV) distribution boxes for common areas (Figure 43). The HVAC system is equipped with a full Building Automation System (BAS) that has a full array of sensors both inside and outside, along with the accompanying controls to make the BAS work. There are separate mini-split unitary heat-pump systems for specialty spaces such as mechanical rooms. The elevator and stairwell shafts have pressurization systems, and the entire building has a full sprinkler system. On the electrical side there is a complete emergency generator along with all of the switchgear, automatic transfer switches, circuitry and distribution necessary to provide a static uninterruptible power supply.

The list for Summit could go on. Of course there are lighting fixtures, and plumbing fixtures, and all of the components that make a building. Enumerating each of those will not provide a better context for understanding the building as it pertains to this study. However, it is notable that the plumbing fixtures have low flow ratings, and the lighting fixtures have high efficacy.

Figure 43. One basement mechanical room of Summit Hall with chilled water and building hot water lines connected to circulation pumps (photo by author).

Mountaineer, by contrast, is simple compared to Summit. The primary heating and cooling system for each unit is a Packaged Terminal Air Conditioning Unit (PTAC). These PTACs are actually independent heat pumps that provide both warm and cool air. They are the sorts of equipment seen in motel rooms, where the controls, diffuser, and evaporator are located inside the unit on the wall, and the condenser hangs through to the other side where heat is exchanged with the outdoors. Aside from the PTAC, there is a ventilation fan located in each bathroom that is ducted directly outdoors. Areas of the building that are not conditioned by a PTAC have another heat pump service them. These other heat pumps are typical residential split-systems, and there are several located throughout the building. Mountaineer also has an array of controls and sensors to control the indoor environment. Similar to Summit there are BAS sensors and controls in each residential unit and corridor. Mountaineer also has a full, wet fire suppression system. Additionally, there are 42 radon mitigation fans constantly operating to keep the radon gas level inside of the building low—these were a requirement of LEED for Homes (Figure 44). Further details about the energy and resource characteristics of each project are presented in the discussion section of this chapter.

Figure 44. Condensing units of split-system heat pumps visible on the roof of Mountaineer Hall. Also visible near the attic access door is one of the 42 radon mitigation fans (photo by author).

Discussion

From the onset it was noted that Summit and Mountaineer Halls provided the ideal context for a case study comparison between a modular and conventional project. However, as the details of each project bear out, there are more differences than similarities between the two structures, and one-to-one comparisons are out of the question. Nevertheless contrasting the merits of one project and construction system against those of the other illuminates the strengths of each system, even if an outright champion cannot be declared.

Mountaineer took about two years to fully come about, from approved idea to occupancy. Of those two years, approximately 18 months were spent in design and construction, and the actual construction was complete in less than 12 months. Summit, as noted, came to be in about three years of actual design and construction. The construction period lasted for nearly two years, with about 19 months spent building the residential tower without the ancillary site and infrastructural components.

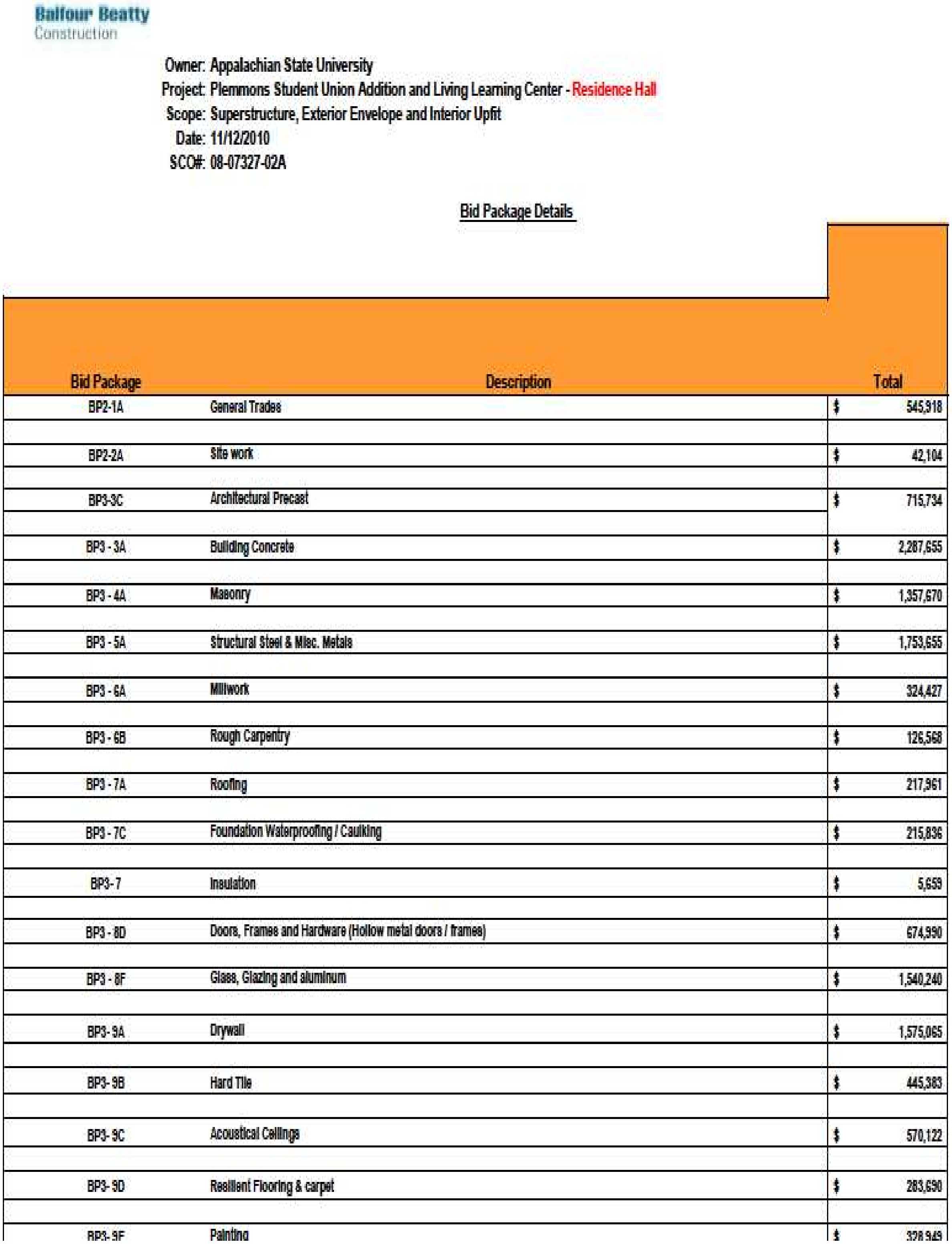
From those figures, a couple of things are obvious. Mountaineer at 118,434 square feet was built in 12 months, and Summit at 106,820 square feet was built in 24 months, give or take for both projects. Choosing a modular approach allowed the structure and accompanying modular components of Mountaineer to begin fabrication while demolition and site prep was taking place on site. Although John S. Clark did not have a cleared site turned over to them until July 2010, along with Hunter Saak they were able to set all of the modules in 30 days, and have the entire modular facility under trusses and a roof before December 2010. This allowed ongoing work to proceed during the winter without much complication due to weather.

Summit, being a cast-in-place concrete building, also got its primary start in the summer—which is often the case on university campuses, where disrupting classes is a serious imposition—but substantial building construction did not commence until January 2011 (Figure 45). Although the building structure was complete in time for winter, the team was not able to get a skin on the building to protect it from winter. They were able to get walls and sheathing installed, but could not install any glazing due to the sequencing required by the cladding detail. Thus, they had to install the plastic and wood enclosures to keep the weather out. Although some of this complication was caused by the construction system used, the other significant contributor was the detailing of the openings—a design detail that could have been worked through if caught earlier in the process.

Figure 45. Deep foundation piles are installed, and reinforcing steel is being tied for pile caps on the foundation of Summit Hall. Notice the date of January 2011. Although construction started in Summer of 2010, building construction was just ramping up in 2011 (photo courtesy of John Schlobohm).

For both projects, there were weather related delays that afflicted the schedule. Luckily, both projects hit the mark with critical milestones that allowed them to work through the winter. However, each project was negatively affected in one way or another. With Mountaineer, the interior finishes were not kept warm, and as a result, flooring was damaged and needed repair. Summit was not able to install glass, and had to build temporary protection throughout the winter. There are more acute examples, but the important point is that neither project was immune from the effects of weather. For Mountaineer, the modular approach curtailed the overall construction duration, but could not prevent later weather complications. Summit, although built completely outdoors, was not completely halted by the winter. The construction schedule allowed the building to go up between winters, and if not for the window debacle, construction progress would not have been impeded.

One other aspect of construction duration that is important to consider is the actual amount of work that went into each project. While the black and white historical record of how long each project took is fact, it does not account for how much labor was attributed to each job. The truncated schedule of Mountaineer was made possible by workers laboring in a factory while others were busy at the jobsite. As Schlobohm pointed out, on Summit, BBC had issues keeping a full staff of subs on site. This is not uncommon in construction, as often a contractor will commit a certain amount of resources to a project on paper, but in practice other jobs and obligations and personal issues with employees, draw those resources away. Considering this common problem, Summit—and Mountaineer, for that matter—could have finished earlier than it actually did. The only way to make a true comparison of time-to-completion is to account for all labor hours that went into the project, and to view those within the context of other needed and available resources necessary to complete the project.



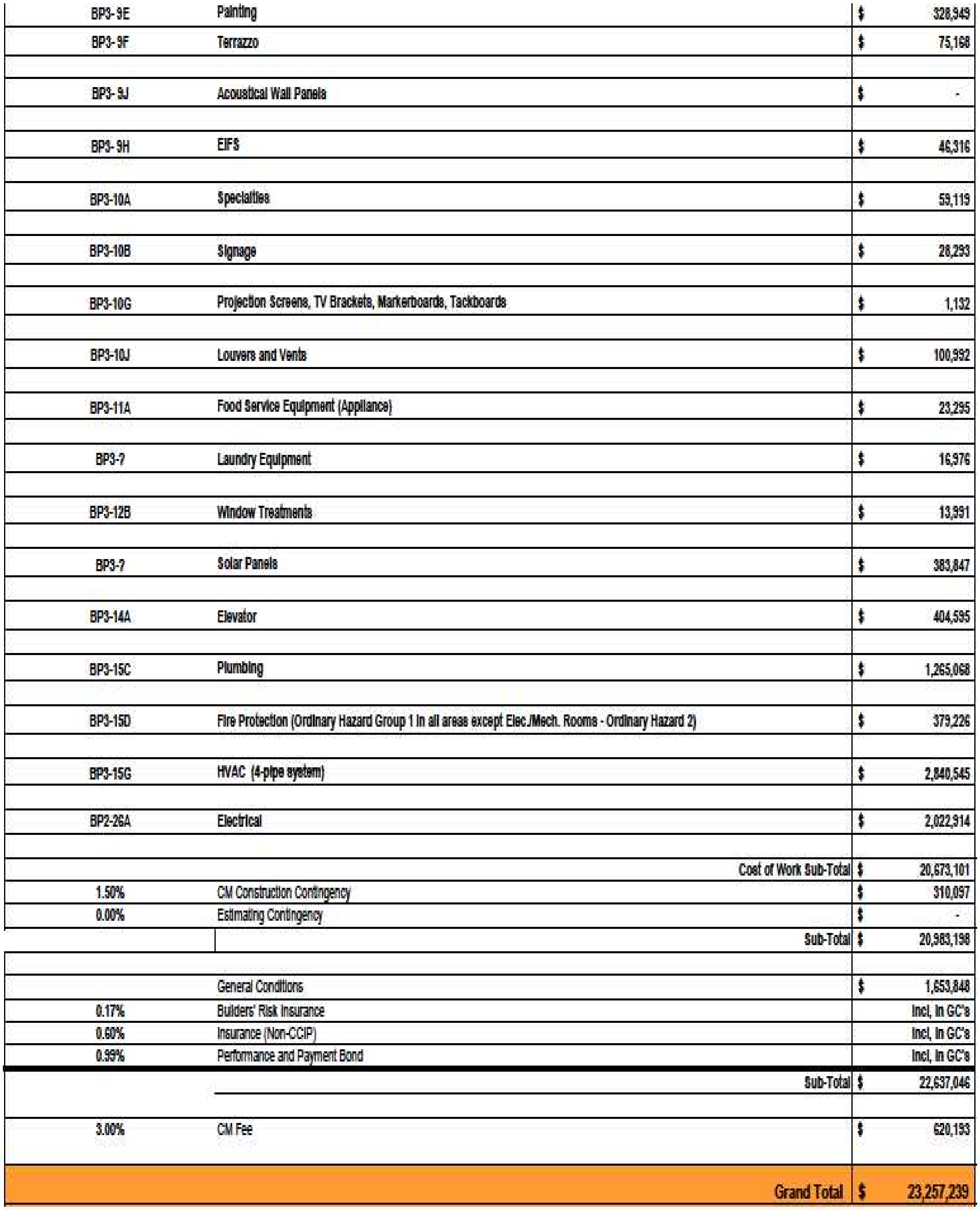
Balfour Beatty
Construction

Owner: Appalachian State University
Project: Plemmons Student Union Addition and Living Learning Center - Residence Hall
Scope: Superstructure, Exterior Envelope and Interior Upfit
Date: 11/12/2010
SCO#: 08-07327-02A

Bid Package Details

Bid Package	Description	Total
BP2-1A	General Trades	$ 545,918
BP2-2A	Site work	$ 42,104
BP3-3C	Architectural Precast	$ 715,734
BP3 - 3A	Building Concrete	$ 2,287,655
BP3 - 4A	Masonry	$ 1,357,670
BP3 - 5A	Structural Steel & Misc. Metals	$ 1,753,655
BP3 - 6A	Millwork	$ 324,427
BP3 - 6B	Rough Carpentry	$ 126,568
BP3 - 7A	Roofing	$ 217,961
BP3 - 7C	Foundation Waterproofing / Caulking	$ 215,836
BP3 - 7	Insulation	$ 5,659
BP3 - 8D	Doors, Frames and Hardware (Hollow metal doors / frames)	$ 674,990
BP3 - 8F	Glass, Glazing and aluminum	$ 1,540,240
BP3- 9A	Drywall	$ 1,575,065
BP3- 9B	Hard Tile	$ 445,383
BP3- 9C	Acoustical Ceilings	$ 570,122
BP3- 9D	Resilient Flooring & carpet	$ 283,690
BP3- 9F	Painting	$ 328,949

Figure 46. Summit Hall Phase III FGMP Bid Package details submitted by Balfour Beatty Construction (NC State Construction Office, 2010).



BP3- 9E	Painting	$	328,949
BP3- 9F	Terrazzo	$	75,168
BP3- 9J	Acoustical Wall Panels	$	-
BP3- 9H	EIFS	$	46,316
BP3-10A	Specialties	$	59,119
BP3-10B	Signage	$	28,293
BP3-10G	Projection Screens, TV Brackets, Markerboards, Tackboards	$	1,132
BP3-10J	Louvers and Vents	$	100,932
BP3-11A	Food Service Equipment (Appliance)	$	23,295
BP3-?	Laundry Equipment	$	16,976
BP3-12B	Window Treatments	$	13,991
BP3-?	Solar Panels	$	383,847
BP3-14A	Elevator	$	404,595
BP3-15C	Plumbing	$	1,265,068
BP3-15D	Fire Protection (Ordinary Hazard Group 1 in all areas except Elec./Mech. Rooms - Ordinary Hazard 2)	$	379,226
BP3-15G	HVAC (4-pipe system)	$	2,840,545
BP2-26A	Electrical	$	2,022,914
	Cost of Work Sub-Total	$	20,673,101
1.50%	CM Construction Contingency	$	310,097
0.00%	Estimating Contingency	$	-
	Sub-Total	$	20,983,198
	General Conditions	$	1,653,848
0.17%	Builders' Risk Insurance		Incl, In GC's
0.60%	Insurance (Non-CCIP)		Incl, In GC's
0.99%	Performance and Payment Bond		Incl, In GC's
	Sub-Total	$	22,637,046
3.00%	CM Fee	$	620,193
	Grand Total	$	23,257,239

Figure 46 (continued). Summit Hall Phase III FGMP Bid Package details submitted by Balfour Beatty Construction (NC State Construction Office, 2010).

Mountaineer was designed and built for roughly $16,500,000; it cost approximately $31,000,000 to design and build Summit. Of the $31 million spent on Summit design fees were around 8.2%, which is standard for that type of project. Design fees are not known for Mountaineer, but in conversations with Sykes, the architect, he did not indicate that there was anything exceptional about the design fees for the project. For Summit the construction management fee was 3%, again a standard figure; any associated margins for the Mountaineer design-build profit are unknown.

From a per-unit perspective, Mountaineer cost $139 per square foot and $5,869 per bed. In contrast, Summit cost $290 per square foot and $93,093 per bed. All other things being equal, there is a large disparity between the cost of Mountaineer and that of Summit. Unfortunately, the quality of information available for the cost of Mountaineer is not equal to that of Summit. For Summit, a wealth of information is available that divides cost by building, trade, bid package, and so on (Figure 46). At the same time, however, there is so much information that it is a challenge to find and ensure the values at hand are correct, and not from preliminary budgets.

Some headway can be made in dissecting different costs that were exceptionally expensive. For one, the cost of the site at Mountaineer was a known $2.4 million. The site work for the entire CLS project, including Summit, was $1.6 million--$42,000 of which was attributed to Summit. Contrarily, the HVAC system for Summit cost $2.8 million. *RS Means 2010 Detailed Costs* (Mews, 2009) data suggests that the type of PTAC units that Mountaineer has should cost about $1000 each, for labor and materials. The building has around 230 PTAC units, which would cost $230,000. Additionally, there are ventilation fans in the bathrooms, ductless mini-split systems in some areas, and ducted air-source heat pumps for common areas; all of those costs combined with the PTAC's are $500,000 at most.

There are other significant costs as well. For instance, combining the cost of concrete and steel for Summit gives a value in excess of $4 million for the structure alone. Of course, looking at the first cost is only considering part of the total cost. The first cost tells nothing about the cost to operate the building, the life of the assembly, or maintenance costs. Through an LCCA, the whole life-cycle cost of an entire building or an HVAC system can be determined.

Life Cycle Cost Analysis

An LCCA was performed for Mountaineer and Summit using the data collected for initial costs and operational costs. The LCCA accounted for the initial cost of each building, non-recurring maintenance costs, recurring maintenance costs, operational costs such as utilities, and the replacement or renovation costs for each facility. An inflation rate of 2.7%, as recommended by the SCO, was used for all future costs. Additionally, the costs were discounted at a rate of 5% to estimate how much could be made by investing today the capital and operating costs into an investment account earning 5%. The LCCA was initially performed for a 100-year period, assigning a lifespan of 30 years to Mountaineer, and 100 years to Summit.

Table 11. *Life Cycle Cost Assessment summaries for Mountaineer Hall and Summit Hall.*

LCCA COMPARISON		
MODULAR		
TOTAL	**UNDISCOUNTED**	**DISCOUNTED**
COST	$ 418,502,067.58	$ 39,273,488.09
MODULAR ADJUSTED FOR SALVAGE		
COST	$ 288,217,528.08	$ 38,900,085.78
CONVENTIONAL		
COST	$ 339,360,506.55	$ 55,485,657.91
DIFFERENCE CONVENTIONAL - MODULAR		
NON ADJUSTED	$ (79,141,561.03)	$ 16,212,169.82
ADJUSTED	$ 51,142,978.47	$ 16,585,572.12
LCCA COMPARISON NO MAINTENANCE		
MODULAR		
TOTAL	**UNDISCOUNTED**	**DISCOUNTED**
COST	$ 373,007,815.06	$ 36,048,756.31
MODULAR ADJUSTED FOR SALVAGE		
COST	$ 252,022,514.17	$ 35,702,006.11
CONVENTIONAL		
COST	$ 270,793,490.08	$ 50,159,995.65
DIFFERENCE CONVENTIONAL - MODULAR		
NON ADJUSTED	$ (102,214,324.98)	$ 14,111,239.34
ADJUSTED	$ 18,770,975.91	$ 14,457,989.54
LCCA COMPARISON NO MAINTENANCE NO UTILITIES		
MODULAR		
TOTAL	**UNDISCOUNTED**	**DISCOUNTED**
COST	$ 316,275,970.15	$ 31,606,862.55
MODULAR ADJUSTED FOR SALVAGE		
COST	$ 195,290,669.26	$ 31,260,112.35
CONVENTIONAL		
COST	$ 176,675,158.42	$ 42,790,878.17
DIFFERENCE CONVENTIONAL - MODULAR		
NON ADJUSTED	$ (139,600,811.72)	$ 11,184,015.62
ADJUSTED	$ (18,615,510.83)	$ 11,530,765.82
LCCA COMPARISON 50 YEARS		
MODULAR		
TOTAL	**UNDISCOUNTED**	**DISCOUNTED**
COST	$ 68,074,232.92	$ 31,589,569.58
CONVENTIONAL		
COST	$ 94,010,078.65	$ 49,164,843.09
DIFFERENCE CONVENTIONAL - MODULAR		
NON ADJUSTED	$ 25,935,845.73	$ 17,575,273.50

In the LCCA, Mountaineer was replaced every 30 years with a new building that was calculated as the inflated value of $16.5 million the number of years into the future when it would be built. Summit received a major renovation every 33 years that was valued at half of $31 million inflated to the amount that it would be in the future, an amount that was reached by examining the costs of current UNC dorm renovations. Non-recurring maintenance items were determined according to the SCO LCCA guidelines for life expectancy of building systems (Brinkley & Stanford, 2001). Utility expenses were gathered directly from the ASU Physical Plant, and maintenance expenses were calculated as .04% of the building cost.

As Table 11 demonstrates, over 100 years the total life-cycle cost of operating Mountaineer Hall is estimated at $418,502,067.58. That amount for Summit is $339,360,506.55, a difference of about $79 million. However, that is the inflated amount of each cost without taking into account the discount rate, or the salvage value of the modular building constructed in year 90. A salvage value for this facility is calculated by depreciating its value for the 10 years that it is in use by year 100, and crediting the 20-year value to the overall capital expense. With this salvaged value added, the 100 cost for Mountaineer is $288,217,528.08, which is $51 million less than the 100-year cost of Summit. Regardless of whether a salvage value is credited to Mountaineer, by looking at the discounted value of each project, Mountaineer is about $16 million less by today’s dollars.

The LCCA goes through several iterations that explore how the life-cycle cost of each facility is affected if certain variables are removed. For instance, if all of the maintenance costs are removed from each project, then Mountaineer has a total cost of $373,007,815.06 before salvage and $252,022,514.17 after salvage. For Summit, that amount is

$270,793,490.08. If maintenance and utilities are removed from the calculation, then Mountaineer costs $316 million before salvage and $195 million after; and Summit is $176.6 million. However, if those amounts are discounted back to today, then Mountaineer is $11 million less than Summit.

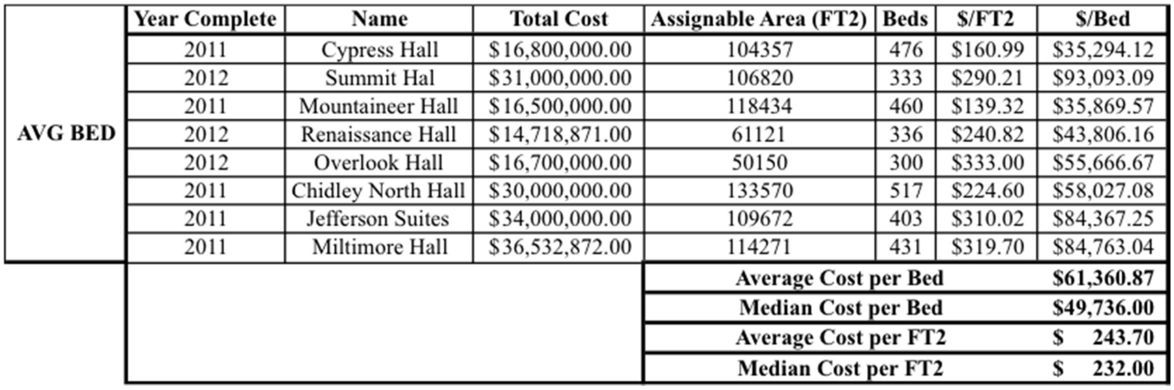
Through all of these calculations, there are a lot of assumptions. One is that inflation will be a steady 2.7% increase per year for the next 100 years, or will at least average somewhere in that range. Another is the discount rate, and the process of applying that. The reason behind applying a discount rate is sound, but perhaps exaggerated in this case. Applying a discount rate is recommended to demonstrate how much money could be earned if the amount of the expense were instead invested in an interest-bearing account earning the discount rate per year. Of course the rate itself is an assumption, because it is unknown if the investment will continue to earn at that rate for the specified period. This technique is useful in determining if an investment in an energy saving device or some other similar measure is worthwhile. However in the case of a university, and a capital expense for a new building, there is not much of an alternative investment. The LCCA comparison could take into account a renovation versus a new building, but either way, money is being spent, not invested. Also, the new building is usually not without a need, so not building is only optional if other space is currently being rented for the future building's use at a cheaper amount—there again, eliminating the offset investment. Regardless, all LCCAs must take into account present values of future expenses, even if the future values are only discounted to the inflation rate.

Another assumption deals with the life expectancy of the building and materials. In 30 years, Mountaineer Hall may be fully functional, and without need for significant repair.

Likewise, in 100 years Summit may be just fine, and ready for another 100 years. The fact is, the life expectancy assigned to buildings is arbitrary, and is based on certain materials and systems lasting for an expected amount of time, even though there is contradictory evidence in both directions. Nonetheless, for planning purposes it is useful to have a baseline to go against.

To take some of the uncertainty out of the calculation, a 50-year LCCA was performed. The 50 year calculation used all of the same inputs as before, but simplified matters by assuming a lifespan of 25 years for Mountaineer, and 50 years for Summit. In this scenario Mountaineer is rebuilt at 25 years, and Summit receives a full-gut renovation at the same time. This removes the uncertainty of salvage value from the calculation, removes the assumed planned maintenance on major systems, and reduces the chance for economic uncertainty over a 100-year span. According to this calculation, Mountaineer has an undiscounted cost of $68 million, while Summit comes in at $94 million, a difference of $25 million.

Table 12. *Average Costs of UNC Residence Halls Completed During 2011 and 2012.*



	Year Complete	Name	Total Cost	Assignable Area (FT2)	Beds	$/FT2	$/Bed
AVG BED	2011	Cypress Hall	$16,800,000.00	104357	476	$160.99	$35,294.12
	2012	Summit Hal	$31,000,000.00	106820	333	$290.21	$93,093.09
	2011	Mountaineer Hall	$16,500,000.00	118434	460	$139.32	$35,869.57
	2012	Renaissance Hall	$14,718,871.00	61121	336	$240.82	$43,806.16
	2012	Overlook Hall	$16,700,000.00	50150	300	$333.00	$55,666.67
	2011	Chidley North Hall	$30,000,000.00	133570	517	$224.60	$58,027.08
	2011	Jefferson Suites	$34,000,000.00	109672	403	$310.02	$84,367.25
	2011	Miltimore Hall	$36,532,872.00	114271	431	$319.70	$84,763.04
				Average Cost per Bed			**$61,360.87**
				Median Cost per Bed			**$49,736.00**
				Average Cost per FT2			**$ 243.70**
				Median Cost per FT2			**$ 232.00**

As Table 12 illustrates, the average cost of UNC residence halls built during 2011-2012 is about $61,000 per bed. If this amount is multiplied by the estimated need of 14,678 beds (see Board of Governors of the University of North Carolina, & Eva Klein and Associates (1999) for explanation) that equals almost \$895 million dollars. If, conservatively, the cost for modular was estimated at \$40,000 per square foot, that would be a cost of about \$590.7 million, or 49% cheaper than the present cost. If, removing all operational costs, those two figures are put through an LCCA that only accounts for capital expenses and renovation costs, then the results are interesting. If, similar to the analyses with Mountaineer and Summit, the renovation cost is assumed at half of the present cost of construction, and the replacement cost is equal to 100% of the current cost inflated to the future value in the corresponding year, then over 50 years, modular would both cost about \$1.8 billion.

