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INDIGENOUS ARCHITECTURE FOR EXPEDITIONARY INSTALLATIONS

THESIS

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AFIT/GEM/ENV/06M-06

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GEM/ENV/06M-06

INDIGENOUS ARCHITECTURE FOR EXPEDITIONARY INSTALLATIONS

THESIS

Presented to the Faculty

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science (Engineering Management)

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INDIGENOUS ARCHITECTURE FOR EXPEDITIONARY INSTALLATIONS

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Abstract

United States (U.S.) outpost building after World War II tended to neglect local design in favor of imported American style and at the expense of efficiency and local acceptance (Gillem, 2005: 70). The numerous expeditionary installations established throughout the Middle East in the Global War on Terrorism (GWOT) offer a clean slate for transition to a policy that favors sustainable design as well as host nation acceptance through the use of indigenous architecture. By investigating desert indigenous architecture, low-tech design elements could be rediscovered and combined with modern technology to build new, environmentally-responsible buildings that are identifiable by the local culture. The potential of indigenous architecture was investigated by comparing its energy performance, force protection and fire safety characteristics, and ease of procurement to the same criteria for a standard prefabricated metal building. The core of the research was a literature review of current Department of Defense (DoD) construction standards and an examination of past and present examples of desert architecture including the Middle East and the southwestern U.S. Architectural drawings for a typical administration facility were created to show how traditional building materials and methods could be employed to match or exceed current standards. Results indicated that indigenous design offers advantages in energy performance and force protection, but initial cost and procurement time are not favorable. Therefore, selection of the optimum building construction technique depends on decision-maker values.

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INDIGENOUS ARCHITECTURE FOR EXPEDITIONARY INSTALLATIONS

I. INTRODUCTION

1.1 Background

At the end of World War II, the United States (U.S.) emerged as a world power and as countries in Europe and the Pacific Rim recovered from the devastation of war, the United States established outposts to monitor the reconstruction, ensure public order, and deter the spread of Communism (Gillem, 2005: 6). In the 50 years encompassing the Cold War, these U.S. outposts matured into established installations. However, these outpost transformations were made using American construction practices as the model rather than local techniques (Gillem, 2005: 10). The result was an obtrusive presence on valued real estate. Since the declared end of the Cold War, tensions have mounted between host countries and the U.S. as our presence is seen more as an intrusion rather than a benefit. Our image in these once amicable countries is further strained by inefficient use of local resources brought about by imported American attitudes regarding land use and facility construction (Gillem, 2005: 49).

The new battle for the U.S. and its allies is the global war on terrorism (GWOT), and the Middle East is one region where military garrisons are being established to support this effort. Lessons learned from Cold War outposts can improve the effectiveness and reception of our GWOT outposts. With the prospect for a protracted fight, these bases are certain to be a critical factor in our ability to maintain pressure on the insurgents who are tied to that part of the world. However, the political relations with our Middle East host nations have generated agreements restricting the U.S. to a temporary presence (Gillem, 2005: 57) at all but a few specially designated locations called Main Operating Bases (MOBs). With the exception of MOBs, the footprints of our expeditionary bases are confined to relatively small areas compared to what we are accustomed to and our facilities must be constructed with materials that convey a temporary appearance. In addition, the threats posed to the safety of personnel and assets at these locations are different than past threats. Therefore, we must learn to be more effective with the available resources.

Since Operation DESERT STORM in 1991, several documents have been drafted by the Air Force (AF) and its sister services that govern expeditionary construction. These documents cover responsibilities of the different U.S. governmental entities, Antiterrorism/Force Protection (AT/FP) considerations, and appropriate construction materials and methods (USCENTCOM Reg. 415-1, 2004). Some of the more prominent ones include: AFP 10-219, Vol. 7: *Facility Hardening*; DoD Directive 2000.12: *DoD Antiterrorism Standards*; DoD Instruction 5210.84: *Security of DoD Personnel at U.S. Missions Abroad*; and USCENTCOM Reg. 415.1: *Construction and Base Camp Development in the USCENTCOM Area of Responsibility* ("*The Sand Book*"). Initial beddown of forces employs pre-positioned assets known as War Readiness Material (WRM) and include tents, expandable shelters, and tensioned fabric structures like those shown in Figure 1.1. Historically, these facilities experience unacceptable wear after several months in the harsh desert climate (USCENTCOM Reg. 415-1, 2004). In addition, commanders begin to look for more comfortable and effective working environments once the main components of the living and working areas are established.

The preferred means of construction for facilities intended for higher use and durability are prefabricated metal structures like the one shown in Figure 1.2 because they are still politically accepted as a temporary structure, they are relatively quick to procure, and they provide an improved environment over the WRM assets used for the initial beddown (USCENTCOM Reg. 415-1, 2004: 92).

Figure 1.1. Prepositioned Assets. TEMPER Tents are commonly used for initial beddown of forces (Global Security, 2005a).

Figure 1.2. Prefabricated Building. Metal buildings improve the living and working conditions for troops (Global Security, 2005b).

1.2 Problem Identification

The easy answer to a problem is seldom the best answer. In the case of finding an appropriate construction method for semi-permanent or permanent facilities at our Middle East outposts (where permitted by host nation agreement), the accepted policy of procuring prefabricated metal structures illustrates this point. When considering all the factors, the positive aspects of using metal structures are outnumbered by the negative. On the positive side, prefabricated metal buildings are quick and easy to procure and can be easily removed, leaving little or no trace. However, some of their more significant detractors include poor energy efficiency, lack of inherent force protection characteristics, and a significant logistics requirement to maintain them.

Prefabricated Metal Building Benefits:

Easy to Procure: Several prefabricated metal building contactors have become well-established in the Middle East through their support of petroleum prospecting and drilling operations. They have adapted their construction and delivery techniques to respond to varying conditions, allowing the customer to choose from numerous building sizes and prescribe layouts and amenities that are tailored to their function. In the past, the AF has established Indefinite Delivery, Indefinite Quantity (IDIQ) contracts for prefabricated metal building procurement at its more established installations such as Prince Sultan Air Base in Saudi Arabia. These IDIQ contracts allowed engineers to choose from pre-established contract line items to custom-order buildings depending on the need. This process is quick and easy, often producing a final product within a month from initial design to installation.