The reason for the shift in cost is simple, as can be seen in the equation for calculating future values is:

$$FV = PV(1 + r)^n$$

Where:

FV = future value

PV = present value

r = interest rate

n = number of years of interest

Therefore:

$$590 + 590 * 1.03^{25} \approx 895 + 448 * 1.03^{25}$$

This means that without any operational costs to temper the initial expenses, working with the assumptions that modular buildings will be replaced and conventional buildings will be renovated according to a strict schedule, and an inflation rate greater than 2%, then modular projects will cost the same as conventional over 50 years if undiscounted. Thus, it is obvious that any LCCA of this nature that is carried out for actual decision-making purposes must carefully weigh which assumptions are valid to ensure accurate results.

Another financial comparison that sheds a similar light on the two projects is a profit and loss comparison. As seen in Table 13, the 2014-2015 rental rate for Mountaineer and Summit is $4,900 and $4,700 per student per semester, respectively (ASU Housing and Residence Life, 2014). Multiplying the rate per bed by the maximum capacity of each facility gives the maximum anticipated revenue per year. Using historical data for utility rates, and a uniform cost for maintenance, a yearly operating cost was determined for each building. The two were also hypothetically financed with 20 year debt, at 5% annual interest, as is suggested by the SCO LCCA Guidance (North Carolina State Construction Office, 2014). Given these inputs, during the first calculated year of operation, Mountaineer earned a net $687,930 or $1,495 per bed, while Summit lost $1,201,242 or $3,607 per bed.

Running the inputs through a 20-year cycle with 2.7% inflation per year, and Mountaineer revenues would be positive by over $29 million, while Summit would operate at a 20-year loss of over $14 million. In each of these cases, the fact that Summit has only 333 beds greatly influences its profitability. If Summit had the same number of beds as Mountaineer, then it would be net positive over the 20-year span.

Table 13. *Profit and Loss Table for Mountaineer and Summit Over One Year, 20 Years, and the Life of Each Building.*

Profit and Loss Summary		
Categories	**Mountaineer Hall**	**Summit Hall**
Initial Capital Costs	$16,500,000.00	$31,000,000.00
Renovation Capital Costs	$0.00	$15,500,000.00
Utility Costs per Year	$113,267.00	$187,247.00
Cost per Work Order	$250.00	$250.00
Square Feet	118,434	106,820
Beds	460	333
Work Orders per Bed per Year	1.12	1.10
Amortization Period (years)	20	20
Interest Rate	5%	5%
Inflation Rate	2.7%	2.7%
Rental Rate per Bed per Year	$4,900.00	$4,700.00
Lifespan	30	60
Gross Revenue at Max Capacity	$2,254,000.00	$1,565,100.00
Annual Capital Debt	($1,324,002.69)	($2,487,520.20)
Annual Operating Expense (Year 1)	($242,067.00)	($278,822.00)
Net Annual Revenue (Year 1)	$687,930.31	($1,201,242.20)
Annual Capital Expense per Bed	($2,878.27)	($7,470.03)
Annual Operating Expense per Bed (Year 1)	**($526.23)**	**($837.30)**
Net Annual Revenue per Bed (Year 1)	**$1,495.50**	**($3,607.33)**
Gross 20 Year Revenue	$62,591,355.17	$43,461,282.15
Gross 20 Year Operating Expense	($6,721,961.66)	($7,742,611.73)
Total Capital Expense	**($26,480,053.77)**	**($49,750,404.06)**
Net 20 Year Revenue	**$29,389,339.74**	**($14,031,733.63)**
Gross Lifetime Revenue	$107,184,801.03	$236,458,809.92
Gross Lifetime Operating Expense	($11,511,048.46)	($42,125,051.63)
Total Capital Expense	**($26,480,053.77)**	**($105,070,117.85)**
Net Lifetime Revenue	**$69,193,698.80**	**$89,263,640.44**
Net Lifetime Revenue / Lifespan	**$ 2,306,456.63**	**$ 1,487,727.34**
Present Values		
Gross Lifetime Operating Expense	$5,176,087.08	$8,517,533.11
Total Capital Expense	$11,907,087.77	$21,244,797.88
Combined Expense Present Value	**$17,083,174.85**	**$29,762,330.98**

When the operating costs for each of these facilities are extended to the buildings' hypothetical full service life, then Summit is profitable. At 60 years Summit would have generated $89 million in gross profit while also including a renovation capital expense valued at half of the original construction cost. At 30 years, Mountaineer would have earned $69 million in gross profit. However this does not include any renovations or major repairs as it is assumed that the building would serve 30 years and expire with most of its major systems intact. If the gross lifetime profit of each building is divided by the number of years in its lifespan, then the ratio of profit to lifespan is in Mountaineers favor at $2.3 million versus $1.5 million for Summit. Giving consideration to the time value of money, when the lifetime capital and operating expenses for each building are discounted at the inflation rate this yields a $17 million investment for Mountaineer, and a $29.8 million investment for Summit at present value.

Much of the data concerning quality has already been discussed, but there are some pieces warranting further analysis. As noted, quality is much more than quantitative data and it is difficult to assign a quality score to Mountaineer and Summit. Yet, to start with the quantitative data that does express some level of quality, work orders provide a starting point.

Summit and Mountaineer are almost on par with each other on a per-unit basis for work orders, with Summit at 1.1 per bed and Mountaineer at 1.12 per bed. However, solely on number of work orders issued Mountaineer edges out Summit with 1028 compared to 729 (removing lock and keys and null work orders). There is not much else within the work orders, and based on those measures, the two buildings are nearly one for one, with Mountaineer accumulating more total work orders. Year by year graphs of work orders per building are included in Appendix D.

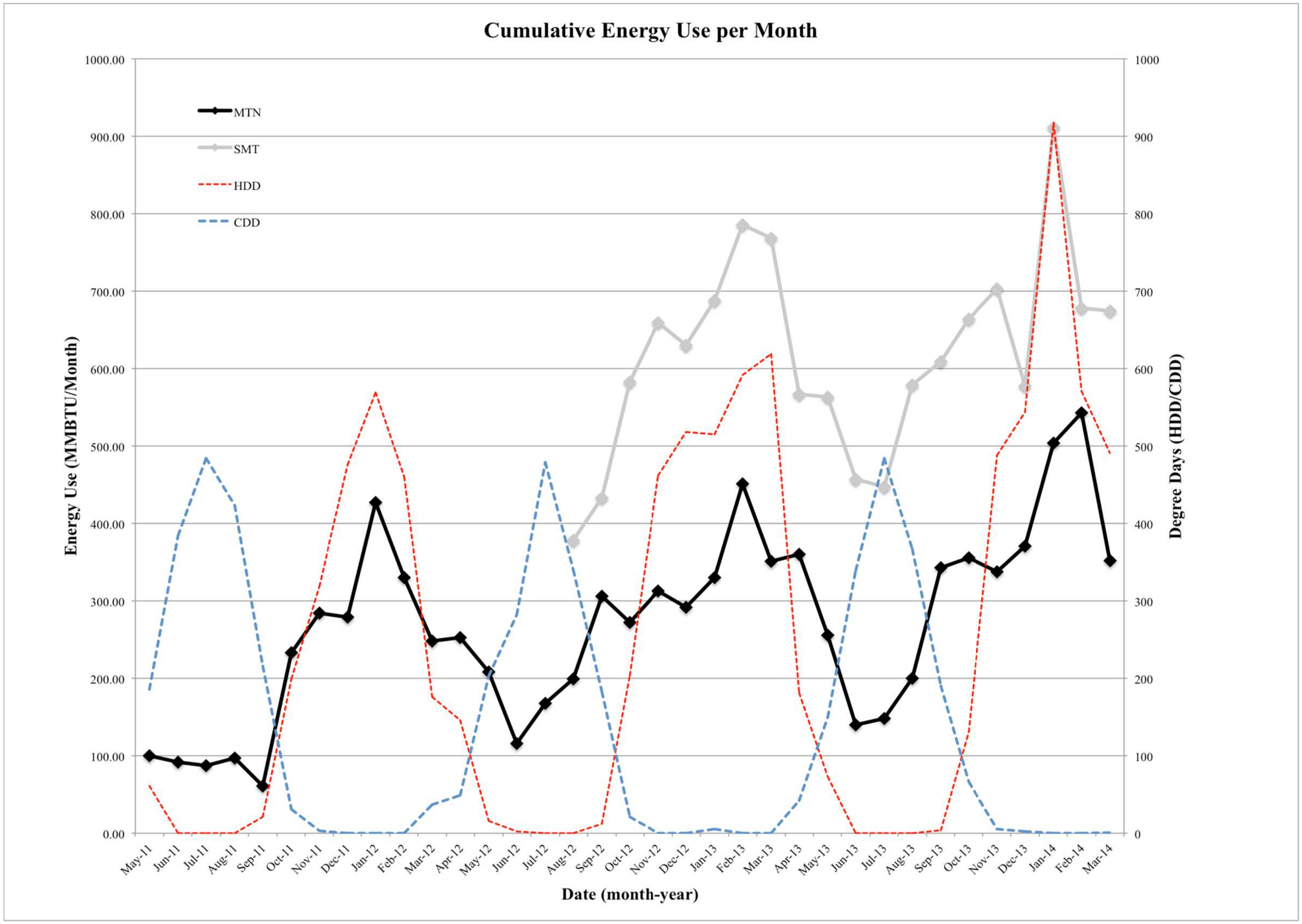


Figure 47. Cumulative energy use at Mountaineer and Summit with Heating Degree Days (HDD) and Cooling Degree Days (CDD)

The other quantitative measure that reflects quality is energy and water consumption. Summit far exceeds the consumption of Mountaineer at 7,408 MMBTU per year versus 3,388 MMBTU per year; this amount of energy comes at a cost of $171,362, and $84,157, respectively. With respect to building size, this equals 69,350 BTU/SQFT for Summit and 28,606 BTU/SQFT for Mountaineer. By volume, these equal 6,274 BTU/CUFT for Summit, and 2,946 BTU/CUFT for Mountaineer.

With water the relationship changes, and Mountaineer used 2.8 million gallons to Summit's 1.7 million gallons per year. The same is true on sewage production, with Mountaineer leading at 2.8 million gallons per year, and Summit following with 1.2 million gallons. The number of plumbing fixtures is strongly tied to these numbers, and when examined on a per capita basis, the difference in consumption drops from a 61% increase to a 12% increase between Mountaineer and Summit.

As seen in Figure 47, energy use at both buildings is strongly tied to the number of Heating Degree Days (HDD). Because Boone is a heating-dominated climate, there is more demand for heating throughout the year than cooling. Additionally, when there is demand for cooling, most of the student population is not living on campus. As Figure 47 shows, during the months of June and July, energy use drops precipitously when the dorms are vacated. Additionally, Figure 47 shows that the energy data available for Summit does not go back further than August 2012, only providing one complete year of energy data.

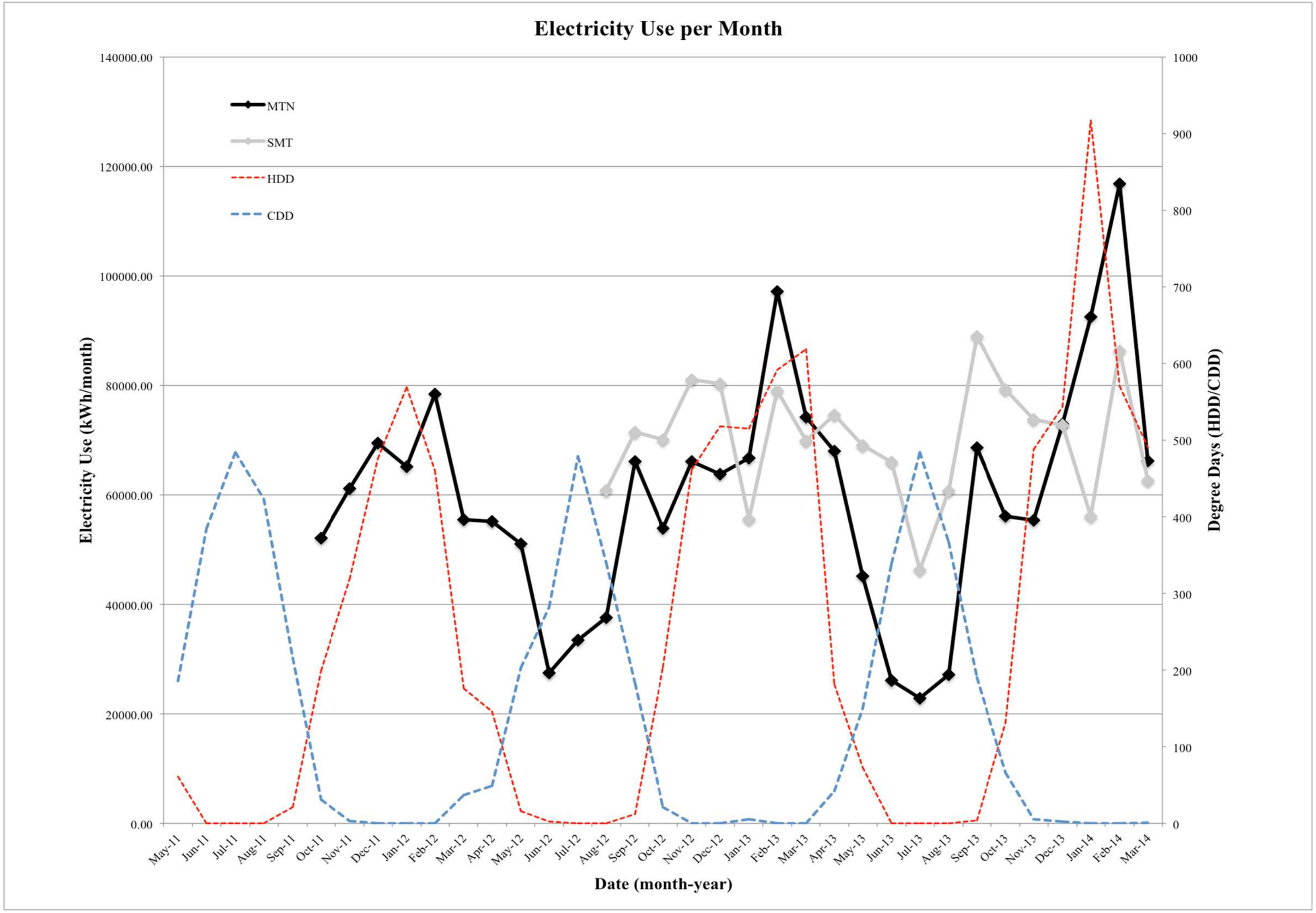


Figure 48. Average electricity use per month at Mountaineer Hall and Summit Hall with Heating Degree Days (HDD) and Cooling Degree Days (CDD).

As Figure 59 represents, steam use at Summit trumped that of Mountaineer because Summit has a four-pipe HVAC system with a heat exchanger that utilizes the campus steam system. Likewise, electricity use at Summit exceeds that of Mountaineer even though Mountaineer is conditioned with electric HVAC equipment (Figure 48). Accordingly, Figure 49 shows how the electricity use at both buildings escalated as the HDD's increased, especially at Mountaineer.

Figure 50 shows how energy use in both buildings generally decreased as the Total Degree Days (TDD) decreased. There are some exceptions to this, such as during academic breaks when students are largely not present, and some spikes that are otherwise unexplainable without examining a greater range of historical data and variables, but for the most part, as TDDs go down, so does energy consumption. This trend continues until the TDDs decrease to around 200 per month, which would be a daily average temperature of about 60º-70ºF. Figure 50 also charts the difference in energy consumption between the two buildings. As indicated by the trend line, the difference in energy consumption between buildings decreased as the number of TDDs decreased. This suggests that Summit uses a greater portion of its energy for heating and cooling than Mountaineer. However, a complete energy audit of each facility would be needed to unequivocally make this assertion. Appendix E contains additional graphs that track energy and water use at each facility.

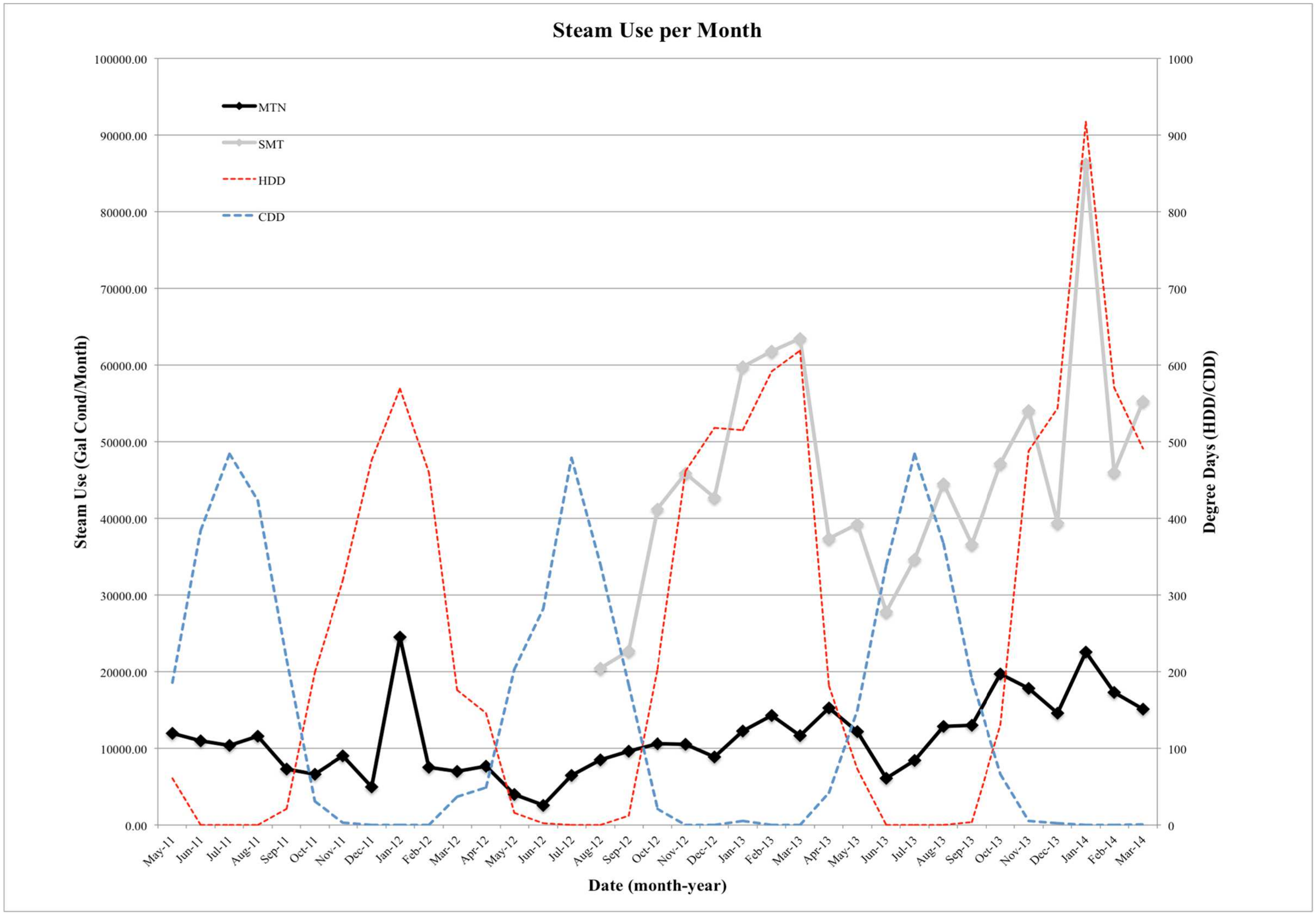


Figure 49. Average steam use per month at Mountaineer Hall and Summit Hall with Heating Degree Days (HDD) and Cooling Degree Days (CDD).

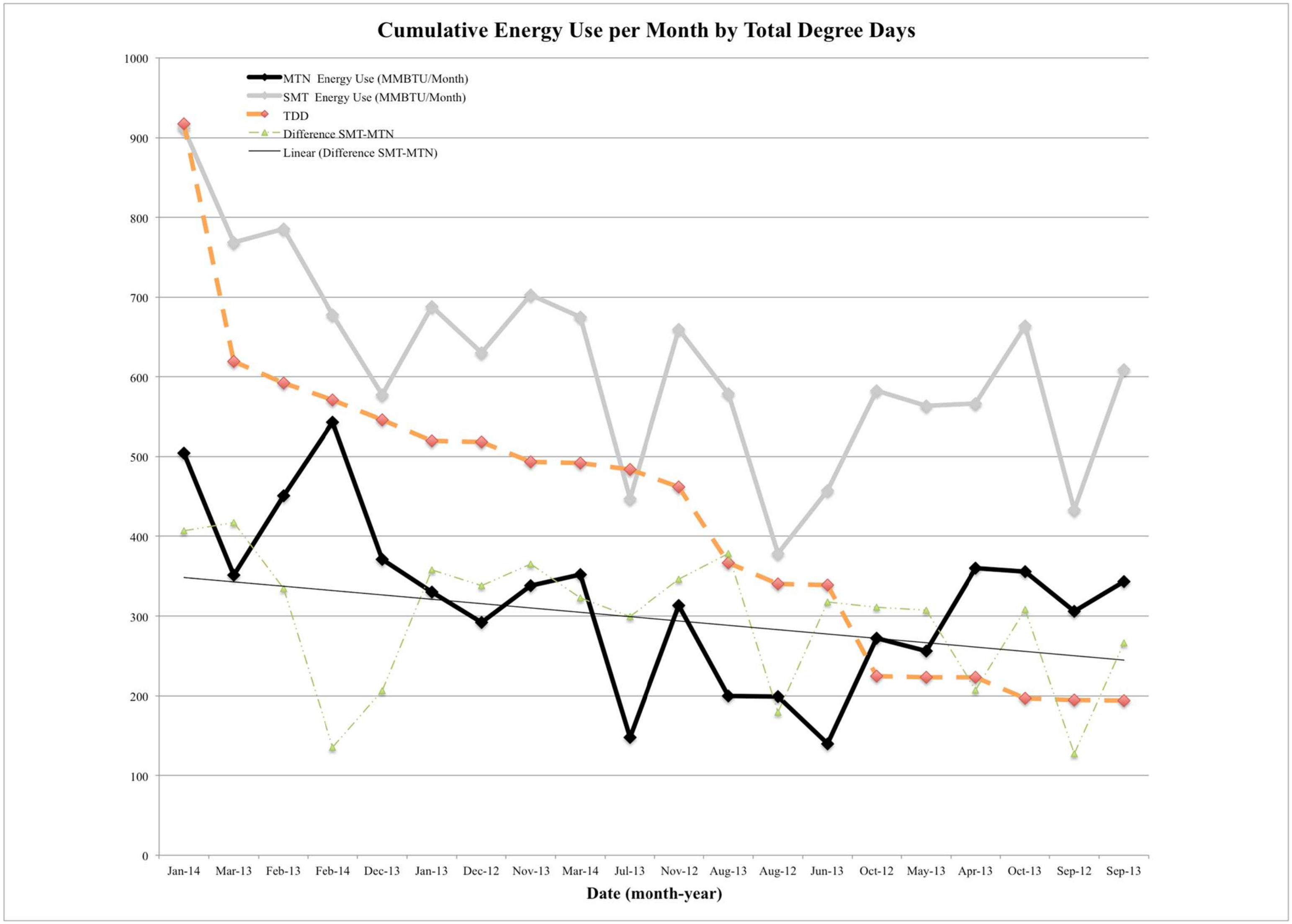


Figure 50. Average cumulative energy use per month at Mountaineer Hall and Summit Hall in relation to Total Degree Days per month.

Of particular interest at each facility is how certain energy efficiency and sustainable design measures have been undermined. Both facilities have solar thermal water heating systems, and both of these systems are disabled and have been for some time. McDonald with ASU University Housing claims that these systems are decommissioned because the Physical Plant does not have the expertise needed to troubleshoot and maintain them. As of August 2014, McDonald and other staffers were trying to get a few people from the university trained on solar water heating technology.

Additionally, there are controls in each building that are disabled. In Summit, students in the dorm rooms were making drastic changes to their thermostats and were not responsibly controlling the temperature while away from their rooms resulting in undue energy use and maintenance demands. As a result, the Physical Plant staff disabled the HVAC controls in each room, and now the whole building is adjusted remotely. While this could prevent excess energy use and abuse on the individual controls, it also increases energy use. Since students do not have the flexibility to control the heating and air in their rooms, they instead open windows and run fans while the mechanical systems are operating. So in the winter, when the heat is operating and the students are too hot, they leave a window open. Likewise, in the summer if they are too cool they open the window. In both seasons, personal fans are commonplace.

Mountaineer is immune from this dilemma because each PTAC unit is equipped with a sensor that is attached to the window. Similar to a home security system, when the window is opened, the PTAC will automatically turn off.

In Mountaineer, when the first crop of students went through the building, maintenance received many complaints about the lights. The problem was that the lights were turning on during the night, while students were asleep. After investigation, the staff learned that the occupancy sensors, although located at the door and away from the bed, were sensing motion during the night. When students moved in bed while asleep, the occupancy sensor would trigger the lights. Since this was discovered, the sensors have been disabled, and now the lights are manually operated.

Also in Mountaineer, the smoke seals around the perimeter of each door were preventing the doors from closing automatically. To keep the doors shut, the staff went around and removed all of the smoke seals. Additionally, in Mountaineer there are 42 independent radon mitigation systems. According to LEED for Homes, the certification program for Mountaineer, buildings in geographic areas with high radon levels must be mitigated. Boone is an area with high radon levels. Emmons noted that although this was a topic of discussion during design, it was not considered an issue worthy of addressing. However, when the building was under construction and seeking certification, it became apparent that these systems would be required, so they were added retroactively.

From a purely aesthetic and first impression perspective, both buildings look and feel comfortable. Mountaineer looks and feels less grandiose, and it is. When walking the main-level corridors of Mountaineer, sounds travel through the wooden framing, and the feel underfoot does not have the density felt when walking on concrete, but the floors do not noticeably deflect. It is not possible to detect any difference in dorm room wall and ceiling finishes between Summit and Mountaineer, they both look equal in quality. However, the common areas of Summit are more luxurious, and make the lobbies similar to a hotel. There is fritted glass in certain common areas, wood paneling, and stone accents. The common area kitchen in Summit has commercial appliances, and the whole building has more a modern theme.

At the same time, the modern theme of Summit conflicts with many of the finishes, and was a source of contention during construction. When ASU representatives saw the exposed mechanical systems, and just how open the design was supposed to be, they panicked. For this reason, there were many change orders that called for paint, and covering where it was not originally intended. In the Summit dorm rooms the ceilings are painted with a textured paint that accentuates the marks left by concrete formwork (see Appendix F). In the lobby areas on each floor of Summit there is a stark contrast between finished drywall, painted concrete, exposed concrete, cables, and pipes. Altogether, in many places it looks like many different people were designing the same space, and after all, many people were. Unfortunately many of these clashes in style may have been the result of owner changes designed to cut costs or alter the design intent.

However, there are other things that could have been value-engineered out but were not. For instance, in the closed off, auxiliary stairwells, the stairs are overly expensive. The stair treads are made of stainless steel diamond plate. The railing is a continuous piece of expanded, painted metal, and the actual handrail is made of tubular stainless steel. Altogether, a very costly staircase for an area that will not be used much.

As mentioned by ASU Housing Director Kane, one of his pet-peeves in housing maintenance is not being able to easily work on the building, be that systems or paint. With Mountaineer, the PTAC units are an interesting example on this point. Although these units are not bastions of efficiency—they have a Coefficient of Performance of 4.0—and they do not begin to compete with the complexity of the Summit chiller and fan-coil units, what they lack in sophistication, they make up for with ease of use. McDonald noted that his staff has a room of PTAC units located on site, and if one of the units has a problem, his staff can remove and replace the defective unit in less than an hour. This does not disable a large portion of the system, and it does not require a highly-skilled technician to do. What is more, every unit in the entire building could be replaced 10 times, and it still would not cost what the mechanical system in Summit does.