Easy to Remove: The foundation system for these prefabricated metal buildings could be as simple as concrete masonry unit piers placed on compacted, level ground. The building sections are hauled to the site on flatbed trailers and hoisted onto the piers by crane and then spliced together. Due to this construction method, the trailers are also easy to remove from the site. Once removed, the site can be re-graded to eliminate any trace; thereby returning the site to its original condition.

Prefabricated Metal Building Detractors:

Inappropriate for the Environment: Metal buildings function essentially as ovens in the relentless desert sun and refrigerators in the cold desert nights. This is because steel readily conducts heat. In an environment with significant temperature variations, this becomes a liability that is compensated through heavy energy consumption. To control the climate in these facilities, air handlers are a critical piece of equipment. These air handlers require a large amount of electricity that is usually produced by mobile generators which, in turn, run on diesel fuel that must be procured at great expense. In short, metal structures perform poorly in this environment in regard to energy efficiency.

Lack of Inherent Force Protection Characteristics: Since these outposts are located in a war zone, they are required to have specified levels of force protection such as splinter protection and blast mitigation (USCENTCOM Reg. 415-1, 2004: 23). Metal buildings perform poorly in both regards and, therefore, require construction of supplemental structures around them to perform these functions (USAF AFP 10-219, Vol. 7, 2004: 18). While several options are available to provide protection such as earth berms, overhead fragmentation protection, and sand bag walls, all are labor and time intensive and often require careful maintenance to ensure their integrity (USAF AFP 10-219, Vol. 7, 2004: 37). Figure 1.4 illustrates one of the more popular facility hardening techniques where large concrete barriers form a ring around the structure requiring additional protection.

Figure 1.3. Barriers. Concrete barriers are a common blast mitigation measure (Global Security, 2005c).

Long Logistics Tail: Transportation of foreign materials, heavy use of diesel fuel-generated electricity, and regular maintenance all build up to a long logistics tail required to support a cantonment area composed of pre-fabricated metal buildings. Logistic support is often considered the limiting factor in the ability to bring the fight to the enemy (ACSC Staff, 2004: 1). When excessive logistics are used to support facilities within the base boundary, it takes away from the needs of airmen and soldiers in direct contact with the enemy, calling attention to another indirect detractor of metal buildings—support logistics.

An Alternative Approach:

The Sustainable Design Solution: American domestic attitudes towards energy management are beginning to sway again towards conservation and better ways to harness renewable energy sources as foreign policy calls attention to dwindling fossil fuel resources. In recent history, improvements to quality of life were achieved through technological advances that allowed us to artificially manipulate our environment resulting in inefficiency and unnecessary complexity (Bull, 2000: 331). Two common examples which tend to be taken for granted in modern U.S. society are the invention of air temperature regulating devices (i.e. furnaces and air conditioners), and the invention of the light bulb. With the ability to control inside air temperature and light levels regardless of the conditions outside, the need to help control these factors with the building envelope became obsolete. In an effort to reduce the strain on rapidly dwindling fossil fuels as well as reduce the financial burdens of energy consumption, sustainable building concepts are becoming more commonplace in the construction industry and are recognized as fundamental principles underlying successful building design (Masters, 2005: 181).

In the original practice of sustainable design, indigenous architecture responded to the local climate rather than imposed exotic forces (Bull, 2000: 331) such as air conditioning and artificial light. Within the knowledge of tribal elders and investigation of lost cultures exists a wealth of information that could prove invaluable to current sustainable design efforts (Bull, 2000: 331). Knowledge of cultures indigenous to harsh climates is particularly valuable because they had to be inventive in order to survive in such extremes with only local materials (ANSC, 2005).

As a subset of American society, the AF mirrors the civilian community. With a presence in almost every type of environment around the world, the military has a vested interest in learning to successfully cope with each extreme climate using the fewest resources, i.e., employing indigenous knowledge of building technology at austere locations. Employment of low level technology (low-tech) sustainable design concepts makes sense in military applications, particularly in light of the austere conditions typically found at deployed locations and the need to do more with less.

1.3 Research Objectives

The purpose of this research was to investigate indigenous architecture of desert cultures in the American Southwest and the Middle East for underlying principles of effective design in extreme climates. These indigenous techniques were translated into a modern architectural language for use in facility improvements at contingency locations. In order to demonstrate current applications of these techniques, a design was produced for a typical military administration facility. In the course of this process, the answers to three basic research questions were sought.

(1) What are the primary indigenous design concepts used to mitigate effects of harsh climates?

(2) What benefits can be gained from the use of indigenous architecture for replacement of WRM assets in the AF Central Command (CENTAF) area of responsibility (AoR)?

(3) How can traditional building techniques be translated to meet modern requirements?

1.4 Approach/Methodology

In order to answer the questions and achieve the objectives of this study, an extensive literature review on the subjects of current Department of Defense (DoD) construction and force protection policies as well as traditional desert architecture was required. To demonstrate the benefits of indigenous architecture, a comparative analysis using case studies was then made between prefabricated metal buildings and examples of indigenous architecture with regard to energy performance, force protection characteristics, and ease of procurement. In order to synthesize the findings of this research, the indigenous principles were illustrated through facility design to produce architectural drawings for a typical administration building in the Middle East.

1.5 Scope

Due to current political restrictions regarding construction in the Middle East, the design solutions presented through this research are not generally accepted by the DoD (USCENTCOM Reg. 415-1, 2004: 21). However, in the event that continued U.S. presence is permitted in the region, it is in the best interest of the U.S. and host nation governments that indigenous construction techniques be considered.

Furthermore, the interpretations and designs produced through this research were intended to be descriptive of any number of possible solutions rather than prescriptive. Therefore, as with any design-related document, the findings should serve as inspiration for informed design of numerous possibilities rather than a rigid template. Also, the comparison between the two building techniques that were the subject of this study was subjective. Although assessments were based on experience and rudimentary quantitative analysis, they were not presented as absolute truths.

1.6 Significance

The expeditionary military community may benefit from sustainable designs that employ time-tested indigenous knowledge. Facility performance can be increased through integration of construction techniques that respond to the local conditions and are inherently effective against conventional weapons and structural fire.

These characteristics have an even greater significance in deployed locations where supply chains are often limited to mission essential materials. Coping under austere conditions with limited material flow requires creative thinking in order to make living conditions acceptable. Furthermore, an understanding of the importance of indigenous knowledge could be useful in nation-building efforts. The design included in this research effort was intended to be a tool to aid in improving quality of life at expeditionary locations without cost-prohibitive initial or operational costs.

1.7 Summary

The recent flourish of expeditionary construction by the U.S. and its allies in the Middle East offers a clean slate to veer from practices that are neither in the best interest of the U.S. nor the host countries. By building with locally available materials and using indigenous methods that were developed over centuries in response to the environment, much can be gained in terms of revenue required for facility construction, maintenance, and operation as well as in terms of improved relations with the host country.

II. LITERATURE REVIEW

2.1 Historical Overview

As imperial powers extended their influence across the globe, they established military outposts to protect their regional interests (Gillem, 2005: 6). These outposts altered their surroundings culturally as well as ecologically (Gillem, 2005: 6). This was especially the case in territories that were conquered. Occupying forces imposed a policy of assimilation upon the indigenous people, forcing them to adapt to the new model when their traditional views were incompatible (Gillem, 2005: 49). Even when imperial powers were not exercising absolute power over occupied territories, they would still influence indigenous traditions by integrating local and imported cultural practices (Gillem, 2005: 10).

The Cold War outposts established by the United States (U.S.) around the Pacific Rim and in Europe are good examples of how American standards for community planning and architecture conflict with local style (Gillem, 2005: 54). These differences are easily visible in building densities as well as architectural style. In the view shown in Figure 2.1, the high-density of Songton City outside the gates of Osan Air Base in the Republic of Korea is evident with closely packed high-rise buildings. In contrast, most buildings on Osan Air Base have a low profile and are separated by grassy areas. Figure 2.2 further illustrates this difference in the contrasting architectural styles. This alien presence was made possible through the importation of American values while ignoring local traditional architecture (Gillem, 2005: 70). The desire to live in a familiar landscape resulted in a homogenous appearance among all the Cold War outposts with only minor regional differences (Gillem, 2005: 114). Military regulations dictated architectural strategies that did not address context and emphasized standardization to the American aesthetic (Gillem, 2005, 178). The influence of the built form of American outposts reached beyond the base perimeter as the locals changed their way of living to accommodate the Americans (Gillem, 2005: 174). Now that the Cold War is over, resentment of obtrusive American presence is growing and placing strain on relations between the U.S. and its host countries (Gillem, 2005: 121). Today, most of the countries where the U.S. has recently established military outposts maintain their sovereignty and grant the U.S. permission to be on their soil through host nation agreements that prescribe limits to foreign occupation (Gillem, 2005: 57). This creates a different circumstance for the establishment of foreign bases and highlights the need to work in harmony with local traditions.

Figure 2.1. Building Density. High-density of Sonton City (bottom, right) in contrast to low-density Osan AB (top, left) (GoogleEarth, 2005).

Figure 2.2. Architectural Style. Imported American architecture in contrast to Korean Architecture (Osan Air Base, 2005) & (Asian Historical Architecture, 2005).

2.2 Current Policies and Practices

U.S. military presence in Middle East countries was granted (in most cases) through host nation agreements that established conditions for the duration and nature of the installations. In addition to the parameters dictated by host-nation agreements, facility construction for expeditionary installations was guided through various Department of Defense (DoD) directives, instructions, and pamphlets. These documents cover a wide range of topics from individual entity responsibilities, to construction standards, to force protection.

The installation commanders are the focal point for implementation of these requirements. The commanders must ensure timely and accurate anti-terrorism threat assessments and make certain that appropriate protection measures are implemented throughout the deployment (DoDI 2000.16, 2001: 12,33). Since Air Force (AF) operations require a hi-tech support system housed in stationary facilities, the built environment is a major factor in the safety of AF personnel (AFP 10-219, Vol. 7, 2004: 1). To help commanders, general construction standards for contingency and permanent base camps were established in “Construction and Base Camp Development in the United

States Central Command (USCENTCOM) Area of Responsibility (AoR)." More commonly known as "The Sand Book," this document provided general guidance regarding base development, survivability, and acceptable working and living conditions. For example, it prescribed contingency construction standards for surge populations and permanent construction standards for steady state populations; mandated minimal infrastructure demands; and required compliance to USCENTCOM force protection construction standards (USCENTCOM Reg. 415-1, 2004: 24, 27, 31). It also gave commanders the latitude to impose tougher standards based on local conditions (USCENTCOM Reg. 415-1, 2004: 1).

The driving factor behind expeditionary installation planning and facility construction in the Middle East is protection of personnel. One concern of force protection is safety from blast effects. When sufficient real estate is available, stand-off distance is the most effective means of reducing blast effects; however, this luxury is seldom present (AFP 10-219, Vol. 7, 2004: 1). Facility hardening is the second-best facility protection measure. This must be accomplished in response to the assessed threat, the nature of the facility, and the materials on hand (AFP 10-219, Vol. 7, 2004: 6). There are two main types of conventional weapons to consider: direct-fire and indirect fire. Direct-fire weapons like tanks and heavy caliber machine guns are highly accurate and are intended to penetrate exterior protection of the target; indirect-fire weapons like mortars and artillery are less accurate and rely on blast and fragmentation to damage their target (AFP 10-219, Vol. 7, 2004: 7,8). If the main threat is expected from indirect-fire weapons, standard construction materials and practices may provide acceptable protection. In general, however, more massive materials offer better protection than thin, lightweight materials as illustrated in Table 2.1 (AFP 10-219, Vol. 7, 2004: 8). For example, a concrete wall can provide acceptable protection from a 7.62-MM projectile fired from 100 yards away if it is at least 6-inches thick. Furthermore, force protection measures tend to be more effective when incorporated into original construction as opposed to a separate system and, therefore, must be considered in any new construction or renovation (DoDI 2000.16, 2001: 33).