Overall, the difference between the PTAC units at Mountaineer and the centrifugal chillers of Summit could be a metaphor for the difference between Mountaineer and Summit as buildings. Mountaineer is simple, it is an efficient use of space, it was cheap, and it works. Summit is complex, it houses 25% fewer students based on floor area, and it cost 70% more than the average, equivalent UNC residence hall built during the same time—and 90% more than Mountaineer. The true test between these two buildings will be how well they perform over time, and how much time each is able to beneficially contribute to the university.

CHAPTER 7: CONCLUSIONS

Part I: Survey

Through an online survey of 59 design and construction, university housing, and maintenance professionals located throughout the 16-campus University of North Carolina (UNC) System, it was determined that modular construction has been used only one time to date for residence hall construction at a UNC institution. The one project that utilized modular is Mountaineer Hall at Appalachian State University (ASU). Through the survey, reasons cited for choosing or considering modular construction included time and cost savings during construction. Reasons for not considering modular included concern over the quality of the finished product; uncertainty about the regulatory implications of using modular; and little to no information—or misinformation—about what modular construction is, and how it can be used. Survey data with abbreviated questions and answers are listed in Table 13, and the full-text of the survey is listed in Appendix A.

Part II: Interview

Interviews conducted with a sample of UNC officials derived from Part I, and with representatives from the NC State Construction Office (SCO) illustrated what issues are most important while planning for a new student housing project, and how those concerns may impact future adoption of modular construction. Eight interviews were conducted, with questions for each interview derived from answers provided through the survey, and built upon data collected through other primary and secondary sources. The major themes that surfaced in the interviews were project duration, financial implications, quality assurance, regulatory concerns, and other related topics.

Table 13. *Survey Responses and Response Rates by Question. Questions and Answers Are Abbreviated for Brevity. Full Survey Text is Available in Appendix A.*

Number of Responses			**19**
Q#	**Qusestion / Answer**	**Responses**	**Rate**
Q1	**Occupational Title**		
	housing	6	32%
	D+C	5	26%
	facilities	7	37%
	business	1	5%
Q2	**Time in current position**		
	<1	0	0%
	1 to 3	2	11%
	4 to 6	5	26%
	> 6	12	63%
Q3	**Time in the professional field**		
	1 to 9	2	11%
	10 to 15	0	0%
	>15	17	89%
Q4	**Have used modular construction**		
	yes	5	26%
	no	14	74%
Q5	**Number of modular projects**		
	1 to 2	4	80%
	3 to 4	1	20%
	> 5	0	0%
Q6	**Decisions to use modular**		
	time	5	100%
	cost	5	100%
	quality	0	0%
	other	0	0%
	not sure	0	0%
Q7	**Have considered using modular**		
	yes	2	14%
	no	12	86%
Q8	**Reasons for choosing another system over modular**		
	time	1	5%
	cost	2	11%
	quality	6	32%
	other	13	68%
Q9	**Other methods of construction used**		
	conventional site built	7	47%
	other prefab system	1	7%
	not considered	3	20%
	modular	3	20%
Q10	**Will consider using modular on projects that develop in the next 2 years**		
	yes	3	16%
	no	16	84%

Of principal concern when considering new housing projects was how long it would take for the projects to reach beneficial occupancy. Interview subjects noted that a typical housing project that proceeds through the SCO takes at least two to three years from the time the idea is breached. From ideation and approval, projects typically spend a year in design, around six months in review and bidding, and another 12-18 months in construction. For those in university housing, that duration is too long, because they need their projects shortly after initial approval. This duration is partly responsible for the proliferation of privatized housing projects that are built and owned by a university non-profit foundation but operated by the university. After several years, the projects become property of the UNC institution that arranged for their construction.

The other factor contributing to the escalation of privatized university housing is the potential cost savings of this approach. Officials noted that when projects abide by the SCO standards, the projects are built to a higher standard than what is required by NC Building Code. The reason for this is part legislative, and part campus design standard. On each UNC campus, design and construction standards exist to provide a cohesive campus appearance, and to guarantee the durability of capital projects. However, according to UNC officials interviewed, these standards are onerous, and mandate buildings with initial costs that can exceed the revenue expected from those facilities. Furthermore, interviewees contended that projects of this sort are generating undue debt that cripples future expansion unless more debt is accrued.

The SCO contends that the higher standards imposed on UNC projects are in place to protect the best interests of NC and its residents. In one SCO official's words "you've got to make it a little more stout if you want it to last any time at all." This statement refers to the belief that college students inflict extra abuse on student housing facilities, and therefore that, facilities must be more durable to ensure their longevity. However, many UNC representatives interviewed think that this durability edict results in housing facilities that are more akin to bomb shelters. They believe in quality facilities that will last for their intended use, but object to the 50-100 year lifespan required of UNC buildings. It is their belief that building a facility to last for such a span is financially daunting today, and restrictive of future space planning, especially if the building in question does not last the entirety of its planned lifecycle, as was the case with Winkler Hall at ASU.

All of these concerns funnel into skepticism throughout the UNC system about the laws pertaining to UNC capital projects, and about the efficacy of the SCO. Interviewees are frustrated by laws that require them to perform additional tasks, or build to a higher standard, yet provide no additional means to assure compliance. The individuals interviewed would like more flexibility in the contracting methods available to them, but acknowledge that change is slowly transpiring, as is the case with House Bill 857, passed in 2013, that added additional contract structures for public projects. Along with the legislative frustrations, many UNC representatives share an uneasy relationship with the SCO that is often fearful. While officials dislike the policies that SCO is entrusted to uphold, they acknowledge that the office has a difficult task, with far too few resources, and that they have seen progress within the last few years.

Nonetheless, every UNC official interviewed had some derisive comment for the SCO process. From an outsider’s perspective, the way that the SCO was described was analogous to a benevolent dictatorship—do whatever the SCO says, and do not, under any circumstance, do anything that will draw extra attention from, or lose favor with, the SCO. If you do, then your project will be delayed or rejected, and you will rue the day that you offended the SCO. The SCO replies that they are simply enforcing the laws given them, and that they value serving their customers of the UNC system.

Although wide-ranging, all of these facts and opinions influence the foothold of modular construction throughout the UNC System. Starting with the regulations, UNC institutions are simply unsure of what is allowable by the SCO, and often, they are unwilling to test the waters with an unconventional project type. Many people are skeptical about the quality of modular because they have impressions of the technology that are influenced by years of substandard manufactured housing. Likewise, there are not many modular champions throughout the UNC system, with most of them coming from ASU, where they had success using the technology. However, many interviewees grasp the potential time and cost benefits of a modular system, and were it not for opposition at their own campus, or reticence to question the SCO, they would be willing to try it.

Part III: Case Study

Part III was an in-depth investigation into two residential housing projects built at ASU. Mountaineer Hall is a privatized, modular facility that was built during 2010 and 2011, and first opened for residents in July 2011 Summit Hall is a traditional UNC project that was built from 2010 to 2012, and housed its first residents in July 2012. Details of each project are provided in Table 14.

Table 14. *Selected project details for Mountaineer Hall and Summit Hall.*

Project Details	**Mountaineer Hall**	**Summit Hall**
Architect	CJMW	Perkins + Will
General Contractor	John S Clark	Balfour Beatty Construction
Contract	Design-Build	CM at Risk
Dorm Style	Hotel	Suite
Primary Structure	Wood Modular	Reinforced Concrete
Primary Cladding	Brick Veneer	Brick Venner / Glass Curtain Wall
Primary Heating	PTAC	Steam to Water HEX
Primary Cooling	PTAC	Chilled Water
Primary Ventilation	N/A - Spot Ventilation	OAU w/ Heat Recovery
Primary Water Heater	Steam Instantaneous DWH	Steam Instantaneous DWH
Typical Wall U Value	0.041	0.032
Typical Window U Value	0.35	0.27
Green Building Certification	LEED Gold (Homes)	LEED Silver (pending)
Lifespan (years)	30-40	50 +
Year Complete	2011	2012
Area (SQFT)	118,434	106,820
Volume (CUFT)	1,150,046	1,180,750
Capacity (beds)	460	333
Total Cost	$ 16,500,000.00	$ 31,000,000.00
Cost per SQFT	$ 139.32	$ 290.21
Cost per Bed	$ 35,869.57	$ 93,093.09
Project Duration (years)	2	3
Construction Duration (months)	≈ 11	≈ 20
Average Annual Energy Use (MMBTU)	3,388	7,408
Average Annual Energy Use per SQFT (BTU)	28,607	69,350
Average Annual Steam Use (Gal Cond)	133,125	546,033
Average Annual Electricity Use (kWh)	60,834	75,697
Average Annual Energy Expense	$ 84,157.00	$ 171,362.00
Average Annual Water Use (Gal)	2,807,500	1,740,248
Average Annual Water Use per Bed (Gal)	6,103	5,226
Average Annual Water Expense	$ 11,754.00	$ 8,483.00
Average Annual Sewar Use (Gal)	2,865,500	1,272,012
Average Annual Sewar Expense	$ 17,356.00	$ 7,402.00
Average Work Orders per Bed	1.12	1.10

As depicted by Table 14, Summit cost nearly twice as much to build, took almost twice as long to build, and is costing significantly more to operate. However, as straightforward as those measures are, they do not provide a comprehensive overview. Summit was apart of a complicated, multi-phased campus expansion known as the Center for Leadership Studies (CLS) that resulted in four capital projects, with Summit being the largest. The mechanical infrastructure of Summit is closely aligned with underground resources for other buildings, and all of the projects occurred at the same time. Multiple projects simultaneously happening on the same site undoubtedly complicated matters to a heightened degree, and makes objective comparison with a stand-alone project such as Mountaineer unrealistic.

Additionally, Summit is substantially more complicated than Mountaineer—even though Mountaineer is built of pre-made pieces that had to be accurately designed and built at a factory while the foundation was being built, and then trucked to the site. Summit has sophisticated mechanical equipment (and plenty of it) where Mountaineer does not. Summit is a high-rise with deep foundations, and Mountaineer is a low-rise with simple spread footings. Summit is supposed to last at least 50 years (hopefully closer to 100) and Mountaineer is supposed to last 30 to 40 years at most.

Indeed, there are many differences between the two projects that make a direct comparison impossible. What is more, many of the comparable attributes and data, such as operational expenses, are not solely derivatives of modular construction, but rather, independent design decisions (e.g., the mechanical systems). There can be no winner or loser, at this point, and one is not better than the other. Yet, there is enough information about each project to make some justified arguments. Mountaineer Hall has shown that it is viable to use modular construction for residence halls on UNC campuses, despite the fact that it is starkly different from Summit. This poses the question: If one facility can do more with less, why is more necessary? The conventional answer is that Mountaineer will not last, and Summit will. The only way to know the answer to that question is to wait at least 50 years, and that does nothing for the present.

A Life Cycle Cost Assessment (LCCA) is one way to predict future expenses, and is one tool for decision making in such situations. An LCCA of Mountaineer and Summit shows that over 50 years, Mountaineer could be $17.5 million cheaper than Summit; at 100 years Mountaineer is still cheaper by $16 million. The criticism here is that an LCCA makes many assumptions. Although, this is true, the assumptions are grounded in historical data making them more reliable, and follow the precedence of many such projections.

As with the other data regarding these buildings, however, it is again difficult to generalize this LCCA to other modular and conventional projects. While Summit definitely cost $93,000 per bed, and is consuming 7,408 MMBTU per year, that is not typical of other UNC residence halls. The average cost per bed for UNC residence halls built in 2011 and 2012 was about $61,000. If energy and operating costs for Mountaineer were considered average, then at $61,000 per bed, the 50-year costs for a conventional project are only $2 million more than for modular. Furthermore, there is nothing to say that a modular building must be made of wood. For that matter, perhaps a steel modular building would be more appropriate. If a steel modular project of the scale of Mountaineer were constructed, it is estimated that it would approach the $50-$60,000 per bed mark.

Due to the uniqueness of each potential new project, it is impossible to unequivocally state how modular construction could impact the entire UNC System. If UNC adopted modular on all new projects, and the price point of each of those projects was similar to that of Mountaineer, and if they all operated on the same scale of efficiency as Mountaineer, then UNC could save over $250 million across 15,000 beds, the total projected system need over 10 years. However, if the price point for those modular projects approached the average cost currently being spent, it is hard to say if there would be any financial savings other than possible financing charges for a construction loan, and a building that could potentially generate revenue sooner.

Yet, potential benefits of modular go beyond finances. Projects could be built more quickly, thereby providing more immediate benefit to a university. The quality could be higher, which may lower operating costs, and increase customer satisfaction. Contrarily, the results could be disastrous. The fact is, no two projects are the same, and if other universities prefer to wait for 20 years to see how well Mountaineer ages, then they may miss the opportunity to do something progressive now and improve upon it later. Even if the first project does not go well, and the building only lasts for 25 years, a 25-year mistake is easier to justify than a 50-year mistake.

From a global perspective regarding modular construction in relation to the UNC System, the following list describes the principal conclusions from the findings:

1. The NC SCO needs more resources to effectively serve its customers throughout the UNC System.
2. A bilateral, independent commission should be established to educate UNC decision makers about innovative—but vetted—building design and construction measures that would benefit their campus and the State. Although many would contend that the SCO, the NC State Building Commission, and the 16 UNC Campus Design and Construction offices exist to serve in this capacity, it is evident that this relationship does not work to greatest mutual benefit. The SCO seems resource-bound to advise campuses in a self-serving manner, which is to continue building what they know best, and that is the status quo. University architects and engineers seem hampered by a reluctance to challenge the advice of

the SCO (for fear of reprisal in the form of inordinate bureaucratic procedure), and are also duty-bound to recommend what they think is best, which according to historical precedent, is traditional construction. An independent arbiter that does not answer to either party could provide a fresh perspective that is sorely needed.

3. UNC housing projects should be differentiated from academic facilities in a more holistic fashion. This decision should account for the lifespan of residential facilities with regard to the success of past residence halls that have survived an entire service life.
4. The cost of Summit Hall seems egregious. Even as a high-rise—by definition in excess of 75 vertical feet—the cost is beyond what is the norm for a reinforced concrete, multi-family, 11-story building. *RS Means* (Phelan, 2012) reports that the 2013 cost for a multi-family building of this size and finish should be about \$218 per square foot, \$194 for an eight-story dorm; Summit is 33-50% higher at \$290 per square foot, and it was built two years earlier. Depending on how it is measured (Mountaineer and Cypress at Pembroke could be considered outliers at \$135 per square foot), Summit's square foot value is either on par with other conventional UNC dorms, or 15% higher. By bed, the cost of Summit is 50% higher than the comparable UNC dorm of its time. Additionally, depending on the funding source for Summit, it may be operating at a loss. If the project was paid for with NC appropriated dollars, the taxpayers of NC deserve to know why this type of project expense is justified.

5. Modular has proven to be beneficial on one UNC project. Although Mountaineer is not an official state asset, it will be soon, and its lifetime performance should be carefully monitored for future reference.
6. Modular construction is not right for every situation, and it may not be right for most situations. However, just because modular in particular is not right for one situation, that should not rule out its consideration on other projects. According the NC *Lifecycle Cost Analysis for State Facilities* guide, all new projects over 20,000 gross square feet should undergo LCCA for all major building systems (Brinkley, & Stanford, 2001). According to law, this process should be inclusive, which means the building should be evaluated as a whole.
7. Modular should not be considered in a vacuum, without full consideration for transportation, logistical, financial, geographical, and social impacts. Likewise, just because a comprehensive modular approach is not viable, does not mean that modular elements, such as bathroom pods, are not suitable alternatives.
8. Prefabrication should be considered as a complimentary process, which may be suitable where modular is not.

Opportunities for Further Research

As alluded to many times, the true measure of project success for Mountaineer and Summit will be long-term performance. A longitudinal study designed to monitor the performance, repairs, and expenses of these two buildings would benefit ASU and the UNC System while also providing more comprehensive information about modular construction in general. Aside or in tandem with this, an in-depth energy analysis at each building would provide better information about the primary energy consuming devices, and what is contributing to overall energy consumption. Along the same lines, the entire UNC system could be revisited in five to ten years to explore whether any campuses have adopted modular since this study.

An expanded case study that covers a larger geographical area would provide more data for generalization. There are known modular projects on campuses in Virginia, and Tennessee, and there could be some at private colleges and universities in NC. This study could also take into account state laws and regulations affecting construction at public universities, and compare the public contracting laws to those in NC.

Similar to the other suggestions, a study adjusted to focus on prefabrication instead of modular would have more comparable projects in NC. At the University of North Carolina Charlotte, there is currently a dorm being constructed with prefabricated metal panels, and it is one of several at that campus in the last few years. Likewise, there have been similar projects at other campuses. Interestingly, these projects cost about 25% less than comparable cast-in-place concrete, or site-built steel, but they are only predicted to last 50 years at most. If, after 20 years, the university wanted to reconfigure the interior spaces, they could not do that because the interior walls are mostly load-bearing. For these reasons, these projects are somewhat hybrid, in that they are less institutional grade (yet still considerably durable), and a little less expensive, and the SCO seems okay with their shorter lifespan.

Another analysis that approaches this topic from an ecological perspective is a Life Cycle Analysis (LCA). Although there are varying degrees of intensity in how they are carried out, the goal of an LCA is to evaluate a product or process throughout its life with respect to its environmental footprint. Through a Material Flow Analysis (MFA) all components that go into making the analyzed subject are evaluated based on their environmental impact. Thus, an MFA takes into account inputs and outputs. Inputs consist of raw materials; energy and water to extract, transport, and process those materials; energy and water to operate the subject; and any hazardous wastes that contribute to the subject. Outputs are solid waste, waterborne waste, airborne waste, co-products, and other waste streams (USEPA, 2006). For an entire building, an LCA is quite labor intensive. Just consider concrete for example. The raw materials are water, Portland cement, and aggregate (sand, gravel, fly ash, etc.). To go through an entire MFA for just the raw materials would take hours. Luckily, there are many sources that have compiled MFA data on common materials, and report this data as a common value such as CO2 emissions.

Therefore, for concrete, the CO2 emissions, or carbon footprint—one method of an Environmental Footprint Analysis—can be looked up, and this value per unit of material can be multiplied by the quantity of material to arrive at the carbon footprint of that material for the whole building. This is still a lot of work, and luckily, there are some software programs, such as SimaPro and BEES 3.0 available to help in this area. For an LCA comparison of this scale, the simplified approach would be recommended, although there are some caveats. For one, reinforced concrete has many different sizes of reinforcing steel embedded in it, and simply using a generic multiplier would likely miss the mark on a complex foundation like that of Summit. Additionally, Mountaineer has double walls, floors, and ceilings where modules meet. It would be easy to overlook some of the redundancies on that project without a more detailed set of shop drawings from the manufacturer. What is more consequential is that published MFA data is generally just for manufacturing, and possible transport to the point of use. Therefore, MFA data would have to be estimated for construction activities unless the contractor has records for similar projects, which is not likely. The same is true for operations and maintenance.

The results of the LCA, when viewed in conjunction with LCCA data, would provide a comprehensive overview of the financial and ecological cost of each building approach. Although these studies would take a concerted effort, the holistic data provided by them is unparalleled, and a true indicator of sustainability.

References

American Institute of Architects [AIA]. (2007). *Integrated project delivery: A guide.* Retrieved from http://www.aia.org/aiaucmp/groups/aia/documents/ document/aiab085539.pdf

American Society of Civil Engineers of North Carolina [ASCENC]. (2014). *Linn Cove Viaduct*. Retrieved from: http://www.ascenc.org/statewide-projects/2014/3/9/linn-cove-viaduct

Appalachian State University [ASU] Special Collections. (2014). "Winkler Residence Hall." *Appalachian State University Digital Collections*. Retrieved from: http://omeka.library.appstate.edu/items/show/7425.

Appalachian State University [ASU] Housing and Residence Life (n.d.). *Residence halls*. Retrieved from http://housing.appstate.edu/pagesmith/2

Appalachian State University [ASU], & The Lawrence Group Architects. (2009). *Facility design manual.* Retrieved from http://physicalplant.appstate.edu/sites/ physicalplant.appstate.edu/files/Design%20Guidelines%2009091%20FDManual%20 06%2022%2010%20low%20res.pdf

Arieff, A., & Burkhart, B. (2002). *Prefab.* Layton, UT: Gibbs Smith.

Atlantic Yards. (2013). Retrieved from http://www.atlanticyards.com/

Azari, R., Javanifard, N., Markert, D., Strobel, K., & Yap, J. (2013). *Modular prefabricated residential construction constraints and opportunities.* (PNCCRE Technical Report #TR002). University of Washington College of Built Environments. Retrieved from http://cm.be.washington.edu/Research/index. php#publications

Balfour Beatty Construction, & Lean Construction Institute. (2014). *Lean practices in action: Prefabrication.* Retrieved from: http://www.leanconstruction.org/training/

Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). *AIA Guide to life cycle assessment of buildings.* Washington, DC: The American Institute of Architects

Bernstein, H., Gudgel, J., Laquidara-Carr, D., & Russo, M. (Eds). (2011). *Prefabrication and modularization: Increasing productivity in the construction industry* (McGraw-Hill Construction Smart Market Report). Retrieved from http://construction.com/market_research/FreeReport/PrefabSMR/

Blythe, A. (2006, October 16). State sees fire threat at NCCU dorm. *The News and Observer.* Retrieved from: http://www.newsobserver.com/2006/10/13/51533/state-sees-fire-threat-at-nccu.html

Board of Governors of the University of North Carolina, & Eva Klein and Associates. (1999). *Facilities profile and 10-year capital plan.* Retrieved from http://www.northcarolina.edu/design-and-construction/forms

Brinkley, D., & Stanford, H. (2001). *Life cycle cost analysis for state facilities.* Retrieved from the NC Department of Administration State Construction Office website: http://www.nc-sco.com/lifecyclecostanalysis.aspx

Bruce, A., & Sandbank, H. (1944). *A history of prefabrication*. New York, NY: John B. Pierce Foundation.

Butler Manufacturing. (2013). http://www.butlermfg.com/products_systems/structural_systems/widespan/

Butts, J. (2012). Lean construction: Continuous improvement comes to construction. *CONNstruction,* winter 2012, p. 13.

Carlyle, E. (2014, May). Lego high-rise: Worlds tallest modular apartment tower getting snapped together in Brooklyn. *Forbes* 2014(5). Retrieved from http://www.forbes.com/sites/erincarlyle/2014/04/16/building-the-worlds-tallest-modular-apartment-tower/

Carter, D. (2014). Retrieved from: www.facebook.com/maisonreciprocity

Chandler, G. (2013, May). Smaller, better, faster Fred Haney's vision turns modular construction theory on its head. *Oilsands Review,* 2013(5), 16-18.

Ching, F., & Winkel, S. (2007). *Building codes illustrated.* Hoboken, NJ: John Wiley and Sons Inc.

Clayton Building Solutions. (2014). *Appalachian State University's Mountaineer Hall receives LEED gold.* Retrieved from: http://www.claytonbuildingsolutions.com/app_state_leed.cfm

Clayton Homes. (2014). *La Almenara.* Retrieved from: www.facebook.com/claytonhomes

Construction Industry Institute (CII). (1992, May). *MODEX: Automated decision support for modular construction* (Publication 29-1). Retrieved from University of Texas at Austin, Construction Industry Institute website: https://www.construction-institute.org/scriptcontent/index.cfm

Crandall, B. (2012). Retrieved from: www. https://brancra.files.wordpress.com/2012/05/5-1-2012-197.jpg?w=510&h=382

Dickson, G. (2013, October 09). West seventh street bridge in fort worth reopens. *Star Telegram.* Retrieved from http://www.star-telegram.com/2013/10/09/5234080/west-seventh-street-bridge-in.html

Dietz, A. (1971). Building technology: Potentials and problems. In Dietz, A. & Cutler, L. (Eds.), *Industrialized building systems for housing* (pp. 10-32). Cambridge, MA: The MIT Press.

DISI Homes. (1995). *Multi-room modular construction system (MRMC/2).* Retrieved from http://disi-inc.com/downloads/mrmc2_brochure.pdf

Fernandez, J. (2006). Material *architecture: Emergent materials for innovative buildings and ecological construction.* Burlington, VT: Architectural Press.

Ferreri, E. (2007, May 05). State: NCCU dorm decaying. *The News and Observer.* Retrieved from: http://www.newsobserver.com/2007/05/05/87005_state-nccu-dorm-decaying.html?rh=1

Fluor Inc. (2014). *Modular construction*. Retrieved from http://www.fluor.com/epc-services/construction/modular-construction/Pages/default.aspx

Gagnon, S., & Pirvu, C. (2011). *CLT Handbook: Cross laminated timber.* Vancouver, BC, Canada: FP Innovations.

Gibb, A. (1999). *Offsite fabrication: Prefabrication, pre-assembly and modularization.* New York, NY: John Wiley and Sons, Inc.

Gilbane Building Company. (2014). *Integrated project delivery*. Retrieved from http://www.gilbaneco.com/IntegratedProjectDelivery.aspx

Grizzly Log Builders. (2014). Retrieved from http://www.grizzlylogbuilders.com/

Hilton. (1968). *A tall story.* Retrieved from http://www.palaciodelrio.com/images/uploads/ATallStory.pdf

Hunter-Saak Modular. (2014). *Permanent modular buildings ASU construction camera*. Retrieved from: http://oxblue.com/open/johnsclark/asu

Huso, D. (2010). *Timeless gem of the Blue Ridge Parkway.* National Precast Concrete Association. Retrieved from http://precast.org/2010/07/timeless-gem-of-the-blue-ridge-parkway/

Hutchings, J. F. (1996). *Builders guide to modular construction.* New York, NY: McGraw-Hill Companies, Inc.

Jackson, S. (2013). Offsite modular construction improves quality and safety of projects. *Constructor,* March/April. The Associated General Contractors of America

Jacobson, M., Silverstein, M., & Winslow, B. (2002). *Patterns of home.* Newtown, CT: The Tauton Press Inc.

Kaysen, R. (2011, June 15). Squeezing costs, builders take new look at prefab. *The New York Times,* p. B5. Retrieved from http://www.nytimes.com/2011/06/15/realestate/commercial/squeezing-costs-builders-take-new-look-at-prefab.html?_r=0

Law, S. (1985, September/October). Choosing a log home kit. *Mother Earth News.* Retrieved from http://www.motherearthnews.com/homesteading-and-livestock/choosing-a-log-home-kit-zmaz85sozgoe.aspx#axzz3A1rgsfzT

Lawson, M., Ogden, R., & Bergin, R. (2012). Application of modular construction in high-rise buildings. *Journal of Architectural Engineering* 18(2), 148-154. doi 10.1061/(ASCE)AE.1943-5568.0000057

Lean Construction Institute. (2014). *Lean practices in action: Prefabrication.* Retrieved from http://www.leanconstruction.org/training/

Leedy, P., & Ormrod, J. (2010). *Practical research: Planning and design*. Upper Saddle River, NJ: Pearson Education Inc.

Mewis, B. (Ed.). (2009). *RS Means residential detailed costs 2010 contractor's pricing guide.* Kingston, MA: Reed Construction Data.

Modular Building Institute. (2011). *Does the offsite construction process equal green?* Retrieved from http://www.modular.org/htmlPage.aspx?name=Offsite_ Construction_Equal_Green

Modular Building Institute. (2013a). *Awards of distinction, permanent modular*. Retrieved from: http://www.modular.org/Awards/AwardsOfDistinction.aspx

Modular Building Institute. (2013b). *Modular building: back to the future?* Retrieved from http://www.modular.org/htmlPage.aspx?HtmlPageId=482

Modular Building Institute. (2014). *Why build modular?* Retrieved from http://www.modular.org/HtmlPage.aspx?name=why_modular

Morton, H. (1983). *Viaduct: Last piece.* Hugh Morton Collection of Photographs and Films, University of North Carolina at Chapel Hill, Wilson Library, North Carolina Collection Photographic Archives. Retrieved from: http://dc.lib.unc.edu/ cdm/singleitem/collection/morton_highlights/id/1146/rec/1

National Academy of Sciences. (2009). *Advancing the competitiveness and efficiency of the U.S. construction industry*. Washington, DC: The National Academies Press.

National Institute of Building Sciences. (2014). *Facility and maintenance operations committee fact-sheet*. Retrieved from: http://c.ymcdn.com/sites/www.nibs.org /resource/resmgr/Docs/NIBS_Factsheet_IRT_FMOC.pdf

National Council for Public-Private Partnerships. (2014). *Types of partnerships*. Retrieved from: http://www.ncppp.org/ppp-basics/types-of-partnerships/

North Carolina State Construction Office. (2006). *North Carolina State construction manual* (9th ed.). Retrieved from http://www.nc-sco.com/scomanual.aspx

North Carolina State Construction Office. (2010, November 12). [Final guaranteed maximum price for Phase III work]. SCO Interscope database. Retrieved from: http://interscope2.doa.state.nc.us:8080/interscope/changeOrderOpen.action?uid=35258&source=jsp

North Carolina State Construction Office. (2011, Febrauary 23). [Project notes from SCO monitor]. SCO Interscope database. Retrieved from: http://interscope2.doa.state.nc.us:8080/interscope/changeOrderOpen.action?uid=31238&source=jsp

North Carolina State Construction Office. (2014). Retrieved from: http://www.nc-sco.com/lifecyclecostanalysis.aspx

NRB Incorporated. (2010). *Project profile Bryn Athyn College*. Retrieved from: http://www.nrb-inc.com/us/project_profiles.php

O'Connor, J. (2004, October). *Survey on actual service lives for North American buildings.* Paper presented at the meeting of Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, NV.

O'Leary, C., & Sludds, T. (2011, November 23). *OLS passive house in carlow – part two* [Web log post]. Retrieved from http://olsarchitects.wordpress.com /2011/11/23/ols-passive-house-in-carlow-part-two/

Oder, N. (2013, Sept 17). *Atlantic yards report.* Retrieved from http://atlanticyardsreport. blogspot.com/2013/09/forest-city-b2-tower-pushed-back-six.html

PCL Construction. (2014). *Permanent modular construction*. Retrieved from http://www.pcl.com/services-that-deliver/capabilitiesservices/pmc/Pages/default.aspx.

Perkins and Will Architecture, & Grassl, A. (Photographer). (2014). *Appalachian State University, honors and engagement community*. Retrieved from http://perkinswill.com/work/appalachian-state-university-academic-village.html

Phelan, M. (Ed.). (2012). *RS Means square foot costs, (34th ed).* Norwell, MA: Reed Construction Data.

Polito, C. (2014, July 14). A Mod history – Modular construction makes a mark. *Earthtechling*. Retrieved from http://earthtechling.com/2014/07/a-mod-history-modular-construction-makes-a-mark/

Qualtrics. (2013). Retrieved from www.qualtrics.com

Reid, K. (2013, November 20). *Engineered heavy logistics: Moving deadlines forward in LNG modular construction.* Retrieved from http://higherlogicdownload.s3. amazonaws.com/SNAME/3383113f-3070-4ddd-acd4 504418eb35a9/UploadedImages/Files/2013/2013-Nov20-Presentation-Kurt_Reid.pdf.

Riggs, M. (2013*). Riggers reference handbook.* Knoxville, TN: Riggsafe Solutions Inc

Romero, R. (2014). *LV construction process*. Retrieved from http://www.rocioromero.com/LVconstructionProcess.html

Said, H., & El-Rayes, K. (2011). Optimizing material procurement and storage on construction sites. *Journal of construction engineering and management* 137(6), 421-431. doi: 10.1061/(ASCE)CO.1943-7862.0000307

Simonson, K. (2013). *Construction spending, labor, and materials outlook*. Associated General Contractors of America. Retrieved from http://www.agc.org/galleries/econ/Construction_Materials_Outlook.pdf

Smith, R. E. (2010). *Prefab architecture: A guide to modular design and construction*. Hoboken, NJ: John Wiley and Sons Inc

Stein Transportation. (2014). *Trailer selector guide for freight shipping*. Retrieved from http://www.steintransportation.com/trailer-selector-guide.html

Sundt Construction. (2013a). *City of Fort Worth West Seventh Street Bridge*. Retrieved from http://www.sundt.com/projects/tarrant-county-seventh-street-bridge/

Sundt Construction. (2013b). *Fort Worth's West 7th Street Bridge opened a month early*. Retrieved from http://www.sundt.com/media/blog/2013/10/10/fort-worths-west-7th-street-bridge-opened-a-month-early/

Templetown Realty. (2013). *The modules at Templetown*. Retrieved from: http://www.themodulesattempletown.com/

University of North Carolina. (2013). *Interactive report buildings search*. Retrieved from http://www.northcarolina.edu/content.php/fac_util

University of North Carolina at Chapel Hill Housing and Residence Education. (2014). Retrieved from: http://old.northcarolina.edu/about/facts.htm

University of North Carolina at Charlotte Housing and Residence Life. (2014). Retrieved from: http://housing.uncc.edu/future-residents/our-buildings/holshouser-hall

United States Energy Information Administration [USEIA]. (2014). *Energy units and calculator explained: Degree days.* Retrieved from: http://www.eia.gov/energyexplained/index.cfm?page=about_degree_days

United State Environmental Protection Agency [USEPA], Scientific Applications International Corporation, & National Risk Management Research Laboratory. (2006) *Life cycle assessment: Principles and practices* (EPA Publication No. EPA/600/R-06/060). Retrieved from http://www.epa.gov/nrmrl/std/lca/lca.html

United States Department of Housing and Urban Development. (2013). *General program information*. Retrieved from http://portal.hud.gov/hudportal/HUD?src=/program_offices/housing/ramh/mhs/faq

Urban, F. (2012). *Tower and slab: Histories of global mass housing*. New York, NY: Routledge.

Williams Scotsman [Willscot]. (2013). *Concurrent construction process and project timeline*. Retrieved from http://www.willscot.com/mb/our-process.php

Whitely Manufacturing [WM]. (2013). *Case studies Evans-Kimmel Hall*. Retrieved from: http://www.whitleyman.com/casestudies/Dormitories

Wood, J. (2014, May 30). Photos, memories of ASU's winkler residence hall, building to be demolished this coming sunday morning. *High Country Press.* Retrieved from http://www.hcpress.com/asu-news/photos-memories-of-asus-winkler-residence-hall-to-be-demolished-this-coming-sunday-morning.html

X-Site Modular. (2011). Retrieved from http://www.xsitemodular.com/index.php

APPENDIX A SURVEY

12 November 2013

Assessment of Modular Construction Utilization Across All Campuses of the University of North Carolina System

You are being invited to participate in a research study about the implementation of modular construction throughout the UNC System. This study is being conducted by Scott Hopkins, Primary Investigator (PI) and advised by Dr. Marie Hoepfl, from the Department of Technology and Environmental Design at Appalachian State University. The PI is a graduate student pursuing a Master of Science degree in Sustainable Building Design and Construction, and Appropriate Technology, and this study is for a Master's Thesis.

You were selected as a possible participant in this study because your design, construction, and operations experience at UNC institutions is directly related to the research questions.

There are no known risks if you decide to participate in this research study. There are no costs to you for participating in the study. The information you provide will be used to determine the extent of modular construction use within the UNC System, and the success rate of those projects that have used modular construction. The survey will take about ten minutes to complete. The information collected may not benefit you directly, but the information learned in this study should provide general societal benefits. Depending on your responses, you may be contacted for an interview.

Should the data be published, no individual information will be disclosed unless your express permission is granted in writing. The results of this study will be made available to you at your request.

Your participation in this study is voluntary. You are free to decline to answer any particular question you do not wish to answer for any reason.

If you have any questions about the study, please contact:

Scott Hopkins, PI	Dr. Marie Hoepfl, Faculty Advisor
1100 East King Street	hoepflmc@appstate.edu
Boone, NC 28607	
828.308.4023 - ah67624@appstate.edu	

Appalachian State University's Institutional Review Board has determined this study to be exempt from IRB oversight.

By continuing on to the survey, you acknowledge you have read and agree to the descriptions and terms outlined in this consent form, and voluntarily agree to participate in this research.

Thank you for participating.

For the purpose of this study, modular construction is defined as building with volumetric components that are fabricated in a factory, and are substantially complete prior to being assembled on site. Figure 1 displays the spectrum of prefabrication. Building with materials, components, and panels, as displayed in the figure, represents conventional site-built construction. Although prefabricated elements are used, it is not modular construction because modules are not used.

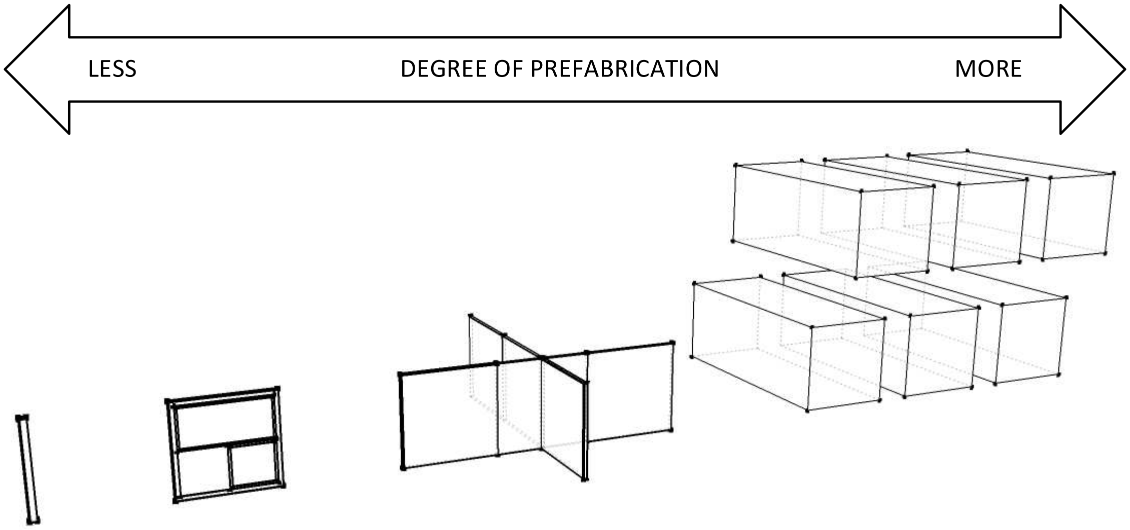


Figure 1. Degrees of prefabrication. From left to right: materials, components, panels, and modules. Adapted from Smith (2010)

1. What is your official occupational title at your institution?
    a. Director of Housing
    b. Director of Design and Construction
    c. Director of Physical Plant
    d. Other (please specify)
2. How long have you been at your current occupational position?
    a. Less than 1 year
    b. 1-3 years
    c. 4-6 years
    d. More than 6 years
3. How long have you worked in the design, construction, or operations and maintenance field?
    a. Less than 1 year
    b. 1-9 years
    c. 10-15 years
    d. More than 15 years
4. Has the institution at which you presently work used modular construction to build and/or substantially renovate residence halls?
    a. Yes
    b. No

If yes, proceed to question 5. If no, proceed to question 7.

5. How many residence halls at your institution have been built with modular construction methods?
    a. 1-2
    b. 3-4
    c. 5 or more
    d. Unsure; I do not believe there are any
    e. Unsure; I think there may be one or more
6. In each instance, what factors influenced the decision to use modular construction? (circle all that apply)
    a. Time
    b. Cost
    c. Quality
    d. Other – please specify
    e. Unsure
7. Has your institution considered using modular construction to construct and/or substantially renovate residence halls?
    a. Yes
    b. No

8. If your institution considered using modular construction, but elected to use another method of construction for a residence hall, what were the reason/reasons for this decision? (circle all that apply)

   Concerns related to:

   a. Time
   b. Cost
   c. Quality
   d. Other
9. If your institution considered using modular construction, but elected to use another method of construction for a residence hall, what was the method of construction selected?

Briefly Describe:

____

____

____

____-

____

10. If your institution is planning on constructing and/or substantially renovating a residence hall within the next two years, will modular construction be considered as a possible construction method? (briefly describe why it will or will not be considered)
    a. Yes
    b. No

    ____

    ____

    ____

    ____

    ____

11. Please list any additional comments or observations.

____

____

____

____

12. Are you willing to participate in an interview? (if yes, please provide your contact information)
    a. Yes
    b. No

    ____

    ____

    ____

    ____

Thank you for participating in this survey. Your time is appreciated.

APPENDIX B INTERVIEW

Sample Interview Questions

What housing projects on your campus utilized modular construction?

Why did you choose modular construction for this project?

Did all of the decision makers at your institution, with respect to this project, accept the decision to use modular?

Were there any comparable on-site housing projects under development while the aforementioned modular projects were being built?

What lifespan was the modular project designed for? What about the site-built?

What was the duration of the modular project? What about the site-built?

What was the budget of the modular project? What about the site-built?

What do you think about the construction quality of the modular project?

How does this compare to site-built projects?

What did you think about the design and construction process with relation to past experiences?

Have you considered using modular for other projects? Why or why not?

Will you consider using modular in the future?

Can you recommend any other people with knowledge of your modular project with whom I should speak?

Do you have any other comments or observations that you would like to share?

LCCA Calculations

Modular

Dicsount Rate	Maintenance Costs (% of Initial Cost)	Inflation Rate
0.05	0.004	**0.03**

	NON-ANNUAL RECURRING COSTS						ELECTRICITY	STEAM	WATER	SEWER	OM	TOTAL OPERATING COSTS			CUMULATIVE
	INVESTMENT			PLANNED MAINT			**$ 60,834.46**	**$ 23,323.50**	**$ 11,754.25**	**$ 17,356.00**	**$ 66,000.00**				COST
YEAR	DESCRIPTION	COST	DISCOUNTED	DESCRIPTION	COST	ESCALATED	ESCALATED	ESCALATED	ESCALATED	ESCALATED	ESCALATED	YEAR	UNDISCOUNTED	DISCOUNTED	DISCOUNTED COSTS
0	Initial	$ 16,500,000.00	$ 16,500,000.00									2014			$ 16,500,000.00
1							$ 61,077.80	$ 23,953.23	$ 12,071.61	$ 17,824.61	$ 67,782.00	2015	$ 182,709.26	$ 174,008.82	$ 174,008.82
2							$ 62,726.90	$ 24,599.97	$ 12,397.55	$ 18,305.88	$ 69,612.11	2016	$ 187,642.41	$ 170,197.20	$ 170,197.20
3							$ 64,420.52	$ 25,264.17	$ 12,732.28	$ 18,800.14	$ 71,491.64	2017	$ 192,708.75	$ 166,469.07	$ 166,469.07
4							$ 66,159.88	$ 25,946.30	$ 13,076.05	$ 19,307.74	$ 73,421.92	2018	$ 197,911.89	$ 162,822.60	$ 162,822.60
5							$ 67,946.20	$ 26,646.85	$ 13,429.11	$ 19,829.05	$ 75,404.31	2019	$ 203,255.51	$ 159,256.01	$ 159,256.01
6							$ 69,780.74	$ 27,366.32	$ 13,791.69	$ 20,364.43	$ 77,440.22	2020	$ 208,743.41	$ 155,767.55	$ 155,767.55
7							$ 71,664.82	$ 28,105.21	$ 14,164.07	$ 20,914.27	$ 79,531.11	2021	$ 214,379.48	$ 152,355.50	$ 152,355.50
8							$ 73,599.77	$ 28,864.05	$ 14,546.50	$ 21,478.96	$ 81,678.45	2022	$ 220,167.73	$ 149,018.18	$ 149,018.18
9							$ 75,586.97	$ 29,643.38	$ 14,939.25	$ 22,058.89	$ 83,883.77	2023	$ 226,112.26	$ 145,753.98	$ 145,753.98
10							$ 77,627.82	$ 30,443.75	$ 15,342.61	$ 22,654.48	$ 86,148.63	2024	$ 232,217.29	$ 142,561.27	$ 142,561.27
11							$ 79,723.77	$ 31,265.73	$ 15,756.86	$ 23,266.15	$ 88,474.64	2025	$ 238,487.15	$ 139,438.50	$ 139,438.50
12				CRAWL SPACE	$ 25,000.00	$ 34,417.98	$ 81,876.31	$ 32,109.91	$ 16,182.30	$ 23,894.34	$ 90,863.46	2026	$ 279,344.28	$ 155,549.35	$ 155,549.35
13				ELEVATOR	$ 100,000.00	$ 141,389.05	$ 84,086.97	$ 32,976.87	$ 16,619.22	$ 24,539.48	$ 93,316.77	2027	$ 392,928.37	$ 208,378.30	$ 208,378.30
14				RADON MITIGATION SYSTEMS	$ 100,000.00	$ 145,206.55	$ 86,357.32	$ 33,867.25	$ 17,067.94	$ 25,202.05	$ 95,836.32	2028	$ 403,537.43	$ 203,813.82	$ 203,813.82
15				PTAC UNITS	$ 200,000.00	$ 298,254.26	$ 88,688.96	$ 34,781.67	$ 17,528.78	$ 25,882.50	$ 98,423.90	2029	$ 265,305.81	$ 127,616.63	$ 127,616.63
16				CONTROLS	$ 120,000.00	$ 183,784.27	$ 91,083.57	$ 35,720.77	$ 18,002.05	$ 26,581.33	$ 101,081.35	2030	$ 456,253.34	$ 209,014.91	$ 209,014.91
17				OTHER	$ 50,000.00	$ 78,644.35	$ 93,542.82	$ 36,685.23	$ 18,488.11	$ 27,299.03	$ 103,810.55	2031	$ 358,470.09	$ 156,399.31	$ 156,399.31
18							$ 96,068.48	$ 37,675.73	$ 18,987.29	$ 28,036.10	$ 106,613.43	2032	$ 287,381.03	$ 119,412.75	$ 119,412.75
19							$ 98,662.33	$ 38,692.98	$ 19,499.94	$ 28,793.08	$ 109,491.99	2033	$ 295,140.32	$ 116,797.05	$ 116,797.05
20							$ 101,326.21	$ 39,737.69	$ 20,026.44	$ 29,570.49	$ 112,448.28	2034	$ 303,109.11	$ 114,238.63	$ 114,238.63
21							$ 104,062.02	$ 40,810.61	$ 20,567.16	$ 30,368.89	$ 115,484.38	2035	$ 311,293.05	$ 111,736.26	$ 111,736.26
22							$ 106,871.69	$ 41,912.49	$ 21,122.47	$ 31,188.85	$ 118,602.46	2036	$ 319,697.97	$ 109,288.71	$ 109,288.71
23							$ 109,757.23	$ 43,044.13	$ 21,692.78	$ 32,030.95	$ 121,804.73	2037	$ 328,329.81	$ 106,894.77	$ 106,894.77
24							$ 112,720.67	$ 44,206.32	$ 22,278.48	$ 32,895.79	$ 125,093.45	2038	$ 337,194.72	$ 104,553.26	$ 104,553.26
25							$ 115,764.13	$ 45,399.89	$ 22,880.00	$ 33,783.97	$ 128,470.98	2039	$ 346,298.97	$ 102,263.05	$ 102,263.05
26							$ 118,889.76	$ 46,625.69	$ 23,497.76	$ 34,696.14	$ 131,939.69	2040	$ 355,649.04	$ 100,023.00	$ 100,023.00
27							$ 122,099.79	$ 47,884.58	$ 24,132.20	$ 35,632.94	$ 135,502.06	2041	$ 365,251.57	$ 97,832.02	$ 97,832.02
28							$ 125,396.48	$ 49,177.47	$ 24,783.77	$ 36,595.03	$ 139,160.62	2042	$ 375,113.36	$ 95,689.03	$ 95,689.03
29							$ 128,782.19	$ 50,505.26	$ 25,452.93	$ 37,583.09	$ 142,917.96	2043	$ 385,241.42	$ 93,592.99	$ 93,592.99
30	REPLACEMENT	$ 36,694,185.50	$ 8,490,207.02				$ 132,259.30	$ 51,868.90	$ 26,140.16	$ 38,597.84	$ 146,776.74	2044	$ 395,642.94	$ 91,542.85	$ 8,581,749.88
31							$ 135,830.31	$ 53,269.36	$ 26,845.94	$ 39,639.98	$ 150,739.71	2045	$ 406,325.30	$ 89,537.63	$ 89,537.63
32							$ 139,497.72	$ 54,707.63	$ 27,570.78	$ 40,710.26	$ 154,809.69	2046	$ 417,296.08	$ 87,576.33	$ 87,576.33
33							$ 143,264.16	$ 56,184.74	$ 28,315.20	$ 41,809.43	$ 158,989.55	2047	$ 428,563.08	$ 85,657.99	$ 85,657.99
34							$ 147,132.29	$ 57,701.73	$ 29,079.71	$ 42,938.29	$ 163,282.27	2048	$ 440,134.28	$ 83,781.67	$ 83,781.67
35							$ 151,104.87	$ 59,259.67	$ 29,864.86	$ 44,097.62	$ 167,690.89	2049	$ 452,017.91	$ 81,946.46	$ 81,946.46
36							$ 155,184.70	$ 60,859.68	$ 30,671.21	$ 45,288.26	$ 172,218.54	2050	$ 464,222.39	$ 80,151.44	$ 80,151.44
37							$ 159,374.69	$ 62,502.90	$ 31,499.33	$ 46,511.04	$ 176,868.44	2051	$ 476,756.39	$ 78,395.74	$ 78,395.74
38							$ 163,677.80	$ 64,190.47	$ 32,349.81	$ 47,766.84	$ 181,643.89	2052	$ 489,628.82	$ 76,678.50	$ 76,678.50
39							$ 168,097.10	$ 65,923.62	$ 33,223.26	$ 49,056.54	$ 186,548.27	2053	$ 502,848.79	$ 74,998.88	$ 74,998.88
40							$ 172,635.72	$ 67,703.55	$ 34,120.29	$ 50,381.07	$ 191,585.08	2054	$ 516,425.71	$ 73,356.04	$ 73,356.04
41							$ 177,296.89	$ 69,531.55	$ 35,041.53	$ 51,741.36	$ 196,757.87	2055	$ 530,369.21	$ 71,749.20	$ 71,749.20
42				CRAWL SPACE	$ 25,000.00	$ 76,541.79	$ 182,083.90	$ 71,408.90	$ 35,987.66	$ 53,138.38	$ 202,070.34	2056	$ 621,230.97	$ 80,039.16	$ 80,039.16
43				ELEVATOR	$ 100,000.00	$ 314,433.69	$ 187,000.17	$ 73,336.94	$ 36,959.32	$ 54,573.11	$ 207,526.24	2057	$ 873,829.47	$ 107,222.72	$ 107,222.72
44				RADON MITIGATION SYSTEMS	$ 100,000.00	$ 322,923.40	$ 192,049.17	$ 75,317.04	$ 37,957.22	$ 56,046.59	$ 213,129.44	2058	$ 897,422.87	$ 104,874.03	$ 104,874.03
45				PTAC UNITS	$ 200,000.00	$ 663,284.67	$ 197,234.50	$ 77,350.60	$ 38,982.07	$ 57,559.84	$ 218,883.94	2059	$ 1,253,295.62	$ 139,487.43	$ 139,487.43
46				CONTROLS	$ 120,000.00	$ 408,716.01	$ 202,559.83	$ 79,439.07	$ 40,034.58	$ 59,113.96	$ 224,793.81	2060	$ 1,014,657.26	$ 107,550.30	$ 107,550.30
47				OTHER	$ 50,000.00	$ 174,896.39	$ 208,028.95	$ 81,583.92	$ 41,115.52	$ 60,710.04	$ 230,863.24	2061	$ 797,198.06	$ 80,476.52	$ 80,476.52
48							$ 213,645.73	$ 83,786.69	$ 42,225.64	$ 62,349.21	$ 237,096.55	2062	$ 639,103.81	$ 61,444.79	$ 61,444.79