Table 2.1. Protection from Projectiles and Explosions (AFP 10-219, Vol. 7, 2004).

Protection from Projectiles				Protection from Explosions (50ft away)			
	Projectile				Projectile		
Material (Depth in inches)	7.62-MM @ 100 yds	37-MM @ 400 yds	75-MM @ >500 yds	Material (Depth in inches)	120-MM Mortar	122-MM Rocket	250 lbs Bomb
SOLID WALLS				SOLID WALLS			
Concrete, reinforced	6	36	48	Concrete, reinforced	4	4	9
Stone/Masonry	12	42	60	Brick Masonry	6	6	10
Lumber	24	NR*	NR	Lumber	12	12	18
LOOSE MATERIAL				LOOSE MATERIAL			
Clay, dry	36	NR	NR	Soil	12	12	30
Sand, dry	12	60	NR	Sand, dry	NR	NR	NR
FILLED BAGS				FILLED BAGS			
Sand, dry	20	60	NR	Sand, dry	8	16	30

* NR = Not Rated

There are many combinations of force protection materials and methods prescribed for use on DoD installations. Some of the most common are revetments, earth berms, and reinforced masonry walls. Revetments are modular earth containment systems and are typically constructed separate from the facility they protect. The most common revetment material is fabric sandbags, but revetments are also made of metal panels, fabric-and-wire bins, logs, and plastic grids; examples of each are shown in Figure 2.3. The size of the protected asset, amount of available material, site drainage, and climate determine the best application. Regardless, revetments usually require continual upkeep to maintain their integrity (AFP 10-219, Vol. 7, 2004: 37, 38). In contrast, earth berms are easy to construct and offer expedient protection from indirect- as well as direct-fire munitions (AFP 10-219, Vol. 7, 2004: 50). When built up against exterior walls, earth berms offer the best protection from explosive air blast pressure and require less material (AFP 10-219, Vol. 7, 2004: 58), but special care must be taken to ensure the walls are strong enough to prevent collapse from the weight of the earth berm and to ensure adequate drainage to prevent moisture penetration into the wall. The third common facility hardening strategy is the reinforced wall. Reinforced walls, like the one shown in Figure 2.4, are integral to facility construction, but provide limited protection from explosive air blast and also tend to fracture and break off into chunks or spall under explosive forces. These concrete fragments become dangerous projectiles on the interior of the facility (AFP 10-219, Vol. 7, 2004: 66). To prevent spalling, polymer composites are sometimes applied to interior wall surfaces. These materials help absorb the blast energy while containing debris (AFP 10-219, Vol. 7, 2004: 67). Figure 2.5 illustrates the effectiveness of these coatings.

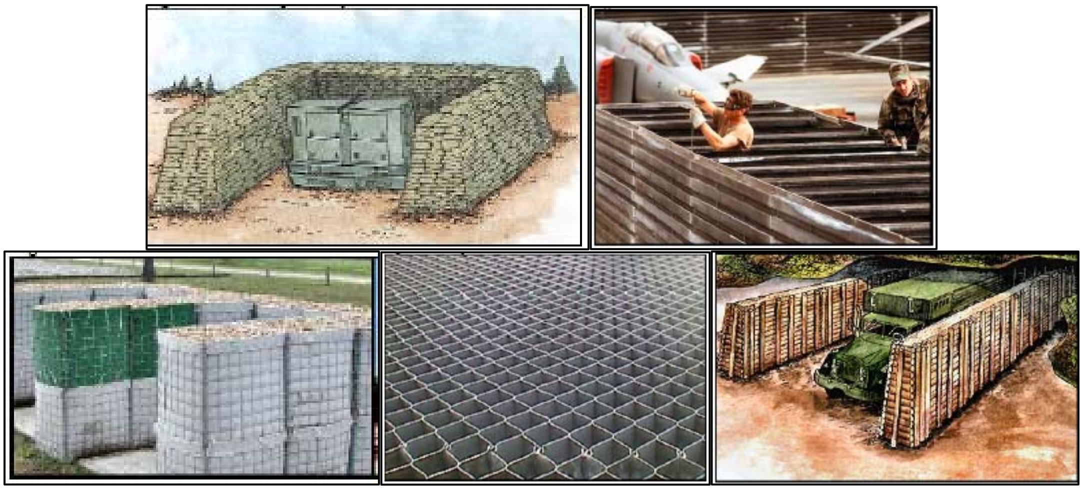


Figure 2.3. Revetment Materials. Common revetment materials include (a) sandbags, (b) metal panels, (c) fabric containers, (d) grids, and (e) logs (AFP 10-219, Vol. 7, 2004).