48							$ 213,645.73	$ 83,786.69	$ 42,225.64	$ 62,349.21	$ 237,096.55	2062	$ 639,103.81	$ 61,444.79	$ 61,444.79
49							$ 219,414.17	$ 86,048.93	$ 43,365.73	$ 64,032.64	$ 243,498.15	2063	$ 656,359.61	$ 60,098.85	$ 60,098.85
50							$ 225,338.35	$ 88,372.25	$ 44,536.60	$ 65,761.52	$ 250,072.60	2064	$ 674,081.32	$ 58,782.40	$ 58,782.40
51							$ 231,422.48	$ 90,758.30	$ 45,739.09	$ 67,537.08	$ 256,824.56	2065	$ 692,281.52	$ 57,494.79	$ 57,494.79
52							$ 237,670.89	$ 93,208.77	$ 46,974.05	$ 69,360.58	$ 263,758.83	2066	$ 710,973.12	$ 56,235.38	$ 56,235.38
53							$ 244,088.00	$ 95,725.41	$ 48,242.35	$ 71,233.31	$ 270,880.32	2067	$ 730,169.39	$ 55,003.56	$ 55,003.56
54							$ 250,678.38	$ 98,310.00	$ 49,544.89	$ 73,156.61	$ 278,194.08	2068	$ 749,883.97	$ 53,798.72	$ 53,798.72
55							$ 257,446.70	$ 100,964.37	$ 50,882.60	$ 75,131.84	$ 285,705.32	2069	$ 770,130.83	$ 52,620.27	$ 52,620.27
56							$ 264,397.76	$ 103,690.40	$ 52,256.43	$ 77,160.40	$ 293,419.37	2070	$ 790,924.36	$ 51,467.63	$ 51,467.63
57							$ 271,536.50	$ 106,490.04	$ 53,667.36	$ 79,243.73	$ 301,341.69	2071	$ 812,279.32	$ 50,340.25	$ 50,340.25
58							$ 278,867.98	$ 109,365.28	$ 55,116.38	$ 81,383.31	$ 309,477.92	2072	$ 834,210.86	$ 49,237.56	$ 49,237.56
59							$ 286,397.42	$ 112,318.14	$ 56,604.52	$ 83,580.66	$ 317,833.82	2073	$ 856,734.56	$ 48,159.02	$ 48,159.02
60	REPLACEMENT	$ 81,603,833.31	$ 4,368,703.96				$ 294,130.15	$ 115,350.73	$ 58,132.84	$ 85,837.34	$ 326,415.33	2074	$ 879,866.39	$ 47,104.11	$ 4,415,808.06
61							$ 302,071.66	$ 118,465.20	$ 59,702.43	$ 88,154.95	$ 335,228.55	2075	$ 903,622.78	$ 46,072.30	$ 46,072.30
62							$ 310,227.60	$ 121,663.76	$ 61,314.39	$ 90,535.13	$ 344,279.72	2076	$ 928,020.60	$ 45,063.10	$ 45,063.10
63							$ 318,603.74	$ 124,948.68	$ 62,969.88	$ 92,979.58	$ 353,575.27	2077	$ 953,077.15	$ 44,076.00	$ 44,076.00
64							$ 327,206.04	$ 128,322.29	$ 64,670.07	$ 95,490.03	$ 363,121.80	2078	$ 978,810.24	$ 43,110.53	$ 43,110.53
65							$ 336,040.61	$ 131,787.00	$ 66,416.16	$ 98,068.26	$ 372,926.09	2079	$ 1,005,238.11	$ 42,166.20	$ 42,166.20
66							$ 345,113.70	$ 135,345.24	$ 68,209.40	$ 100,716.10	$ 382,995.10	2080	$ 1,032,379.54	$ 41,242.56	$ 41,242.56
67							$ 354,431.77	$ 138,999.57	$ 70,051.05	$ 103,435.44	$ 393,335.96	2081	$ 1,060,253.79	$ 40,339.15	$ 40,339.15
68							$ 364,001.43	$ 142,752.55	$ 71,942.43	$ 106,228.20	$ 403,956.03	2082	$ 1,088,880.64	$ 39,455.54	$ 39,455.54
69							$ 373,829.47	$ 146,606.87	$ 73,884.87	$ 109,096.36	$ 414,862.85	2083	$ 1,118,280.42	$ 38,591.27	$ 38,591.27
70							$ 383,922.87	$ 150,565.26	$ 75,879.76	$ 112,041.96	$ 426,064.14	2084	$ 1,148,473.99	$ 37,745.94	$ 37,745.94
71							$ 394,288.78	$ 154,630.52	$ 77,928.52	$ 115,067.09	$ 437,567.88	2085	$ 1,179,482.79	$ 36,919.12	$ 36,919.12
72							$ 404,934.58	$ 158,805.54	$ 80,032.59	$ 118,173.90	$ 449,382.21	2086	$ 1,211,328.83	$ 36,110.42	$ 36,110.42
73							$ 415,867.81	$ 163,093.29	$ 82,193.47	$ 121,364.60	$ 461,515.53	2087	$ 1,244,034.70	$ 35,319.43	$ 35,319.43
74							$ 427,096.24	$ 167,496.81	$ 84,412.69	$ 124,641.44	$ 473,976.45	2088	$ 1,277,623.64	$ 34,545.76	$ 34,545.76
75							$ 438,627.84	$ 172,019.23	$ 86,691.83	$ 128,006.76	$ 486,773.81	2089	$ 1,312,119.48	$ 33,789.05	$ 33,789.05
76							$ 450,470.80	$ 176,663.75	$ 89,032.51	$ 131,462.94	$ 499,916.70	2090	$ 1,347,546.70	$ 33,048.91	$ 33,048.91
77							$ 462,633.51	$ 181,433.67	$ 91,436.39	$ 135,012.44	$ 513,414.46	2091	$ 1,383,930.47	$ 32,324.98	$ 32,324.98
78							$ 475,124.61	$ 186,332.38	$ 93,905.17	$ 138,657.78	$ 527,276.65	2092	$ 1,421,296.59	$ 31,616.91	$ 31,616.91
79							$ 487,952.98	$ 191,363.35	$ 96,440.61	$ 142,401.54	$ 541,513.12	2093	$ 1,459,671.60	$ 30,924.35	$ 30,924.35
80							$ 501,127.71	$ 196,530.16	$ 99,044.51	$ 146,246.38	$ 556,133.97	2094	$ 1,499,082.73	$ 30,246.96	$ 30,246.96
81							$ 514,658.15	$ 201,836.48	$ 101,718.71	$ 150,195.03	$ 571,149.59	2095	$ 1,539,557.96	$ 29,584.40	$ 29,584.40
82							$ 528,553.92	$ 207,286.06	$ 104,465.12	$ 154,250.30	$ 586,570.63	2096	$ 1,581,126.03	$ 28,936.36	$ 28,936.36
83							$ 542,824.88	$ 212,882.78	$ 107,285.68	$ 158,415.06	$ 602,408.03	2097	$ 1,623,816.43	$ 28,302.52	$ 28,302.52
84							$ 557,481.15	$ 218,630.62	$ 110,182.39	$ 162,692.26	$ 618,673.05	2098	$ 1,667,659.47	$ 27,682.56	$ 27,682.56
85							$ 572,533.14	$ 224,533.65	$ 113,157.31	$ 167,084.96	$ 635,377.22	2099	$ 1,712,686.28	$ 27,076.18	$ 27,076.18
86							$ 587,991.54	$ 230,596.05	$ 116,212.56	$ 171,596.25	$ 652,532.41	2100	$ 1,758,928.81	$ 26,483.08	$ 26,483.08
87							$ 603,867.31	$ 236,822.15	$ 119,350.30	$ 176,229.35	$ 670,150.78	2101	$ 1,806,419.89	$ 25,902.98	$ 25,902.98
88							$ 620,171.73	$ 243,216.35	$ 122,572.76	$ 180,987.54	$ 688,244.85	2102	$ 1,855,193.22	$ 25,335.58	$ 25,335.58
89							$ 636,916.36	$ 249,783.19	$ 125,882.22	$ 185,874.20	$ 706,827.46	2103	$ 1,905,283.44	$ 24,780.61	$ 24,780.61
90	REPLACEMENT	$ 181,477,951.34	$ 2,247,951.58				$ 654,113.11	$ 256,527.33	$ 129,281.04	$ 190,892.81	$ 725,911.81	2104	$ 1,956,726.09	$ 24,237.80	$ 2,272,189.37
91							$ 671,774.16	$ 263,453.57	$ 132,771.63	$ 196,046.91	$ 745,511.42	2105	$ 2,009,557.70	$ 23,706.87	$ 23,706.87
92							$ 689,912.06	$ 270,566.82	$ 136,356.47	$ 201,340.18	$ 765,640.23	2106	$ 2,063,815.76	$ 23,187.58	$ 23,187.58
93							$ 708,539.69	$ 277,872.12	$ 140,038.09	$ 206,776.36	$ 786,312.52	2107	$ 2,119,538.78	$ 22,679.66	$ 22,679.66
94				CRAWL SPACE	$ 25,000.00	$ 368,599.56	$ 727,670.26	$ 285,374.67	$ 143,819.12	$ 212,359.33	$ 807,542.96	2108	$ 2,545,365.89	$ 25,939.17	$ 25,939.17
95				ELEVATOR	$ 100,000.00	$ 1,514,206.99	$ 747,317.36	$ 293,079.79	$ 147,702.23	$ 218,093.03	$ 829,346.62	2109	$ 3,749,746.01	$ 36,393.05	$ 36,393.05
96				RADON MITIGATION SYSTEMS	$ 100,000.00	$ 1,555,090.58	$ 767,494.92	$ 300,992.94	$ 151,690.19	$ 223,981.54	$ 851,738.98	2110	$ 3,850,989.15	$ 35,595.87	$ 35,595.87
97				PTAC UNITS	$ 200,000.00	$ 3,194,156.05	$ 788,217.29	$ 309,119.75	$ 155,785.83	$ 230,029.04	$ 874,735.93	2111	$ 5,552,043.89	$ 48,875.46	$ 48,875.46
98				CONTROLS	$ 120,000.00	$ 1,968,238.96	$ 809,499.15	$ 317,465.98	$ 159,992.05	$ 236,239.83	$ 898,353.80	2112	$ 4,389,789.76	$ 36,803.78	$ 36,803.78
99				OTHER	$ 50,000.00	$ 698,946.48	$ 831,355.63	$ 326,037.56	$ 164,311.83	$ 242,618.30	$ 922,609.35	2113	$ 3,185,879.16	$ 25,438.34	$ 25,438.34
100							$ 853,802.23	$ 334,840.58	$ 168,748.25	$ 249,169.00	$ 947,519.80	2114	$ 2,554,079.86	$ 19,422.47	$ 19,422.47
	SALAVAGE	**$ 120,985,300.89**	**$ 346,750.20**									**TOTAL**		**UNDISCOUNTED**	**DISCOUNTED**
	FUTURE REPAIRS	**$ 9,299,238.62**	**$ 26,652.10**									**COST**		**$ 418,502,067.58**	**$ 39,273,488.09**
	VALUE	**$ 130,284,539.51**	**$ 373,402.30**									**ADJUSTED**			
												COST		**$ 288,217,528.08**	**$ 38,900,085.78**

LCCA Calculations

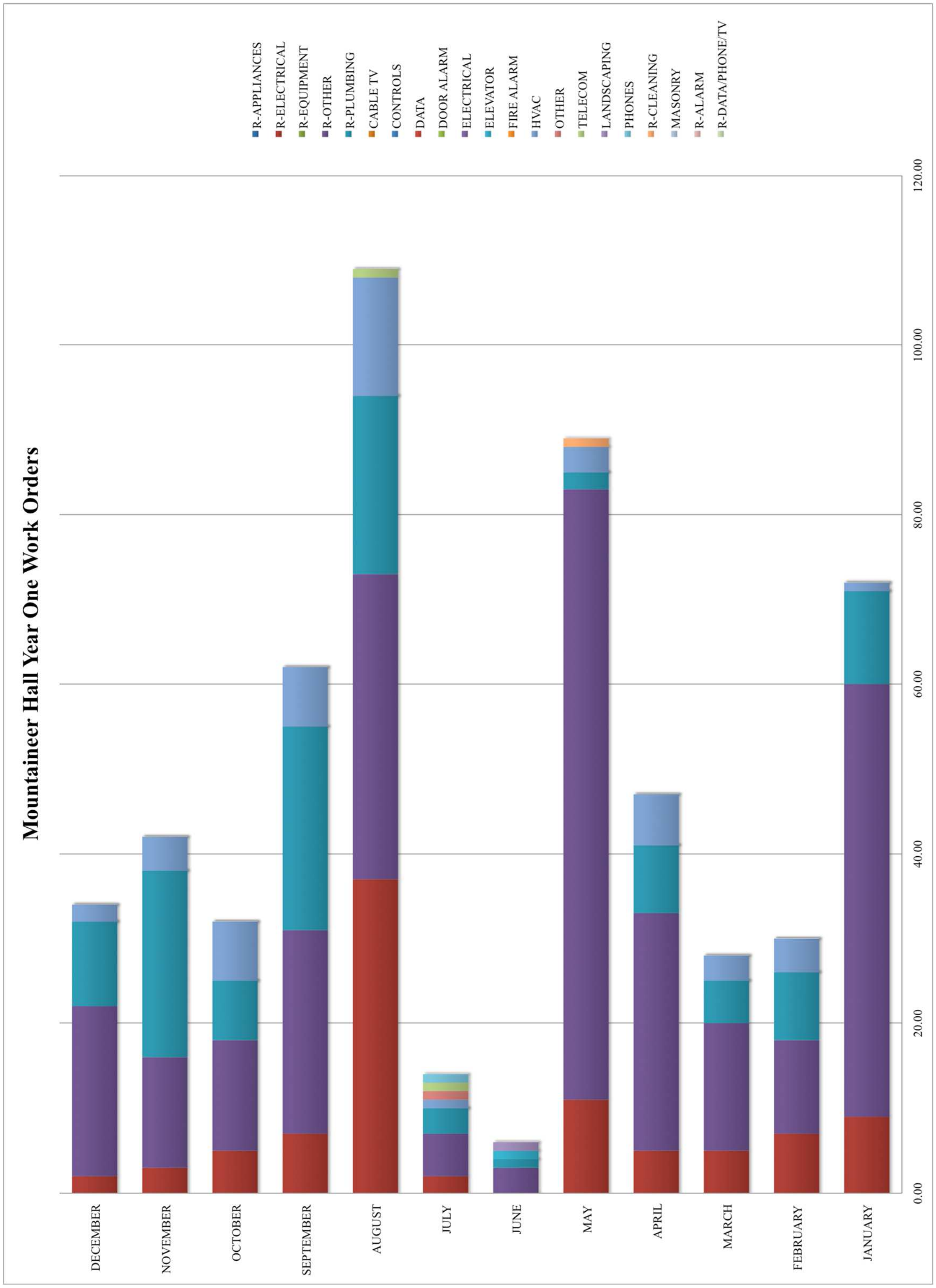
Conventional

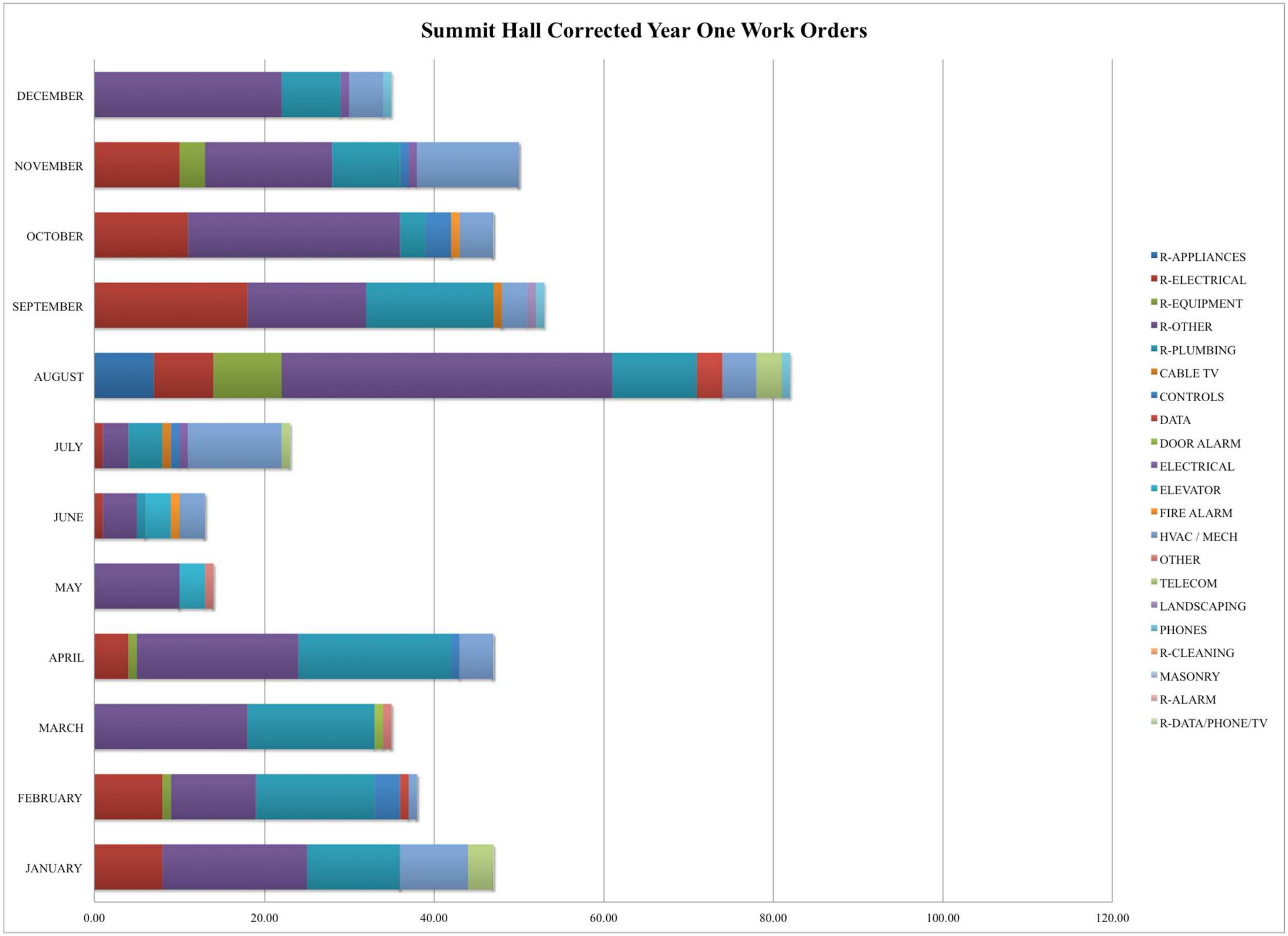
Dicsount Rate	Maintenance Costs (% of Initial Cost)	Inflation Rate
0.05	0.004	**0.03**

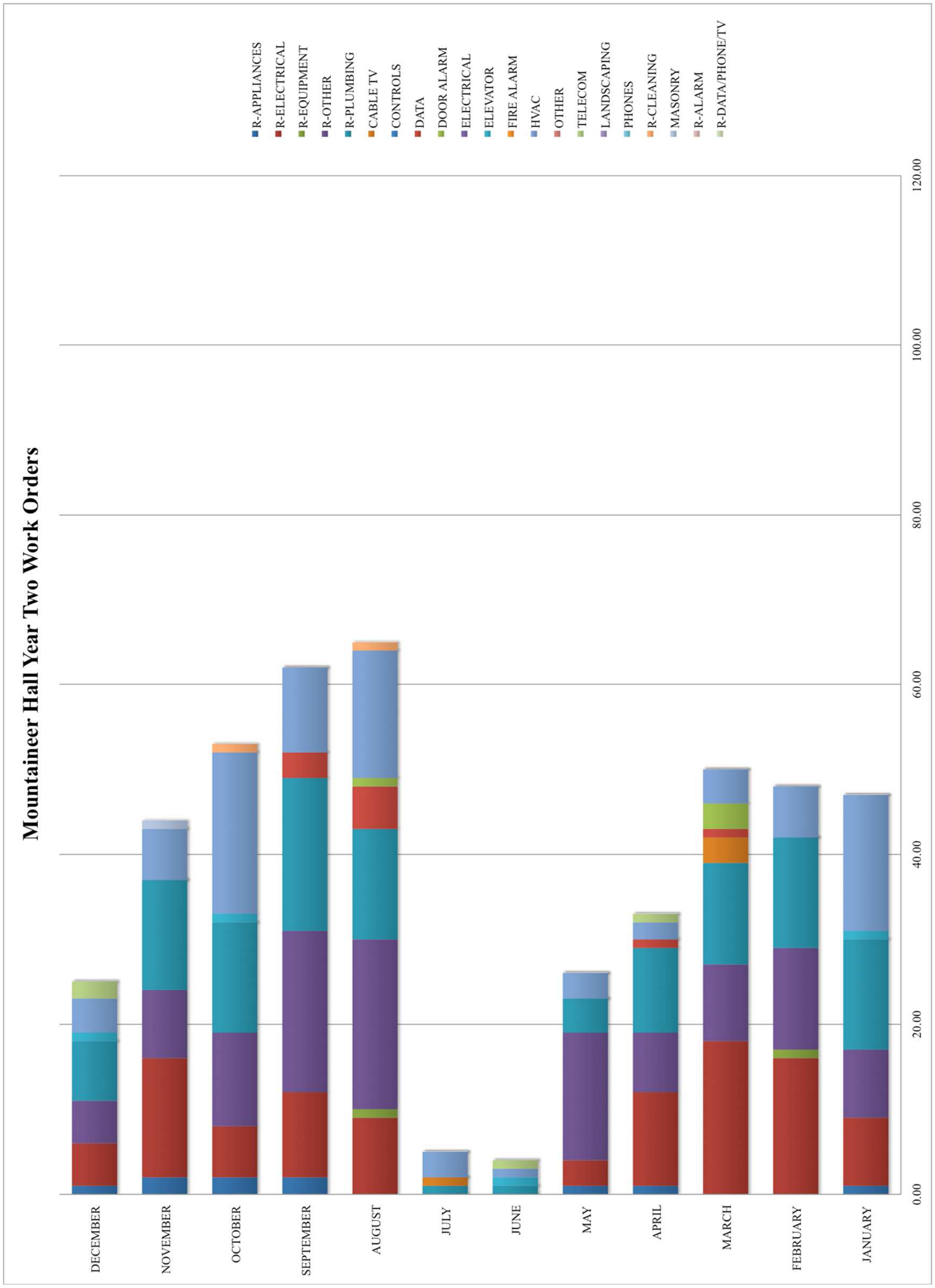
	NON-ANNUAL RECURRING COSTS						ELECTRICITY	STEAM	WATER	SEWER	OM	TOTAL OPERATING COSTS			CUMULATIVE
	INVESTMENT			PLANNED MAINT			**$ 75,697.22**	**$ 95,665.11**	**$ 8,483.92**	**$ 7,402.88**	**$ 124,000.00**				COST
YEAR	DESCRIPTION	COST	DISCOUNTED	DESCRIPTION	COST	ESCALATED	ESCALATED	ESCALATED	ESCALATED	ESCALATED	ESCALATED	YEAR	UNDISCOUNTED	DISCOUNTED	DISCOUNTED COSTS
0	Initial	$ 31,000,000.00	$ 31,000,000.00									2014			$ 31,000,000.00
1							$ 76,000.01	$ 98,248.07	$ 8,712.99	$ 7,602.76	$ 127,348.00	2015	$ 317,911.82	$ 302,773.16	$ 302,773.16
2							$ 78,052.01	$ 100,900.77	$ 8,948.24	$ 7,808.03	$ 130,786.40	2016	$ 326,495.44	$ 296,140.99	$ 296,140.99
3							$ 80,159.41	$ 103,625.09	$ 9,189.84	$ 8,018.85	$ 134,317.63	2017	$ 335,310.82	$ 289,654.09	$ 289,654.09
4							$ 82,323.72	$ 106,422.96	$ 9,437.96	$ 8,235.36	$ 137,944.20	2018	$ 344,364.21	$ 283,309.29	$ 283,309.29
5							$ 84,546.46	$ 109,296.38	$ 9,692.79	$ 8,457.71	$ 141,668.70	2019	$ 353,662.04	$ 277,103.46	$ 277,103.46
6							$ 86,829.21	$ 112,247.39	$ 9,954.49	$ 8,686.07	$ 145,493.75	2020	$ 363,210.92	$ 271,033.58	$ 271,033.58
7							$ 89,173.60	$ 115,278.07	$ 10,223.27	$ 8,920.59	$ 149,422.08	2021	$ 373,017.61	$ 265,096.65	$ 265,096.65
8							$ 91,581.29	$ 118,390.57	$ 10,499.29	$ 9,161.45	$ 153,456.48	2022	$ 383,089.09	$ 259,289.77	$ 259,289.77
9							$ 94,053.98	$ 121,587.12	$ 10,782.78	$ 9,408.81	$ 157,599.81	2023	$ 393,432.49	$ 253,610.09	$ 253,610.09
10							$ 96,593.44	$ 124,869.97	$ 11,073.91	$ 9,662.85	$ 161,855.00	2024	$ 404,055.17	$ 248,054.82	$ 248,054.82
11							$ 99,201.46	$ 128,241.46	$ 11,372.91	$ 9,923.74	$ 166,225.09	2025	$ 414,964.66	$ 242,621.24	$ 242,621.24
12							$ 101,879.90	$ 131,703.98	$ 11,679.97	$ 10,191.69	$ 170,713.16	2026	$ 426,168.71	$ 237,306.68	$ 237,306.68
13							$ 104,630.66	$ 135,259.99	$ 11,995.33	$ 10,466.86	$ 175,322.42	2027	$ 437,675.26	$ 232,108.54	$ 232,108.54
14							$ 107,455.69	$ 138,912.01	$ 12,319.21	$ 10,749.47	$ 180,056.12	2028	$ 449,492.49	$ 227,024.25	$ 227,024.25
15				ELEVATOR	$ 140,000.00	$ 208,777.98	$ 110,356.99	$ 142,662.63	$ 12,651.83	$ 11,039.70	$ 184,917.64	2029	$ 461,628.79	$ 222,051.34	$ 222,051.34
16				CONTROLS	$ 160,000.00	$ 245,045.70	$ 113,336.63	$ 146,514.52	$ 12,993.43	$ 11,337.77	$ 189,910.41	2030	$ 719,138.46	$ 329,445.62	$ 329,445.62
17				OTHER	$ 100,000.00	$ 157,288.71	$ 116,396.72	$ 150,470.41	$ 13,344.25	$ 11,643.89	$ 195,038.00	2031	$ 644,181.98	$ 281,054.46	$ 281,054.46
18							$ 119,539.43	$ 154,533.12	$ 13,704.54	$ 11,958.28	$ 200,304.02	2032	$ 500,039.39	$ 207,776.69	$ 207,776.69
19							$ 122,767.00	$ 158,705.51	$ 14,074.57	$ 12,281.15	$ 205,712.23	2033	$ 513,540.45	$ 203,225.40	$ 203,225.40
20							$ 126,081.70	$ 162,990.56	$ 14,454.58	$ 12,612.74	$ 211,266.46	2034	$ 527,406.05	$ 198,773.79	$ 198,773.79
21							$ 129,485.91	$ 167,391.30	$ 14,844.85	$ 12,953.29	$ 216,970.66	2035	$ 541,646.01	$ 194,419.70	$ 194,419.70
22							$ 132,982.03	$ 171,910.87	$ 15,245.66	$ 13,303.03	$ 222,828.86	2036	$ 556,270.45	$ 190,160.98	$ 190,160.98
23							$ 136,572.54	$ 176,552.46	$ 15,657.30	$ 13,662.21	$ 228,845.24	2037	$ 571,289.75	$ 185,995.55	$ 185,995.55
24							$ 140,260.00	$ 181,319.38	$ 16,080.04	$ 14,031.09	$ 235,024.06	2038	$ 586,714.58	$ 181,921.36	$ 181,921.36
25							$ 144,047.02	$ 186,215.00	$ 16,514.20	$ 14,409.93	$ 241,369.71	2039	$ 602,555.87	$ 177,936.42	$ 177,936.42
26							$ 147,936.29	$ 191,242.81	$ 16,960.09	$ 14,799.00	$ 247,886.70	2040	$ 618,824.88	$ 174,038.76	$ 174,038.76
27							$ 151,930.57	$ 196,406.36	$ 17,418.01	$ 15,198.57	$ 254,579.64	2041	$ 635,533.15	$ 170,226.49	$ 170,226.49
28							$ 156,032.70	$ 201,709.33	$ 17,888.30	$ 15,608.93	$ 261,453.29	2042	$ 652,692.55	$ 166,497.72	$ 166,497.72
29							$ 160,245.58	$ 207,155.49	$ 18,371.28	$ 16,030.37	$ 268,512.53	2043	$ 670,315.24	$ 162,850.62	$ 162,850.62
30							$ 164,572.21	$ 212,748.68	$ 18,867.31	$ 16,463.19	$ 275,762.36	2044	$ 688,413.76	$ 159,283.42	$ 159,283.42
31							$ 169,015.66	$ 218,492.90	$ 19,376.72	$ 16,907.70	$ 283,207.95	2045	$ 707,000.93	$ 155,794.35	$ 155,794.35
32							$ 173,579.08	$ 224,392.21	$ 19,899.89	$ 17,364.21	$ 290,854.56	2046	$ 726,089.95	$ 152,381.72	$ 152,381.72
33	RENOVATION	$ 37,338,454.42	$ 7,462,931.71				$ 178,265.72	$ 230,450.80	$ 20,437.19	$ 17,833.04	$ 298,707.64	2047	$ 745,694.38	$ 149,043.83	$ 7,611,975.54
34							$ 183,078.89	$ 236,672.97	$ 20,989.00	$ 18,314.53	$ 306,772.74	2048	$ 765,828.13	$ 145,779.06	$ 145,779.06
35							$ 188,022.02	$ 243,063.14	$ 21,555.70	$ 18,809.02	$ 315,055.61	2049	$ 786,505.49	$ 142,585.80	$ 142,585.80
36							$ 193,098.62	$ 249,625.84	$ 22,137.70	$ 19,316.87	$ 323,562.11	2050	$ 807,741.14	$ 139,462.50	$ 139,462.50
37							$ 198,312.28	$ 256,365.74	$ 22,735.42	$ 19,838.42	$ 332,298.28	2051	$ 829,550.15	$ 136,407.60	$ 136,407.60
38							$ 203,666.71	$ 263,287.62	$ 23,349.28	$ 20,374.06	$ 341,270.34	2052	$ 851,948.00	$ 133,419.63	$ 133,419.63
39							$ 209,165.72	$ 270,396.38	$ 23,979.71	$ 20,924.16	$ 350,484.64	2053	$ 874,950.60	$ 130,497.10	$ 130,497.10
40							$ 214,813.19	$ 277,697.08	$ 24,627.16	$ 21,489.11	$ 359,947.72	2054	$ 898,574.26	$ 127,638.59	$ 127,638.59
41							$ 220,613.15	$ 285,194.91	$ 25,292.09	$ 22,069.32	$ 369,666.31	2055	$ 922,835.77	$ 124,842.70	$ 124,842.70
42							$ 226,569.70	$ 292,895.17	$ 25,974.98	$ 22,665.19	$ 379,647.30	2056	$ 947,752.34	$ 122,108.05	$ 122,108.05
43							$ 232,687.08	$ 300,803.34	$ 26,676.30	$ 23,277.15	$ 389,897.78	2057	$ 973,341.65	$ 119,433.30	$ 119,433.30
44							$ 238,969.63	$ 308,925.03	$ 27,396.56	$ 23,905.63	$ 400,425.02	2058	$ 999,621.87	$ 116,817.15	$ 116,817.15
45							$ 245,421.81	$ 317,266.00	$ 28,136.27	$ 24,551.08	$ 411,236.49	2059	$ 1,026,611.66	$ 114,258.29	$ 114,258.29
46							$ 252,048.20	$ 325,832.18	$ 28,895.95	$ 25,213.96	$ 422,339.88	2060	$ 1,054,330.18	$ 111,755.49	$ 111,755.49
47							$ 258,853.50	$ 334,629.65	$ 29,676.14	$ 25,894.74	$ 433,743.06	2061	$ 1,082,797.09	$ 109,307.52	$ 109,307.52
48				ELEVATOR	$ 140,000.00	$ 502,932.07	$ 265,842.55	$ 343,664.65	$ 30,477.40	$ 26,593.90	$ 445,454.12	2062	$ 1,614,964.68	$ 155,266.11	$ 155,266.11
49				CONTROLS	$ 160,000.00	$ 590,298.55	$ 273,020.30	$ 352,943.60	$ 31,300.29	$ 27,311.93	$ 457,481.38	2063	$ 1,732,356.05	$ 158,621.30	$ 158,621.30
50				OTHER	$ 100,000.00	$ 378,897.88	$ 280,391.85	$ 362,473.08	$ 32,145.39	$ 28,049.36	$ 469,833.38	2064	$ 1,551,790.93	$ 135,321.95	$ 135,321.95
51							$ 287,962.43	$ 372,259.85	$ 33,013.32	$ 28,806.69	$ 482,518.88	2065	$ 1,204,561.16	$ 100,040.21	$ 100,040.21

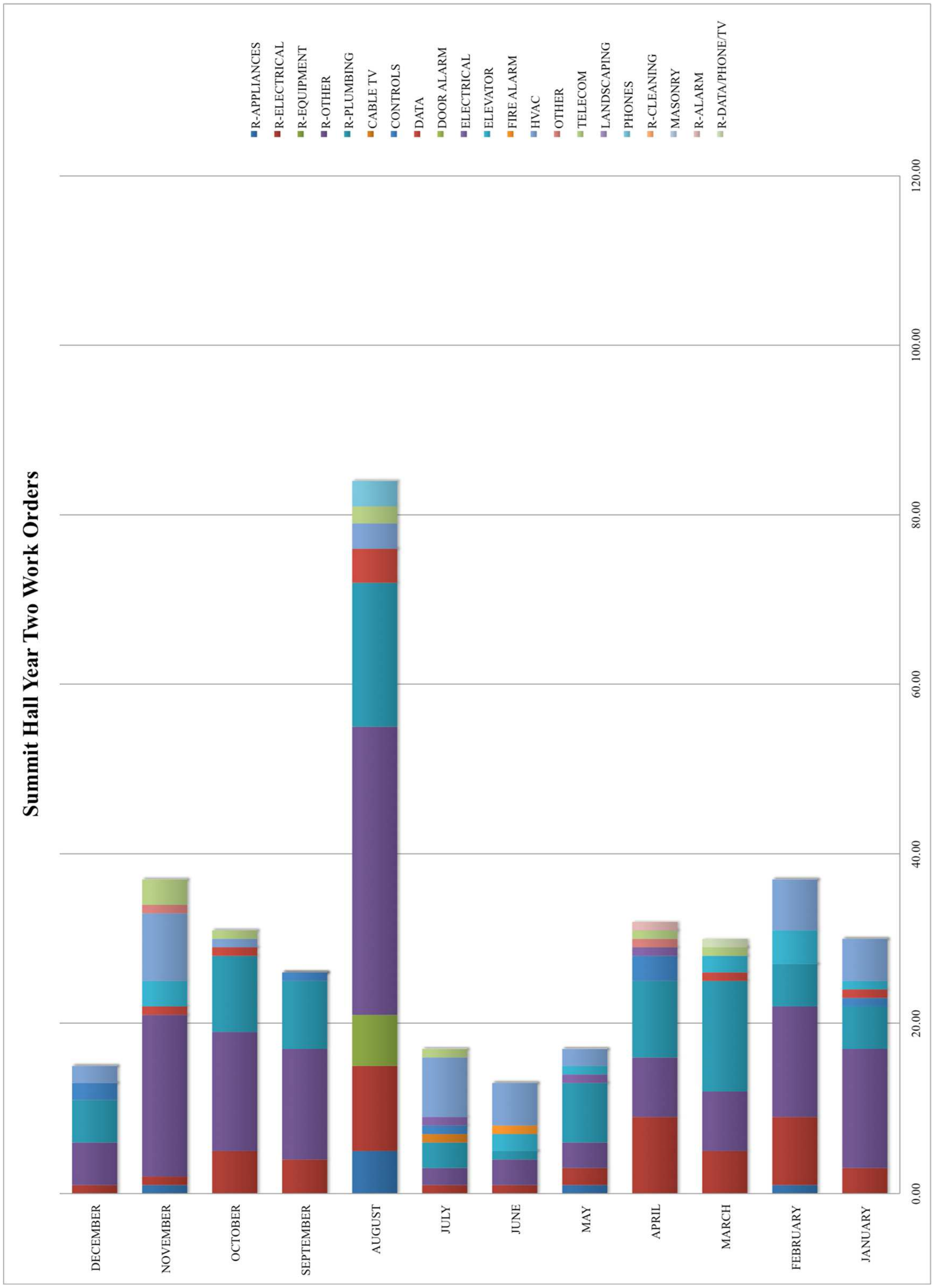
51							$ 287,962.43	$ 372,259.85	$ 33,013.32	$ 28,806.69	$ 482,518.88	2065	$ 1,204,561.16	$ 100,040.21	$ 100,040.21
52							$ 295,737.41	$ 382,310.87	$ 33,904.68	$ 29,584.47	$ 495,546.89	2066	$ 1,237,084.31	$ 97,848.85	$ 97,848.85
53							$ 303,722.32	$ 392,633.26	$ 34,820.10	$ 30,383.25	$ 508,926.65	2067	$ 1,270,485.59	$ 95,705.50	$ 95,705.50
54							$ 311,922.82	$ 403,234.36	$ 35,760.25	$ 31,203.60	$ 522,667.67	2068	$ 1,304,788.70	$ 93,609.09	$ 93,609.09
55							$ 320,344.74	$ 414,121.69	$ 36,725.77	$ 32,046.09	$ 536,779.70	2069	$ 1,340,017.99	$ 91,558.61	$ 91,558.61
56							$ 328,994.05	$ 425,302.97	$ 37,717.37	$ 32,911.34	$ 551,272.75	2070	$ 1,376,198.48	$ 89,553.04	$ 89,553.04
57							$ 337,876.89	$ 436,786.15	$ 38,735.74	$ 33,799.95	$ 566,157.12	2071	$ 1,413,355.84	$ 87,591.40	$ 87,591.40
58							$ 346,999.56	$ 448,579.38	$ 39,781.60	$ 34,712.54	$ 581,443.36	2072	$ 1,451,516.45	$ 85,672.73	$ 85,672.73
59							$ 356,368.55	$ 460,691.02	$ 40,855.71	$ 35,649.78	$ 597,142.33	2073	$ 1,490,707.39	$ 83,796.09	$ 83,796.09
60							$ 365,990.50	$ 473,129.68	$ 41,958.81	$ 36,612.33	$ 613,265.17	2074	$ 1,530,956.49	$ 81,960.56	$ 81,960.56
61							$ 375,872.25	$ 485,904.18	$ 43,091.70	$ 37,600.86	$ 629,823.33	2075	$ 1,572,292.32	$ 80,165.23	$ 80,165.23
62							$ 386,020.80	$ 499,023.59	$ 44,255.18	$ 38,616.08	$ 646,828.56	2076	$ 1,614,744.21	$ 78,409.23	$ 78,409.23
63							$ 396,443.36	$ 512,497.23	$ 45,450.07	$ 39,658.72	$ 664,292.93	2077	$ 1,658,342.30	$ 76,691.70	$ 76,691.70
64							$ 407,147.33	$ 526,334.65	$ 46,677.22	$ 40,729.50	$ 682,228.84	2078	$ 1,703,117.54	$ 75,011.78	$ 75,011.78
65							$ 418,140.31	$ 540,545.69	$ 47,937.50	$ 41,829.20	$ 700,649.02	2079	$ 1,749,101.72	$ 73,368.67	$ 73,368.67
66	RENOVATION	$ 108,336,704.00	$ 4,327,946.46				$ 429,430.09	$ 555,140.42	$ 49,231.81	$ 42,958.59	$ 719,566.54	2080	$ 1,796,327.46	$ 71,761.54	$ 4,399,708.01
67							$ 441,024.71	$ 570,129.22	$ 50,561.07	$ 44,118.47	$ 738,994.84	2081	$ 1,844,828.31	$ 70,189.62	$ 70,189.62
68							$ 452,932.37	$ 585,522.70	$ 51,926.22	$ 45,309.67	$ 758,947.70	2082	$ 1,894,638.67	$ 68,652.14	$ 68,652.14
69							$ 465,161.55	$ 601,331.82	$ 53,328.23	$ 46,533.03	$ 779,439.29	2083	$ 1,945,793.91	$ 67,148.33	$ 67,148.33
70							$ 477,720.91	$ 617,567.78	$ 54,768.09	$ 47,789.42	$ 800,484.15	2084	$ 1,998,330.35	$ 65,677.46	$ 65,677.46
71							$ 490,619.37	$ 634,242.11	$ 56,246.83	$ 49,079.73	$ 822,097.22	2085	$ 2,052,285.27	$ 64,238.81	$ 64,238.81
72							$ 503,866.10	$ 651,366.64	$ 57,765.50	$ 50,404.89	$ 844,293.85	2086	$ 2,107,696.97	$ 62,831.68	$ 62,831.68
73							$ 517,470.48	$ 668,953.54	$ 59,325.16	$ 51,765.82	$ 867,089.78	2087	$ 2,164,604.79	$ 61,455.36	$ 61,455.36
74							$ 531,442.19	$ 687,015.29	$ 60,926.94	$ 53,163.50	$ 890,501.20	2088	$ 2,223,049.12	$ 60,109.20	$ 60,109.20
75							$ 545,791.12	$ 705,564.70	$ 62,571.97	$ 54,598.91	$ 914,544.74	2089	$ 2,283,071.44	$ 58,792.52	$ 58,792.52
76							$ 560,527.49	$ 724,614.95	$ 64,261.41	$ 56,073.08	$ 939,237.45	2090	$ 2,344,714.37	$ 57,504.68	$ 57,504.68
77							$ 575,661.73	$ 744,179.55	$ 65,996.47	$ 57,587.05	$ 964,596.86	2091	$ 2,408,021.66	$ 56,245.06	$ 56,245.06
78							$ 591,204.59	$ 764,272.40	$ 67,778.38	$ 59,141.91	$ 990,640.97	2092	$ 2,473,038.25	$ 55,013.02	$ 55,013.02
79							$ 607,167.12	$ 784,907.75	$ 69,608.39	$ 60,738.74	$ 1,017,388.28	2093	$ 2,539,810.28	$ 53,807.98	$ 53,807.98
80							$ 623,560.63	$ 806,100.26	$ 71,487.82	$ 62,378.68	$ 1,044,857.76	2094	$ 2,608,385.16	$ 52,629.32	$ 52,629.32
81				ELEVATOR	$ 140,000.00	$ 1,211,529.43	$ 640,396.77	$ 827,864.97	$ 73,417.99	$ 64,062.91	$ 1,073,068.92	2095	$ 3,890,340.98	$ 74,757.44	$ 74,757.44
82				CONTROLS	$ 160,000.00	$ 1,421,989.40	$ 657,687.48	$ 850,217.32	$ 75,400.28	$ 65,792.61	$ 1,102,041.78	2096	$ 4,173,128.86	$ 76,372.90	$ 76,372.90
83				OTHER	$ 100,000.00	$ 912,739.44	$ 675,445.04	$ 873,173.19	$ 77,436.08	$ 67,569.01	$ 1,131,796.91	2097	$ 3,738,159.68	$ 65,154.74	$ 65,154.74
84							$ 693,682.06	$ 896,748.87	$ 79,526.86	$ 69,393.37	$ 1,162,355.43	2098	$ 2,901,706.58	$ 48,167.31	$ 48,167.31
85							$ 712,411.47	$ 920,961.09	$ 81,674.08	$ 71,266.99	$ 1,193,739.02	2099	$ 2,980,052.66	$ 47,112.21	$ 47,112.21
86							$ 731,646.58	$ 945,827.04	$ 83,879.28	$ 73,191.20	$ 1,225,969.98	2100	$ 3,060,514.08	$ 46,080.23	$ 46,080.23
87							$ 751,401.04	$ 971,364.37	$ 86,144.02	$ 75,167.36	$ 1,259,071.17	2101	$ 3,143,147.96	$ 45,070.86	$ 45,070.86
88							$ 771,688.87	$ 997,591.21	$ 88,469.91	$ 77,196.88	$ 1,293,066.09	2102	$ 3,228,012.95	$ 44,083.59	$ 44,083.59
89							$ 792,524.47	$ 1,024,526.17	$ 90,858.60	$ 79,281.20	$ 1,327,978.87	2103	$ 3,315,169.30	$ 43,117.95	$ 43,117.95
90							$ 813,922.63	$ 1,052,188.37	$ 93,311.78	$ 81,421.79	$ 1,363,834.30	2104	$ 3,404,678.88	$ 42,173.46	$ 42,173.46
91							$ 835,898.54	$ 1,080,597.46	$ 95,831.20	$ 83,620.18	$ 1,400,657.83	2105	$ 3,496,605.20	$ 41,249.66	$ 41,249.66
92							$ 858,467.80	$ 1,109,773.59	$ 98,418.64	$ 85,877.92	$ 1,438,475.59	2106	$ 3,591,013.55	$ 40,346.10	$ 40,346.10
93							$ 881,646.43	$ 1,139,737.48	$ 101,075.95	$ 88,196.62	$ 1,477,314.43	2107	$ 3,687,970.91	$ 39,462.33	$ 39,462.33
94							$ 905,450.89	$ 1,170,510.39	$ 103,805.00	$ 90,577.93	$ 1,517,201.92	2108	$ 3,787,546.13	$ 38,597.91	$ 38,597.91
95							$ 929,898.06	$ 1,202,114.17	$ 106,607.73	$ 93,023.54	$ 1,558,166.37	2109	$ 3,889,809.87	$ 37,752.43	$ 37,752.43
96							$ 955,005.31	$ 1,234,571.25	$ 109,486.14	$ 95,535.17	$ 1,600,236.86	2110	$ 3,994,834.74	$ 36,925.48	$ 36,925.48
97							$ 980,790.45	$ 1,267,904.68	$ 112,442.27	$ 98,114.62	$ 1,643,443.26	2111	$ 4,102,695.28	$ 36,116.63	$ 36,116.63
98							$ 1,007,271.79	$ 1,302,138.10	$ 115,478.21	$ 100,763.72	$ 1,687,816.23	2112	$ 4,213,468.05	$ 35,325.51	$ 35,325.51
99							$ 1,034,468.13	$ 1,337,295.83	$ 118,596.12	$ 103,484.34	$ 1,733,387.26	2113	$ 4,327,231.69	$ 34,551.71	$ 34,551.71
100							$ 1,062,398.77	$ 1,373,402.82	$ 121,798.22	$ 106,278.42	$ 1,780,188.72	2114	$ 4,444,066.94	$ 33,794.86	$ 33,794.86
	SALAVAGE	**$ -**	**$ -**										**TOTAL**	**UNDISCOUNTED**	**DISCOUNTED**
	FUTURE REPAIRS	**$ -**	**$ -**										**COST**	**$ 339,360,506.55**	**$ 55,485,657.91**
	VALUE	**$ -**	**$ -**										**ADJUSTED**		
													COST	**$ 339,360,506.55**	**$ 55,485,657.91**

APPENDIX D: WORK ORDERS

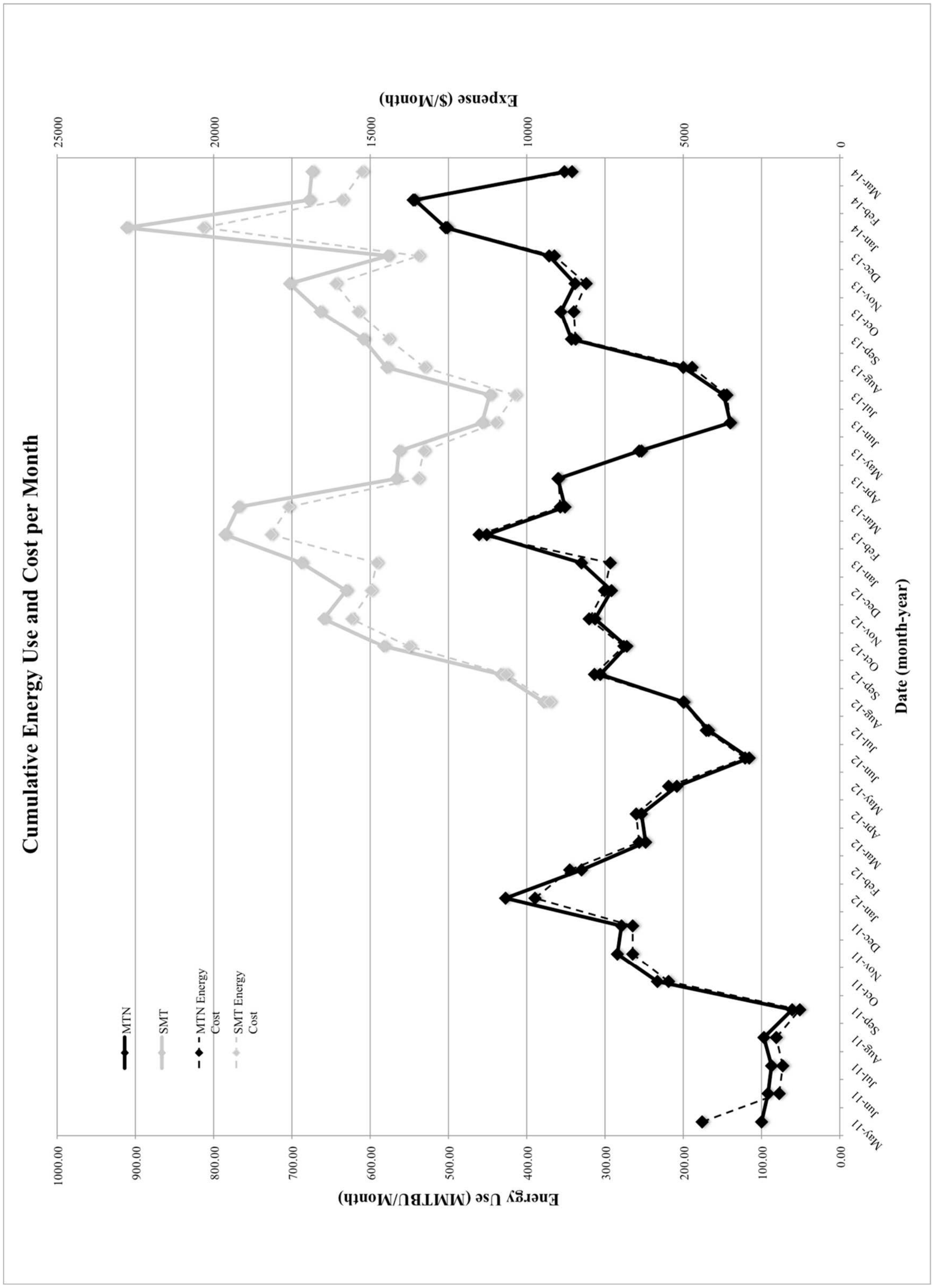


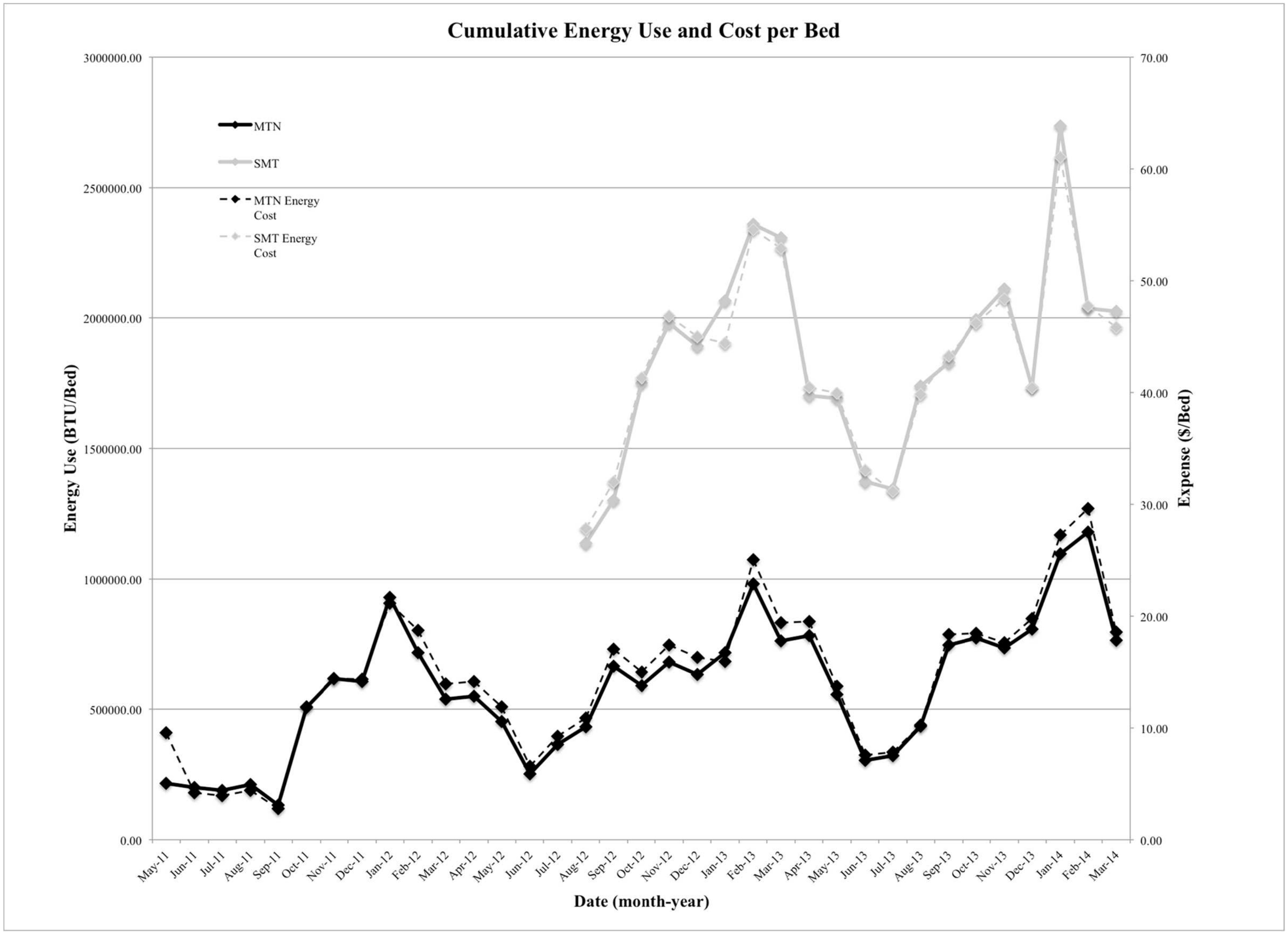

Summit Hall Corrected Year One Work Orders
DECEMBER
NOVEMBER
OCTOBER
SEPTEMBER
AUGUST
JULY
JUNE
MAY
APRIL
MARCH
FEBRUARY
JANUARY
0.00
20.00
40.00
60.00
80.00
100.00
120.00
R-APPLIANCES
R-ELECTRICAL
R-EQUIPMENT
R-OTHER
R-PLUMBING
CABLE TV
CONTROLS
DATA
DOOR ALARM
ELECTRICAL
ELEVATOR
FIRE ALARM
HVAC / MECH
OTHER
TELECOM
LANDSCAPING
PHONES
R-CLEANING
MASONRY
R-ALARM
R-DATA/PHONE/TV

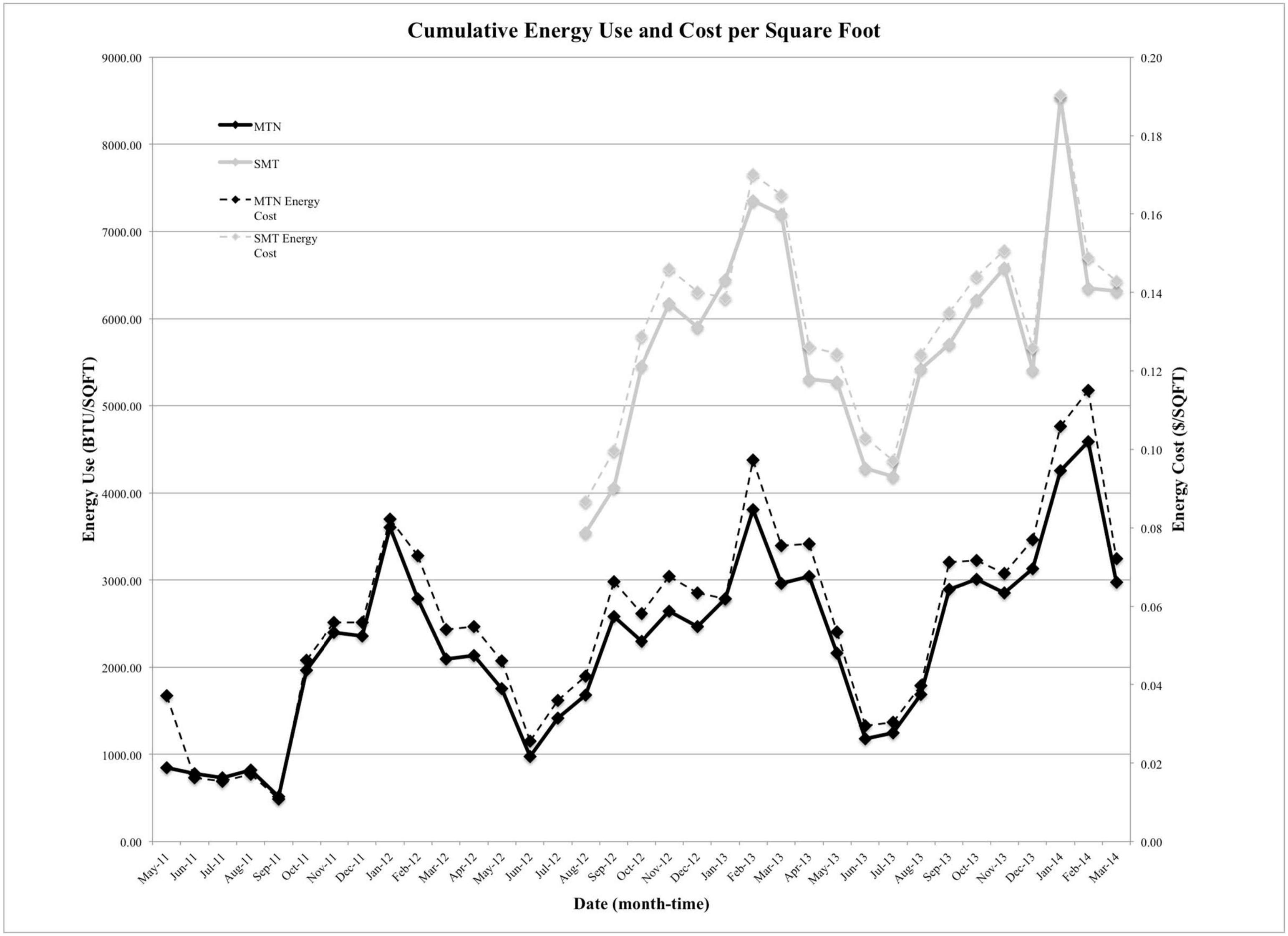

Mountaineer Hall Year Two Work Orders
R-APPLIANCES
R-ELECTRICAL
R-EQUIPMENT
R-OTHER
R-PLUMBING
CABLE TV
CONTROLS
DATA
DOOR ALARM
ELECTRICAL
ELEVATOR
FIRE ALARM
HVAC
OTHER
TELECOM
LANDSCAPING
PHONES
R-CLEANING
MASONRY
R-ALARM
R-DATA/PHONE/TV
0.00
20.00
40.00
60.00
80.00
100.00
120.00
DECEMBER
NOVEMBER
OCTOBER
SEPTEMBER
AUGUST
JULY
JUNE
MAY
APRIL
MARCH
FEBRUARY
JANUARY