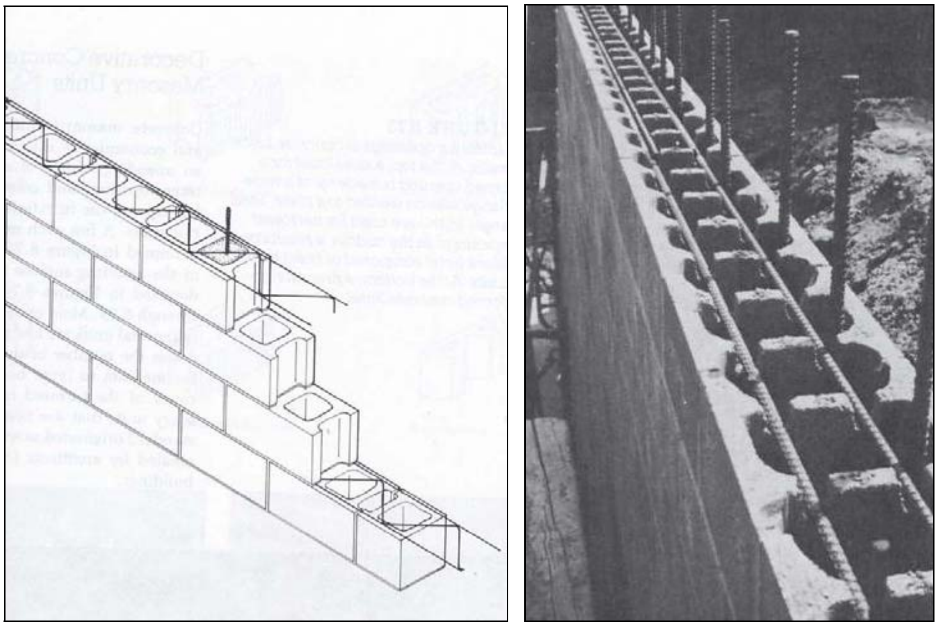


Figure 2.4. Reinforced Masonry. Reinforced concrete masonry walls are a popular permanent construction method (Allen, 1990).

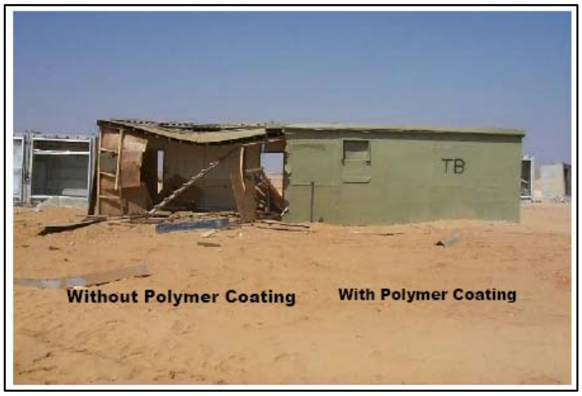


Figure 2.5. Protective Polymer Coating. The polymer coated right side survived the blast while the uncoated left side did not (AFP 10-219, Vol. 7, 2004).

Another type of wall system used to mitigate blast effects is the sacrificial panel. This system can be employed in renovation of existing facilities or in new construction and its purpose is to absorb some of the blast energy through its destruction, thereby reducing the blast energy reaching the primary building envelope (AFP 10-219, Vol. 7, 2004: 36). As illustrated in Figure 2.6, the sacrificial panel is built offset from the façade it protects and is destroyed as it absorbs the explosive impact with minimal damage to the primary wall (AFP 10-219, Vol. 7, 2004: 35).

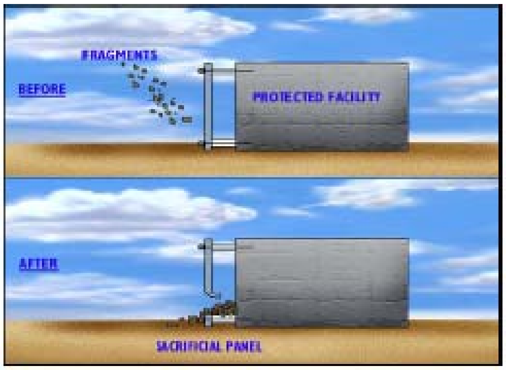


Figure 2.6. Sacrificial Panels. Sacrificial panels absorb explosive forces to protect the main facility (AFP 10-219, Vol. 7, 2004).

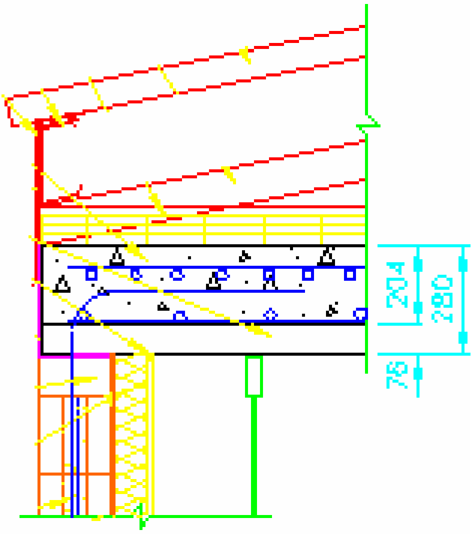
Once expedient facility hardening has been accomplished, enhancements can be made later as mission requirements dictate and if the base transforms from a contingency to permanent status. Replacement of initial facilities by more durable structures requires USCENTCOM commander approval with the age of the facility in question not being sufficient justification on its own (USCENTCOM Reg. 415-1, 2004: 21). Construction standards are also closely monitored in order to reduce the amount of infrastructure required to support them; additionally, the use of moveable structures is preferred over immobile structures (USCENTCOM Reg. 415-1, 2004: 27). In fact, permanent construction is reserved for permanent party functions and typically found only at a few key bases designated as main operating bases (MOBs) (USCENTCOM Reg. 415-1, 2004: 13, 27). Sometimes, host nation standards apply to permanent construction when prescribed by host nation agreements (USCENTCOM Reg. 415-1, 2004: 31).

Fire protection considerations are especially critical for facilities built under temporary construction standards; therefore, additional measures must be addressed through zoning restrictions (USCENTCOM Reg. 415-1, 2004: 45). These concerns as well as many others are addressed by the USCENTCOM Joint Civil-Military Engineering Board (JCMEB). This board is chaired by the CENTCOM Command Engineer (CCJ4-E) and provides oversight to all construction in the theater (USCENTCOM Reg. 415-1, 2004: 10). CCJ4-E duties also include managing construction requirements for all bases in the AoR, coordinating host nation construction standards, and continual reshaping of anti-terrorism/force protection (AT/FP) construction standards based on the evolving threats (USCENTCOM Reg. 415-1, 2004: 6, 7).