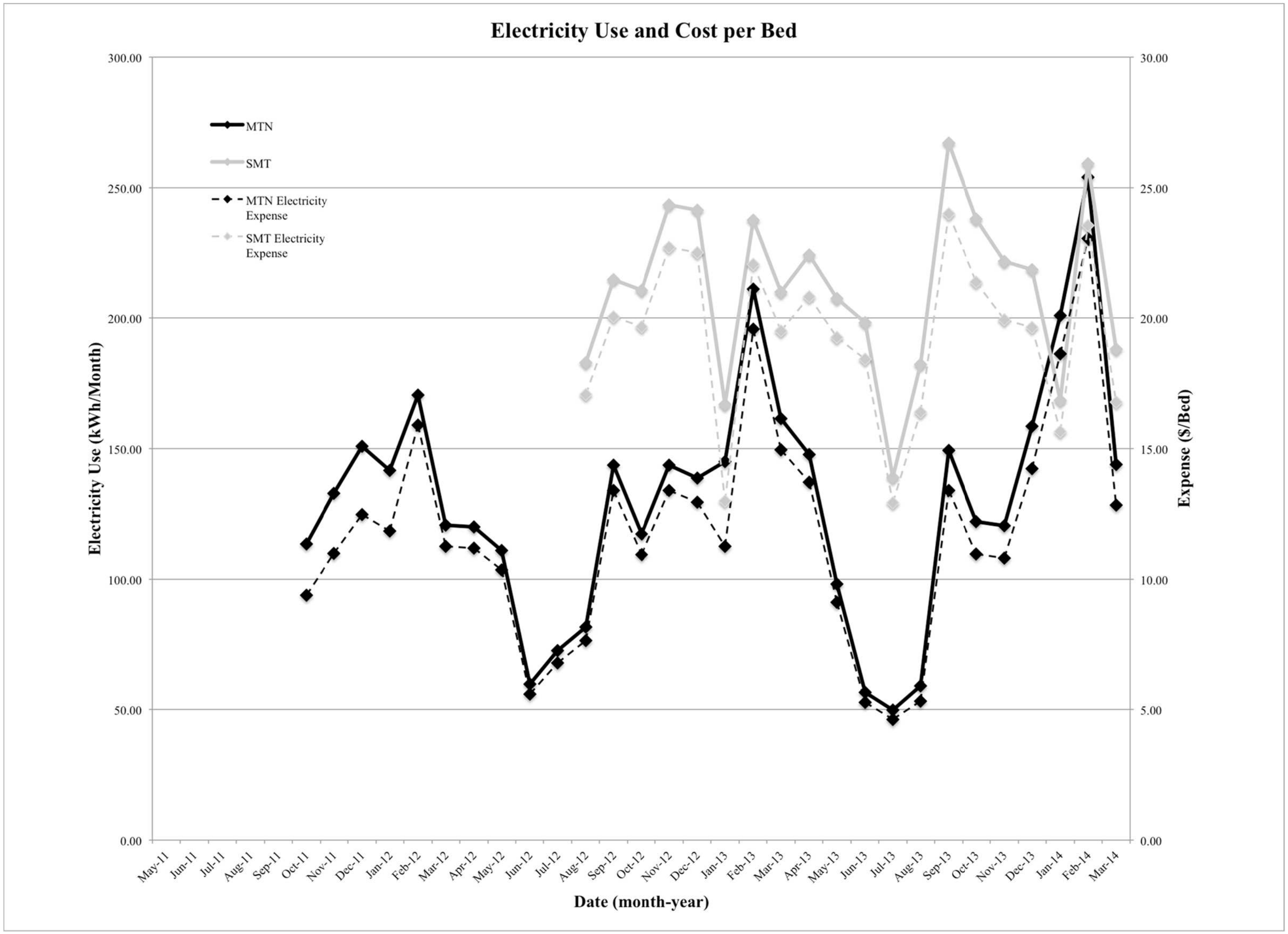

Summit Hall Year Two Work Orders
R-APPLIANCES
R-ELECTRICAL
R-EQUIPMENT
R-OTHER
R-PLUMBING
CABLE TV
CONTROLS
DATA
DOOR ALARM
ELECTRICAL
ELEVATOR
FIRE ALARM
HVAC
OTHER
TELECOM
LANDSCAPING
PHONES
R-CLEANING
MASONRY
R-ALARM
R-DATA/PHONE/TV
0.00
20.00
40.00
60.00
80.00
100.00
120.00
DECEMBER
NOVEMBER
OCTOBER
SEPTEMBER
AUGUST
JULY
JUNE
MAY
APRIL
MARCH
FEBRUARY
JANUARY

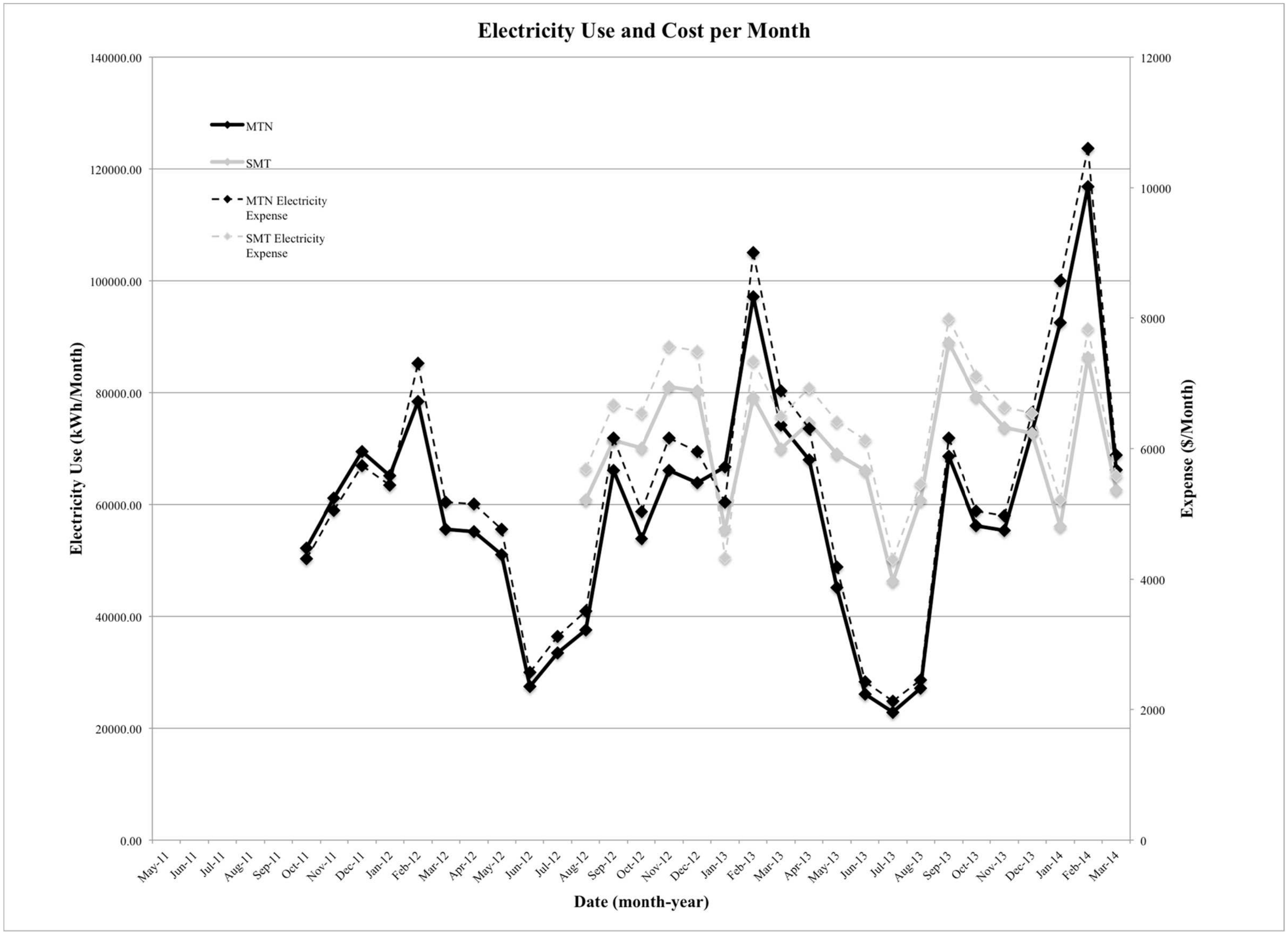
APPENDIX E: ENERGY USE GRAPHS

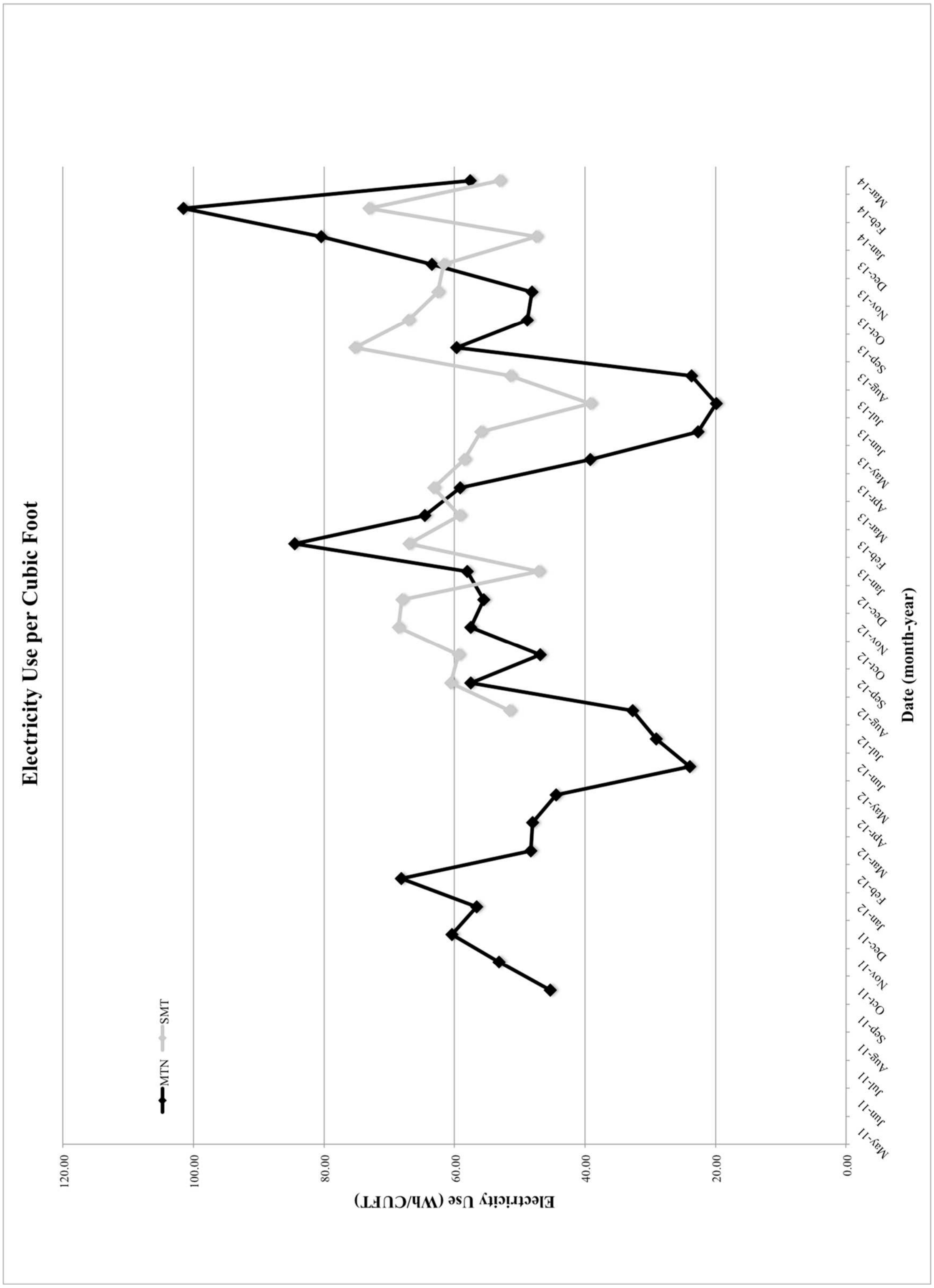


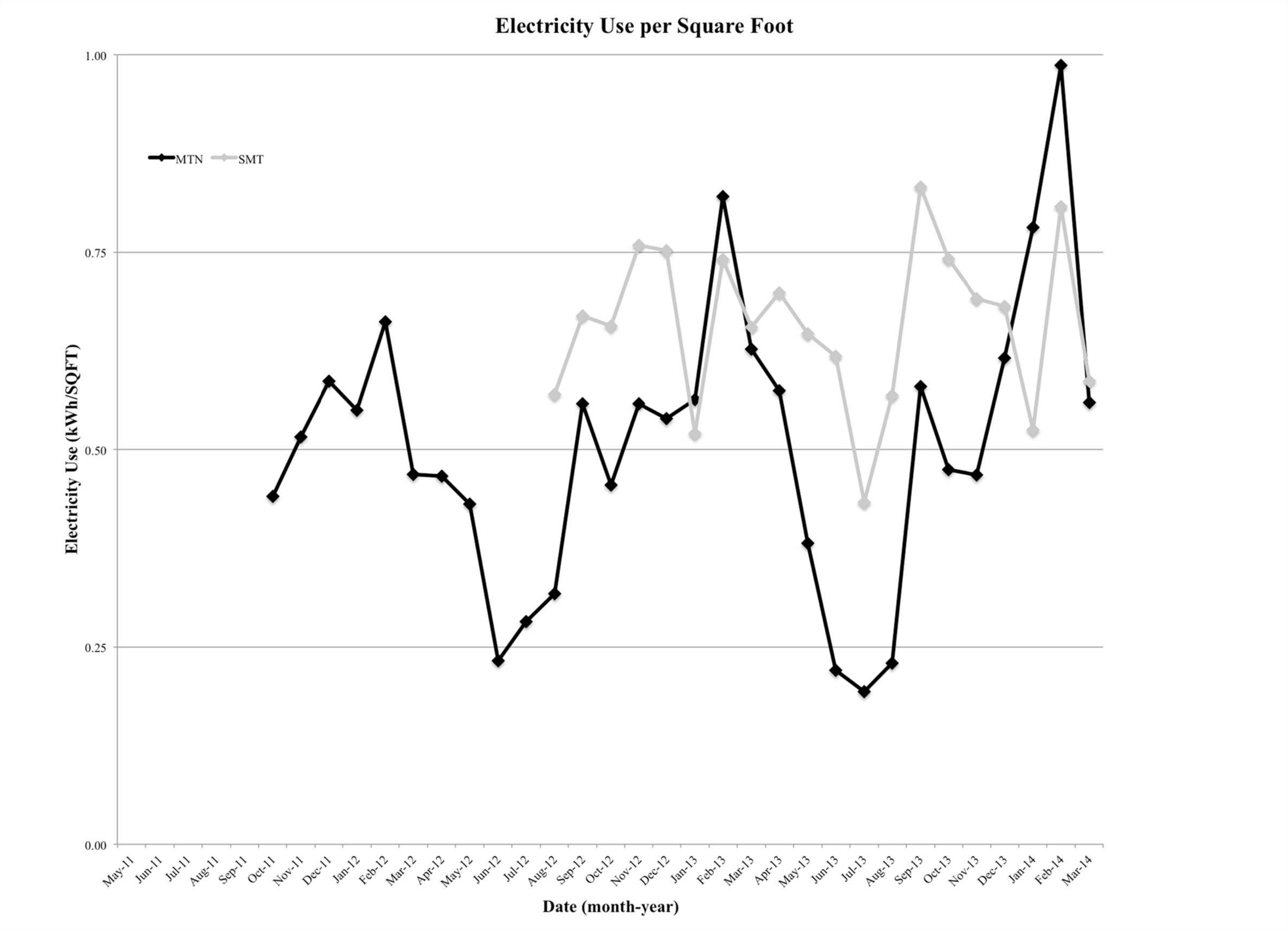

Cumulative Energy Use and Cost per Bed

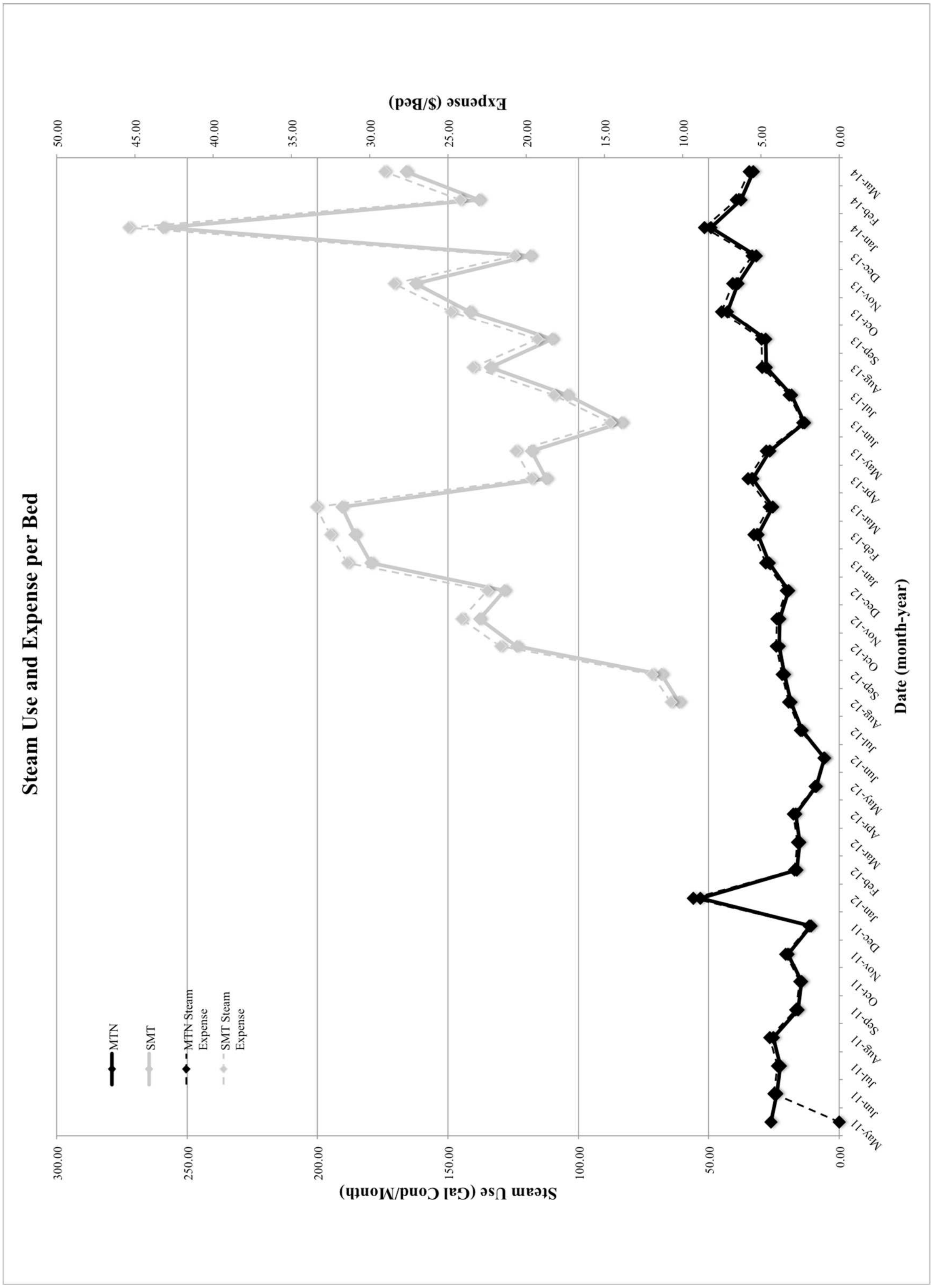

Cumulative Energy Use and Cost per Square Foot

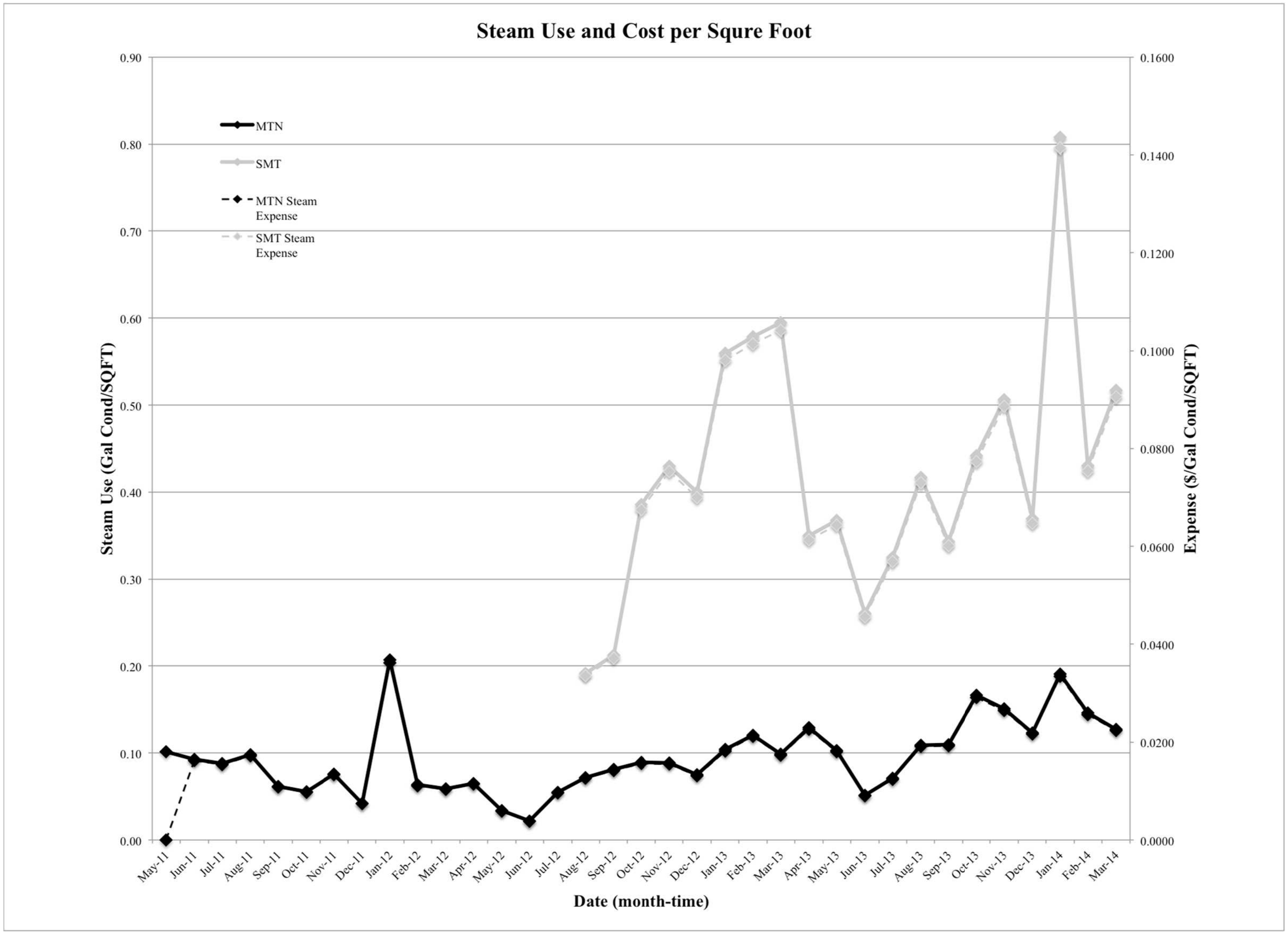

Electricity Use and Cost per Bed
MTN
SMT
MTN Electricity Expense
SMT Electricity Expense
Electricity Use (kWh/Month)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Expense ($/Bed)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)

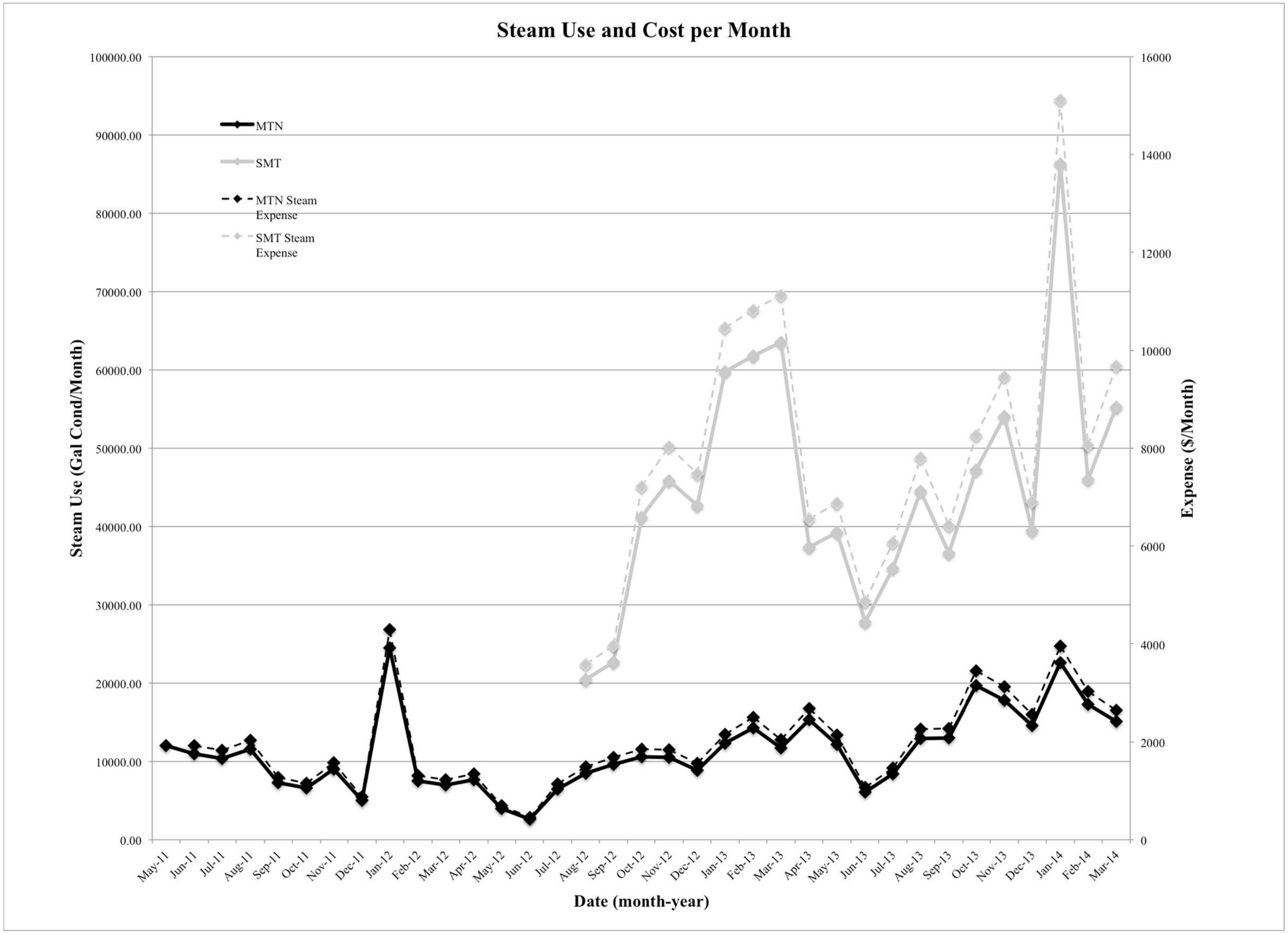

Electricity Use and Cost per Month
MTN
SMT
MTN Electricity Expense
SMT Electricity Expense
Electricity Use (kWh/Month)
140000.00
120000.00
100000.00
80000.00
60000.00
40000.00
20000.00
0.00
Expense ($/Month)
12000
10000
8000
6000
4000
2000
0
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)