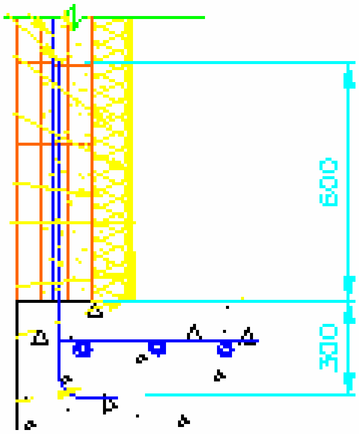
The current standard for most permanent structures in the AoR is the prefabricated metal building. Occasionally, certain facilities at main operating bases (MOBs) are constructed of reinforced masonry walls. Prefabricated metal buildings, like the one shown in Figure 2.7, are relatively quick and easy to procure because they can be readily constructed in modules in the controlled environment of the manufacturing plant and delivered to the site for rapid placement. Indefinite Delivery, Indefinite Quantity (IDIQ) contracts are an effective procurement avenue for this type of construction because they establish a standing agreement with contractors to deliver a product as needed and in a configuration that meets the needs of each situation. When masonry construction is required and approved, standard procurement methods are usually employed and construction occurs on site. Figure 2.8 shows the design for a typical masonry facility in the AoR. The details follow generic American construction standards for this type of system. The primary structure consists of load-bearing, reinforced concrete masonry walls on top of a slab-on-grade foundation. The gabled roof is formed by a prefabricated metal truss sheathed with a standing-seam metal roof. The interior wall finish is painted gypsum board and the ceiling is hung acoustical tiles.

Figure 2.7. Prefabricated Metal Buildings. Prefabricated metal buildings are a popular permanent construction method (RED SEA Housing Services, 2005).

Eave Detail



Foundation Detail



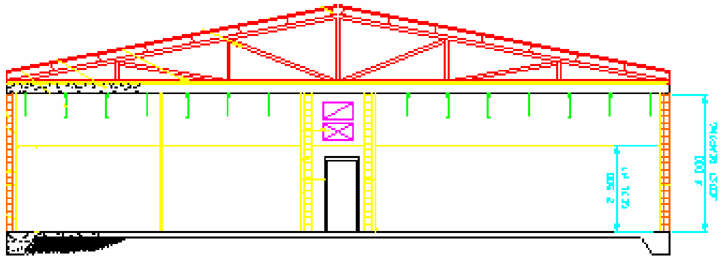


Figure 2.8. Typical Masonry Unit Construction. Details for a typical concrete masonry unit facility (Bergman, 2005)

Although the list of official documents governing military construction in the AoR is extensive and goes beyond AFP 10-219, Vol. 7: *Facility Hardening*; DoD Directive 2000.12: *DoD Antiterrorism Standards*; DoD Instruction 5210.84: *Security of DoD Personnel at U.S. Missions Abroad*; and USCENTCOM Reg. 415.1: *Construction and Base Camp Development in the USCENTCOM Area of Responsibility* ("*The Sand Book*"), they all convey these two major policies: first, installation commanders are responsible for ensuring adequate facilities exist for mission accomplishment and the safety of personnel; second, government funds must be used in moderation in order to make the most of a limited budget.

2.3 Sustainable Design Overview

Throughout the U.S., and other countries that have benefited from technological advances, there is a growing realization that the earth's known resources will not be able to keep up with increasing demands. Sustainable design has, therefore, become the focus for success in the construction industry; "green has become mainstream" (Masters, 2005: 181). At the most basic level, sustainable design strategies seek to reduce environmental waste that can be tied to economics, but a growing awareness of the human-related benefits, such as improved health and safety, highlights unexpected additional economic benefits (Childs, 2000: 41). At the far end of the sustainable design spectrum, the ultimate goal of designers is to eliminate waste altogether (McDonough, 2002: 15).

The first step in reducing, or even eliminating waste, is to abandon the tendency to impose universal solutions to a variety of conditions. The application of a "one size fits all" mentality was made possible through industrial innovations such as the use of fossil fuels and air conditioning systems to influence the natural state of things

(McDonough, 2002: 30, 31). Prior to the Industrial Revolution, nature was seen as a force to be feared. After the Industrial Revolution, control over nature was the desired state. The current trend swings away from control and more towards working in harmony with nature (McDonough, 2002: 84). Nature can be a source of knowledge and inspiration. If a tree can produce more energy than it consumes, it is conceivable that humans can design and build facilities with the same net result; in fact, our prosperity depends on this (McDonough, 2002: 81, 90).

In order to work in concert with nature, an understanding of local influences is necessary (McDonough, 2002: 122). In industrialized areas, this is more difficult because much of the local ingenuity developed through generations of coping with nature has been lost due to the forces of modernization (McDonough, 2002: 130). Aboriginal cultures contain a wealth of information because their relationship with nature can be classified as harmonious (Wines, 2000: 16). By merging indigenous knowledge with new technology, the opportunity exists for development of new, environmentally healthy strategies that also meet modern expectations (Piepkorn, 2005: 9).

The "Natural Building Movement" embodies the philosophy of combining indigenous knowledge of natural construction methods with modern materials, tools, and knowledge (Piepkorn, 2005: 9). Through advanced analysis of the structural properties of natural materials as well as modern understanding of passive heating and cooling principles and natural ventilation, this movement seeks to answer the need to build with the least environmental impact while providing comfortable and durable facilities (Piepkorn, 2005: 9). Aside from requiring fewer resources to deliver and install, the use of indigenous building materials also benefits the local economy (McDonough, 2002: 125).

The federal government is also interested in sustainable design. Through executive orders, the President of the U.S. mandated that the federal government, including the military, incorporate sustainable design principles in its facility construction programs (Clinton, 1999: 7). In support of this initiative, the AF Civil Engineer mandated the application of sustainable design concepts in all aspects of facility management (Robbins, 2001: 1). Furthermore, the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED™) rating system was prescribed as the means for self-assessment in this AF endeavor (Robbins, 2001: 1).

Proponents of sustainable design believe that it is not only the responsible thing to do, it is also vital to human well-being. The rise and fall of civilizations is closely tied to their capacity to "achieve a balance with the natural environment" (Wines, 2000: 17). As resource exploitation continues, future generations are robbed of their ability to live in expected standards (McDonough, 2002: 43).

2.4 Indigenous Architecture

Universal Concepts:

Often lessons of the past provide a good model to guide future sustainable design efforts. This is especially true for the indigenous knowledge of cultures living in extreme climates where building materials and methods had to be selected carefully in order to deal with the harsh realities of their environment (Lee, 2003: 2). Some of the factors that had to be considered include solar radiation, wind direction and velocity, seasonal ranges of air temperature and humidity, precipitation, and available resources such as building materials and water sources (Gerin-Lajoie, 1981: 136). Early builders had to deal directly with the reality of their environment and their buildings incorporated design elements that were the result of practical response to it (Bull, 2000: 331). Because the builders were responding to the unique circumstances of their environment including climate and available materials, each culture produced a vernacular architecture with an "identifiable personality" (Bull, 2000: 332). These adaptations are evident on conceptual as well as functional levels (Gerin-Lajoie, 1981: 136). Careful study of indigenous architecture can provide a wealth of information leading towards more environmentally and economically responsible buildings (Bull, 2000: 331).

Even a comparison between cultures in two polar disparate climates such as the frigid arctic and scorching desert yields three universal themes. At the most basic level of analysis, indigenous cultures in both climates understood the importance of thermal mass to help regulate interior temperatures, and the effect of building orientation in response to solar radiation and prevailing winds. They also realized that by organizing activities within the structure based on the time of day, they could follow the preferable interior climate as it moved from one section of the building to the other depending on the solar load and available ventilation.

Almost without exception, winter dwellings of arctic natives were some type of semi-subterranean house with excavated tunnel entrances (Lee, 2003: 163). Burrowing into the earth or deep snow was the most efficient way of providing for thermal mass that helped contain heat. Other means of adding mass to exterior walls were through adding sod to the exterior of stone or log structures (LeMouel, 2002: 170), or by hanging animal skins inside the structure (Lee, 2003: 13). The Arabs of the Middle East also recognized the benefits of earth mass structures for regulating interior temperatures. When dwellings weren’t built into the earth, they constructed thick walls of mud to approximate the conditions (Nabokov, 1989: 356). Figure 2.9 depicts typical earth structures of both Native American and Arab cultures.

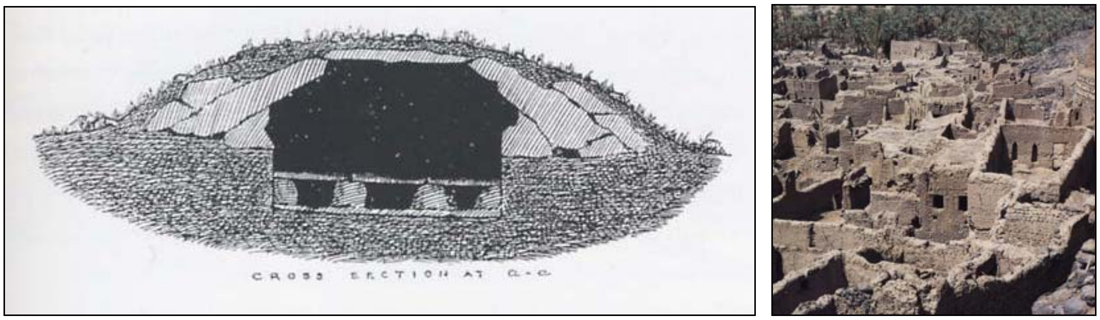


Figure 2.9. Thermal Mass. Native American and Arab cultures recognized the insulation value of earth (Lee, 2003) & (King, 1998).

While desert dwellers were concerned with catching natural breezes to help cool their structures, arctic natives were concerned with inhibiting drafts to retain as much heat as possible. To prevent drafts, arctic natives often constructed tunnel entries that were entered at a lower level and ramped upward toward the main inhabited area (Lee, 2003: 79). This created a cold sink that prevented the warm air from escaping. In addition, a windscreen was sometimes constructed in front of the entry to prevent cold, arctic breezes from penetrating the dwelling when the entry was opened (Lee, 2003: 90). Figure 2.10 illustrates both these design elements. Of course, these structures weren’t so well sealed that they would prevent any fresh air from entering, but they were fairly tight (Lee, 2003: 117). Conversely, desert dwellers developed ingenious ways to harness breezes and facilitate ventilation to help mitigate the stifling heat of their environment.

They created zones of sun and shade to induce convection air currents (King, 1998: 210). Central courtyards were part of this convection system and served as a plenum that circulated cool air to all rooms of the dwelling. In addition, wind catchers, like those shown in Figure 2.11, harnessed prevailing breezes to help circulate air (King, 1998: 50).

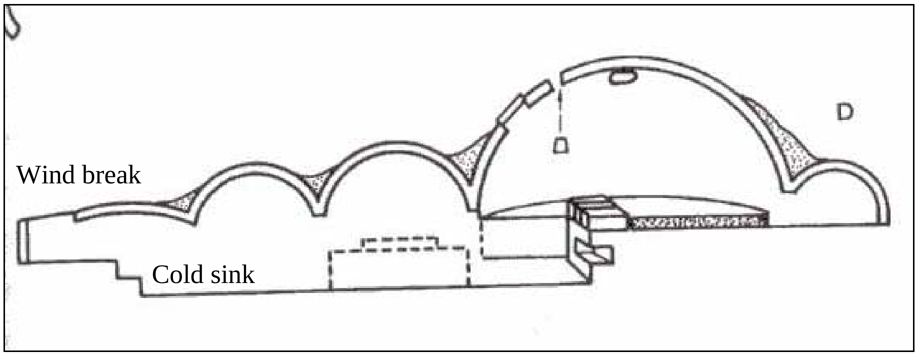


Figure 2.10. Eskimo Architecture. Eskimo architecture included cold sinks and wind breaks to control drafts and retain heat (Lee, 2003).