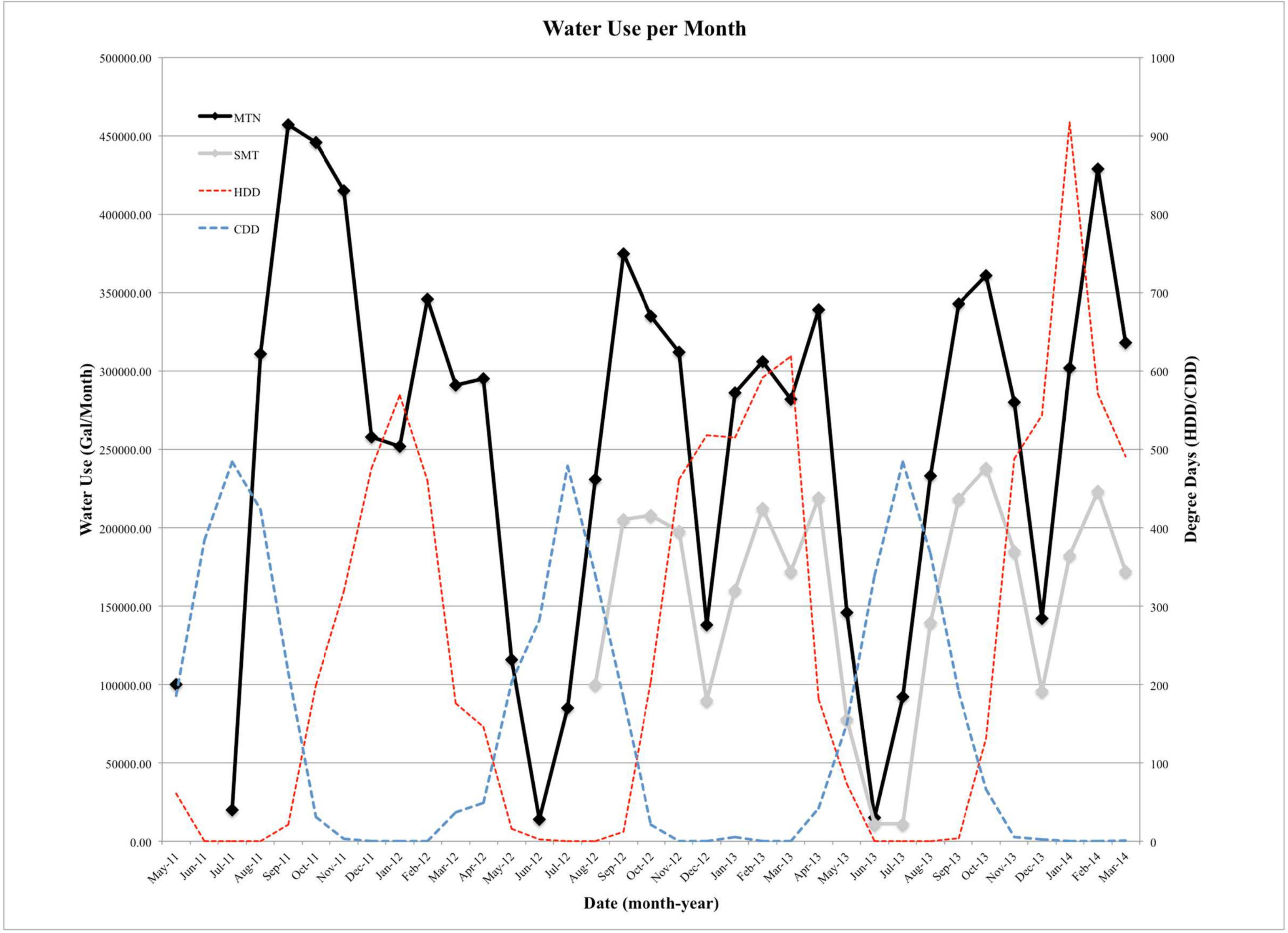

Electricity Use per Cubic Foot
MTN
SMT
Electricity Use (Wh/CU.FT)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)

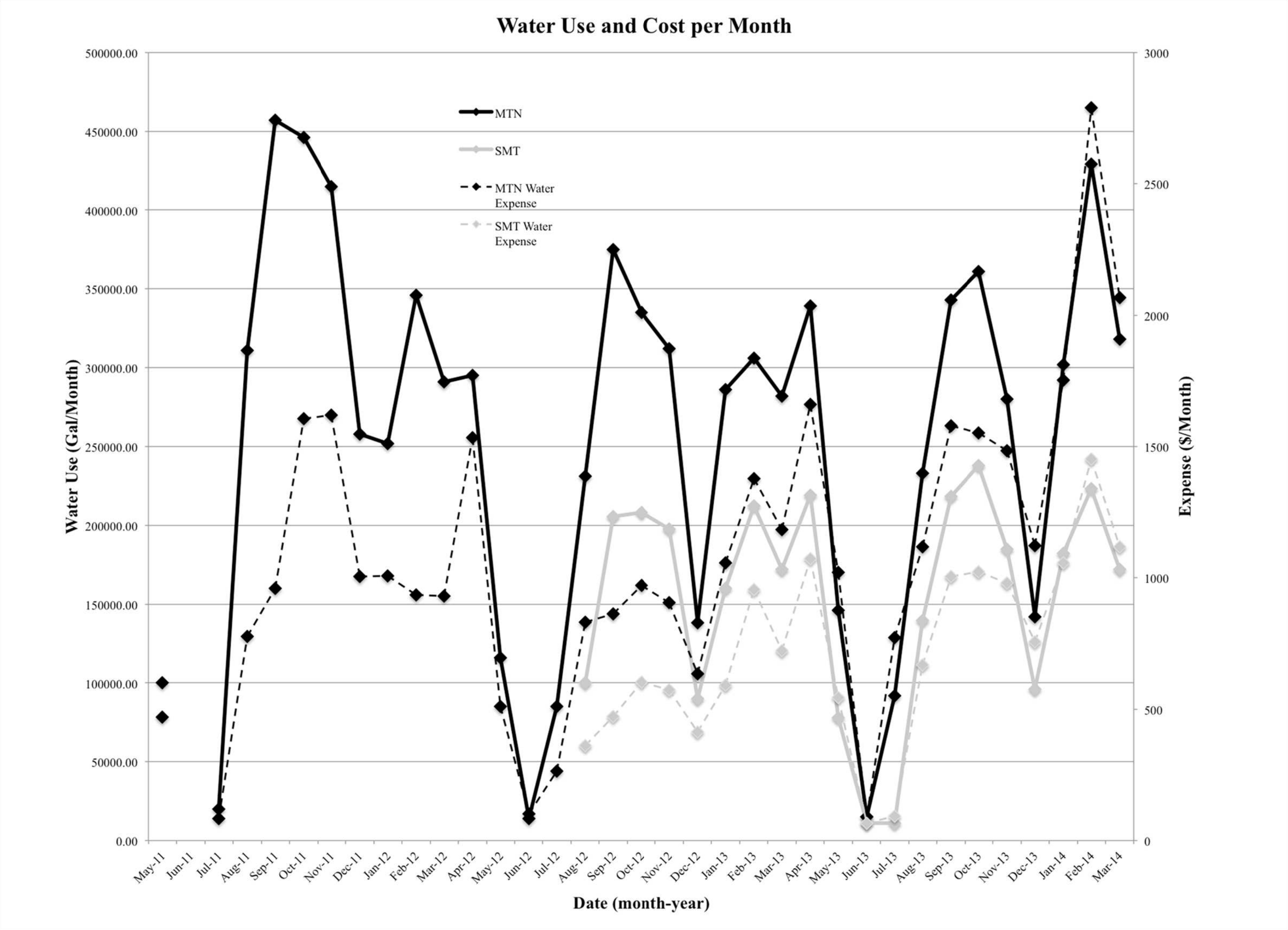

Electricity Use per Square Foot

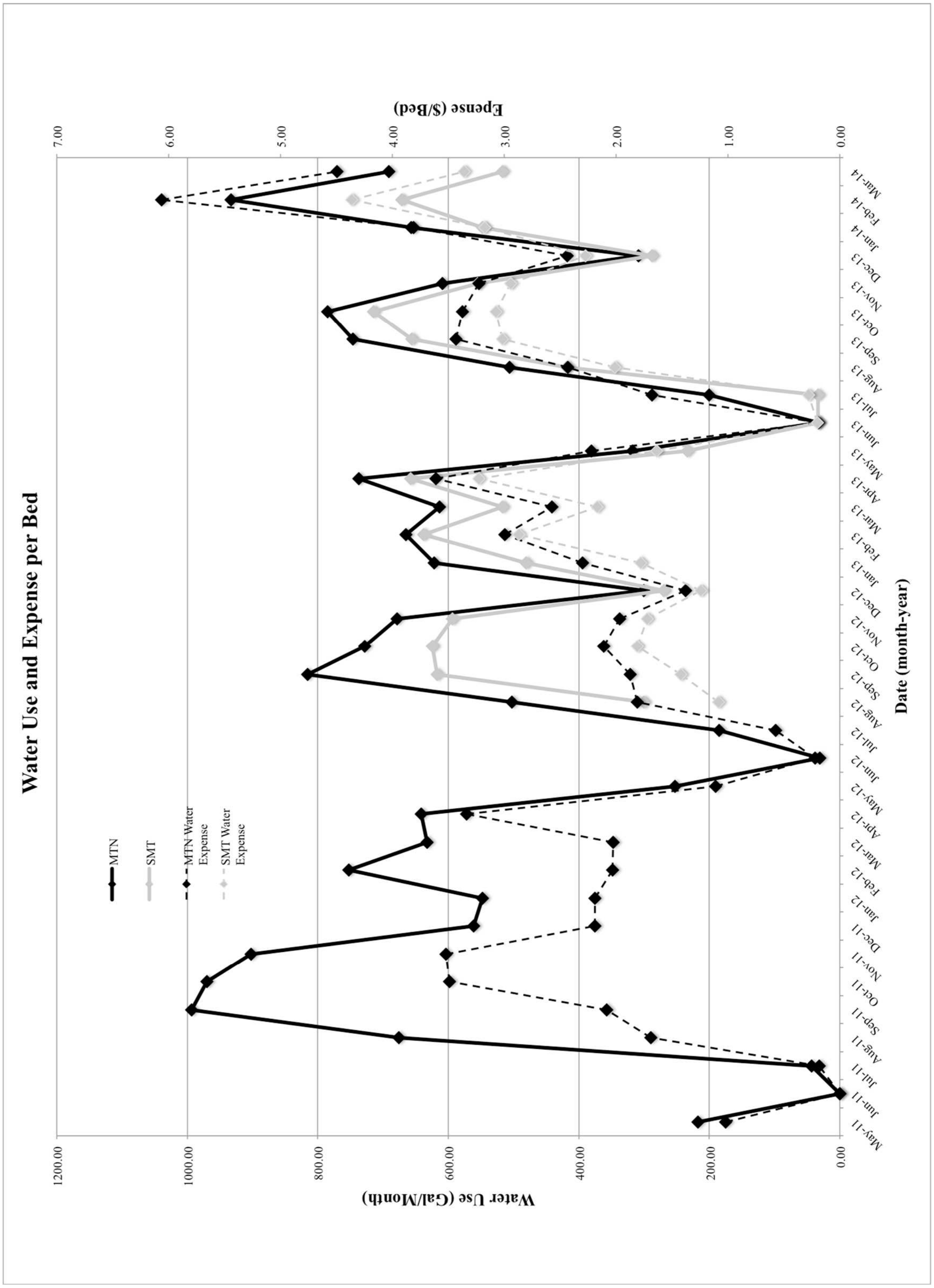

Steam Use and Expense per Bed
MTN
SMT
MTN Steam Expense
SMT Steam Expense
Steam Use (Gal Cond/Month)
0.00
50.00
100.00
150.00
200.00
250.00
300.00
Expense ($/Bed)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
Date (month-year)
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14

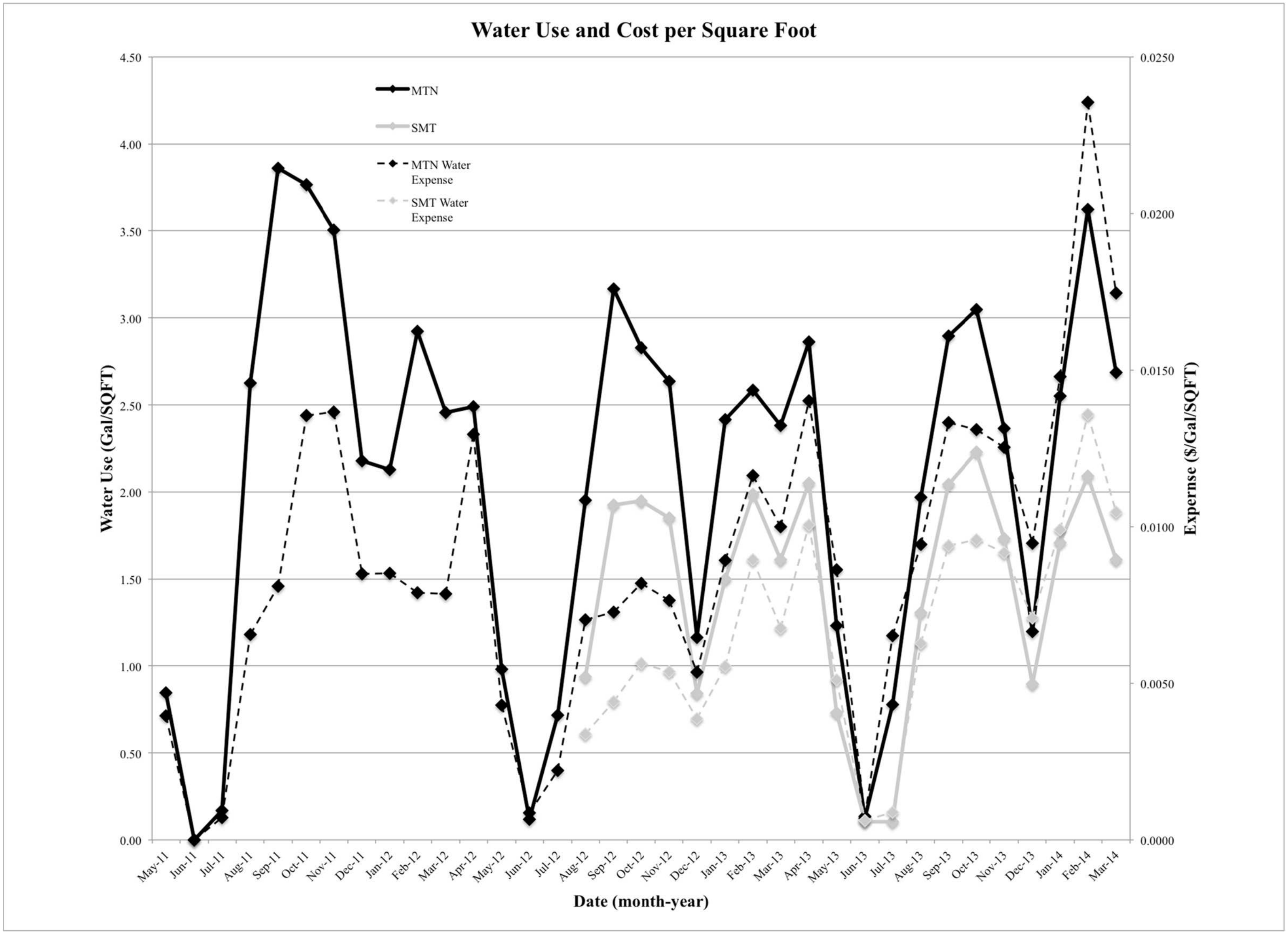

Steam Use and Cost per Squre Foot


Steam Use and Cost per Month
MTN
SMT
MTN Steam Expense
SMT Steam Expense
Steam Use (Gal Cond/Month)
100000.00
90000.00
80000.00
70000.00
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
Expense ($/Month)
16000
14000
12000
10000
8000
6000
4000
2000
0
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)


Water Use per Month
MTN
SMT
HDD
CDD
Water Use (Gal/Month)
500000.00
450000.00
400000.00
350000.00
300000.00
250000.00
200000.00
150000.00
100000.00
50000.00
0.00
Degree Days (HDD/CDD)
1000
900
800
700
600
500
400
300
200
100
0
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)


Water Use and Cost per Month
Water Use (Gal/Month)
500000.00
450000.00
400000.00
350000.00
300000.00
250000.00
200000.00
150000.00
100000.00
50000.00
0.00
Expense ($/Month)
3000
2500
2000
1500
1000
500
0
MTN
SMT
MTN Water Expense
SMT Water Expense
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)


Water Use and Expense per Bed
MTN
SMT
MTN Water Expense
SMT Water Expense
Water Use (Gal/Month)
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
Epense ($/Bed)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Date (month-year)
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14


Water Use and Cost per Square Foot
MTN
SMT
MTN Water Expense
SMT Water Expense
Water Use (Gal/SQFT)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Experse ($/Gal/SQFT)
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Date (month-year)

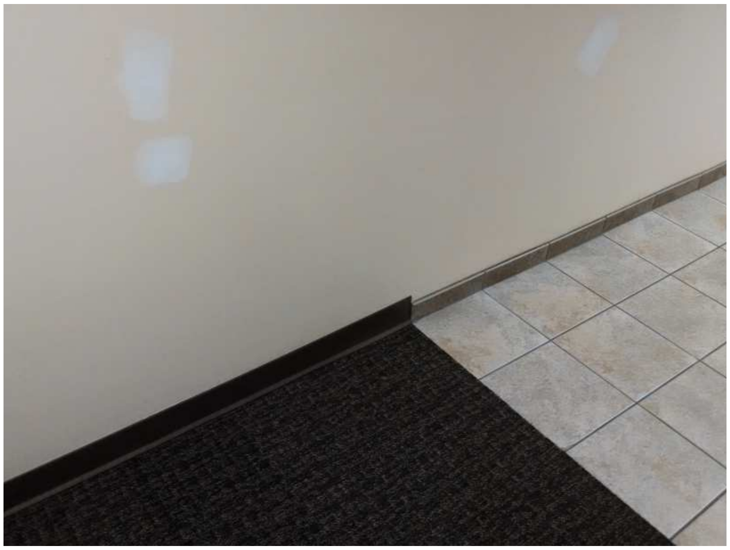
APPENDIX F SITE VISIT PHOTOS

Entrance to Mountaineer hall with walk off grates to prevent tracking in dirt and moisture.

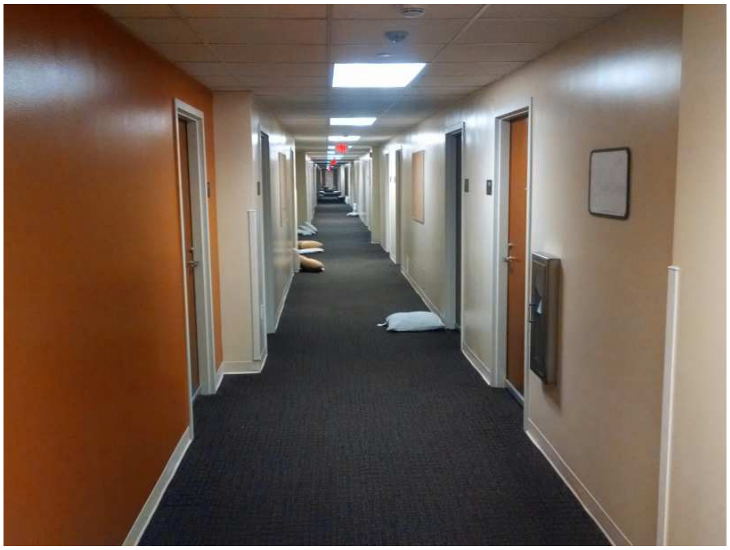
Traco window details with view of exterior courtyard constructed at Mountaineer.

All electrical wires are Metal Clad (MC) cables at Mountaineer.

Laundry facility at Mountaineer that sends an alert to residents when their laundry has finished its cycle.



The transition between site-built work and a module is obvious at this juncture in the floor. It is barely perceptible in the picture, but under foot, the feeling between tile and carpet is distinct.



In Mountaineer, the modules create this corridor, and each module is perpendicular to the length of the corridor.

Typical dorm room in Mountaineer. Notice the PTAC unit located under the window, the wood-pattern vinyl flooring, and the chase in the upper left corner that routes the bath vent to the outside.

With the window shut, the unit is off.

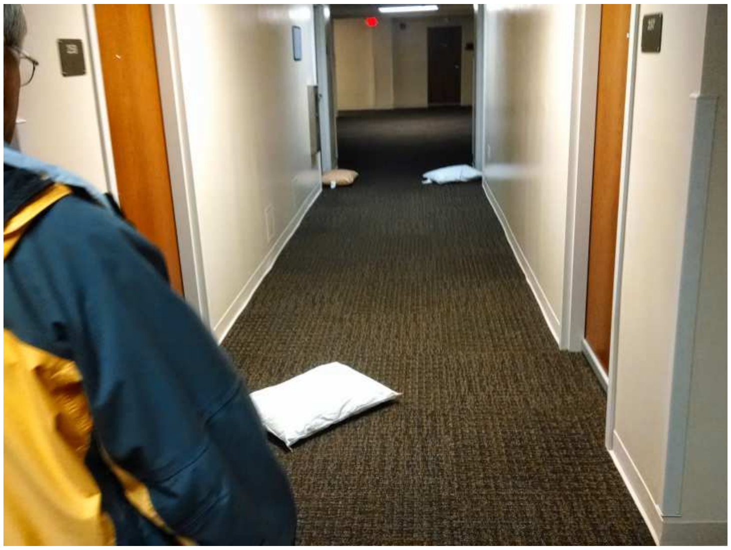
Typical bathroom inside one of the Mountaineer dorms.

Curved shower rods in the Mountaineer baths have caused water to leak on the floor in some units.

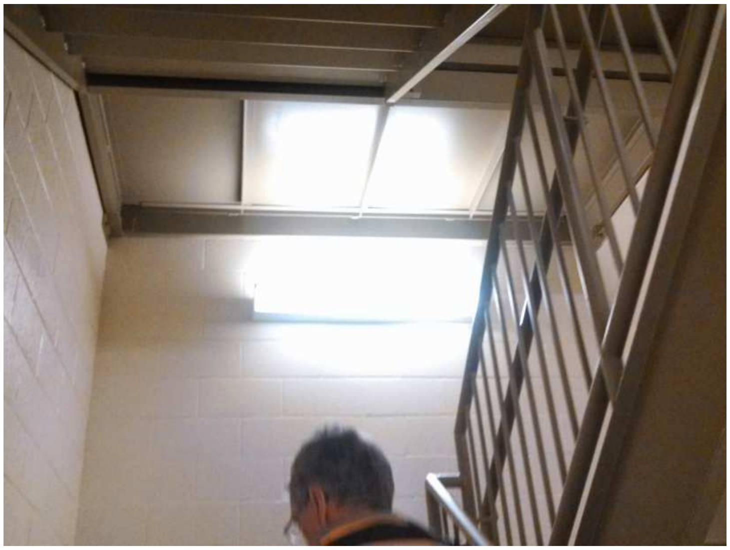
Smoke seals at the threshold of each door have been removed so the doors can completely close.

Crawl space access at Mountaineer.

Closer look at the web of MC cables powering Mountaineer.



A few quality defects are visible in this picture. Wavy vinyl base and wall studs telegraphing through the wall board are seen in the hall way.



Typical Mountaineer stairwell composed of CMU walls, and steel-pan, concrete tread stairs.

Hole in in a wall at Mountaineer because the door stop does not have adequate blocking behind it.

Mechanical room in Mountaineer with the solar thermal water heating balance of system shown.

Brick work and sheet metal detailing at Mountaineer is top-notch.

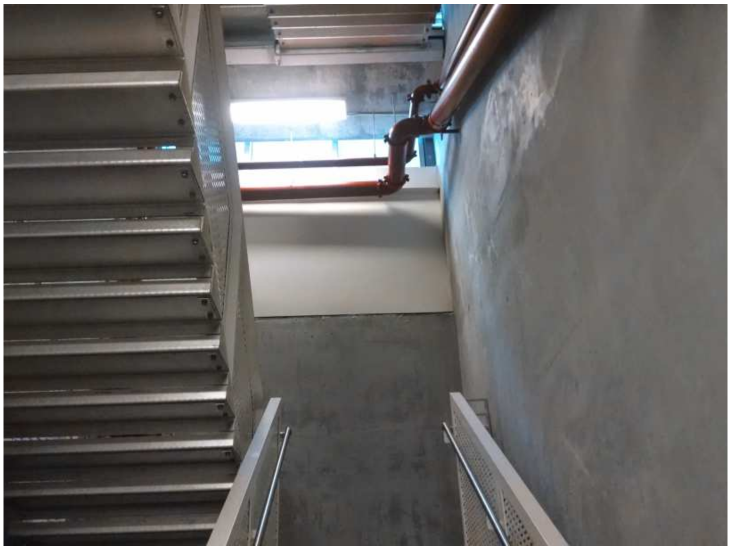
Main entrance at Summit with similar environmental controls.

Summit has an industrial-chic design approach that is often compromised by additional finishes requested by the owner. Notice the exposed concrete and systems.

High quality finishes in the honors lounge including real stone and wood work.

Laundry facility in Summit that is similar to that of Mountaineer.


Neat data cabling in Summit showcasing the high-quality workmanship of the MEP systems


Stairwell in Summit with stainless steel, expanded metal, and diamond plate metal.

Another view of the Summit stairwell.

Air Handling Unit located in a Summit basement mechanical room.

Mechanical room of Summit.

Interior electrical components of Summit generator.

Typical lobby area of each floor of Summit.

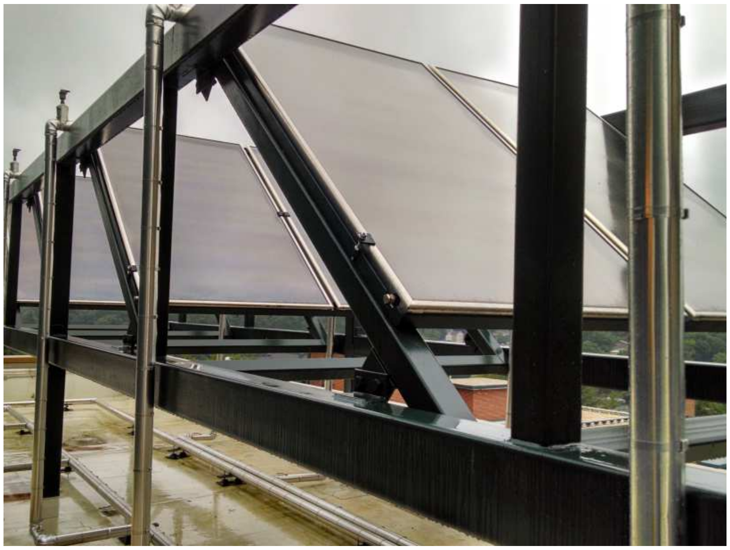
Textured ceiling inside of a Summit dorm room. Notice the patterns left by the formwork that the paint attempts to cover.

Return grill in each room connects to ventilation system.

Typical Summit bathroom shared between two dorms.

Solar thermal balance of system components disconnected and partially disconnected.

Air handling unit in the penthouse of Summit. Notice the copper condensate drain retroactively added.



Solar thermal collectors and racking on the roof of Summit.

Fritted glass on the south walls of Summit that is intended to regulate solar heat gain.

Similar to Mountaineer, there are elements in Summit that are not the highest quality such as the concrete finish on this column.

Exposed mechanical systems in Summit. Notice the two round penetrations filled with fire sealant. These were obviously misplaced, illustrating the difficulty of making changes in concrete buildings.

Vita

Scott Hopkins is the son of Mark and Debra Hopkins, and is a native of western North Carolina. He graduated from West Lincoln High School in 2004, and upon graduation, entered Basic Combat Training for the U.S. Army Reserve in Fort Jackson, South Carolina. Scott spent eight years in the U.S. Army Reserve, serving as a parachute rigger and jumpmaster, was deployed in support of Operation Enduring Freedom, and was honorably discharged at the rank of sergeant in 2011. He began studying at Appalachian State University (ASU) in January 2005, and graduated Magna Cum Laude with a B.S. in Building Sciences in 2009. In August 2012, Scott began graduate study at ASU, pursuing a M.S. in Technology. While a graduate student he was the construction manager for Team Réciprocité, Appalachian State University's entry into the Solar Decathlon Europe 2014 competition in Versailles, France. He earned his master's degree in December 2014, and works as a Project Engineer for the Carolinas Division of Balfour Beatty Construction.