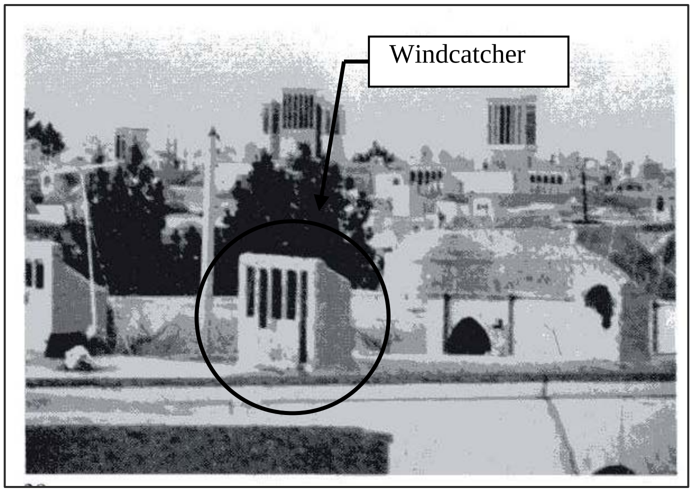


Figure 2.11. Windcatchers. Windcatchers towered above surrounding structures to capture desert breezes (Khalili, 2000).

The activities that occurred within dwellings of both arctic and desert cultures were located with respect to the various interior sub-climates. At the center of the arctic dwelling plan was the heat source and most activity was focused in this area. Sleeping platforms were located on the periphery, but were elevated in order to benefit from the rising heat (Lee, 2003: 40). The temperature gradient inside igloos was so extreme that the ceiling could be as much as 70°F warmer than at the floor (Lee, 2003: 50). Due to the changing sun angles throughout the day, the desert Arabs also experienced sub-climates within their dwellings. As the sun moved from east to west, occupants would move to shaded areas to escape the heat. In the evening, they would often move to the roof to sleep under the stars of the cool desert nights (King, 1998: 211).

While a comparison between arctic and desert cultures results in some universal sustainable design concepts, a more detailed analysis of several desert cultures provides refinements to these broad concepts. These refinements can improve overall building performance in warm, arid climates and yield unique elements that characterize local architecture and provide identity. The Native Americans of the North American desert southwest and the Arab cultures of the Middle Eastern deserts both demonstrated a keen awareness of the forces of nature they faced. Their built environment reduced the harsh aspects and accentuated the desirable aspects of external natural forces. The subtle differences between the two cultures might be explained through their relationship with the earth. For the Native Americans, nature was intrinsic to their ideology and they embraced their environment. For example, at Pueblo Bonita, the Anasazi carefully oriented observation windows so key solar and lunar events that governed agricultural and ceremonial life could be observed (Nabokov, 1989: 363). On the other hand, the

Arabs sought shelter from the unforgiving sun and blowing sand of the Middle Eastern deserts. They placed a heavy emphasis on the transition between the relentless desert sun of the exterior and the cool shade of the secluded interior (Norberg-Schulz, 1984: 116).

Native American Architecture:

It is impossible to single out a particular reason for the appearance and function of Native American architecture; without a doubt, it was a response to the environment, but certain aspects also had significant religious meaning (Nabokov, 1989: 16). Furthermore, Indians tended to view their dwellings as temporary artifices rather than something worthy of permanent craftsmanship (Nabokov, 1989: 17). With a religion intrinsically tied to understanding the earth and a building philosophy tied to their religion, even hastily constructed structures endured for ages and made it possible to live comfortably in the desert southwest of the United States where temperatures ranged from freezing to unbearably hot. Techniques for moderating temperature were sometimes so ingrained into their architecture that they had little to no effect on outward appearance (Nabokov, 1989: 24). Like arctic dwellings, buildings in the southwest were usually designed around a central hearth and insulation was provided by digging into the earth or by building thick walls of stone or adobe (Nabokov, 1989: 24). They even employed double shelled walls and arbors to help control interior temperatures (Nabokov, 1989: 27). Knowledge of construction materials and methods was passed from one generation to the next by incorporating essential details into stories about the origin of mankind and religious rituals (Nabokov, 1989: 38). Their structures blended harmoniously with the land and were comfortable places of refuge (Nabokov, 1989: 50).

The two most significant types of dwellings of the southwest Native Americans were the semi-subterranean earth mounds and apartment-like pueblos built of stone and adobe. Among the Navajo, the Hogan was the preferred dwelling type. One of the more common methods of building the single-room Hogan was to place logs in a circle and pile them up in a corbelled fashion to create a dome with a hole in the roof that permitted smoke from the central hearth to exit (Nabokov, 1989: 325). Shown in Figure 2.12 is an example of a Hogan. To provide insulation through thermal mass, the outside of the log structure was covered with a thick mound of dirt (Nabokov, 1989: 325). The Navajo readily adopted the use of adobe introduced to them through exposure to Spanish explorers entering their territory (Nabokov, 1989: 325). Further exposure to European-American cultures brought several other refinements to Hogan wall construction such as railroad ties and shaped sandstone. However, the basic form and function never changed (Nabokov, 1989: 333). The Ki, built by the Pima and Papago tribes, shown in Figure 2.13, was similar in construction to the Hogan. It was a brush and mud-covered structure that was slightly excavated into the ground, banked with earth on the sides, and capped with a domed adobe-plaster roof (Nabokov, 1989: 340). It was extremely strong and capable of withstanding strong windstorms (Nabokov, 1989: 340). Like the Navajo, the Pima and Papago tribes also adapted their construction techniques as they came in contact with explorers. Consequently, their dwellings changed radically in appearance by transforming into rectangular, flat-roofed buildings with a post and beam frame covered in adobe (Nabokov, 1989: 340). Despite this transformation, they carried their most effective building traditions through to their new structures. In one such adaptation, milled lath was nailed horizontally between the corner posts on all sides and the gaps between the laths were packed with mud to create a sandwich effect as shown in Figure 2.14 (Nabokov, 1989: 346). The house was then finished with plaster inside and out (Nabokov, 1989: 346).

Figure 2.12. Navajo Hogan. The Hogan was a popular construction technique among the Navajo (Nabokov, 1989)

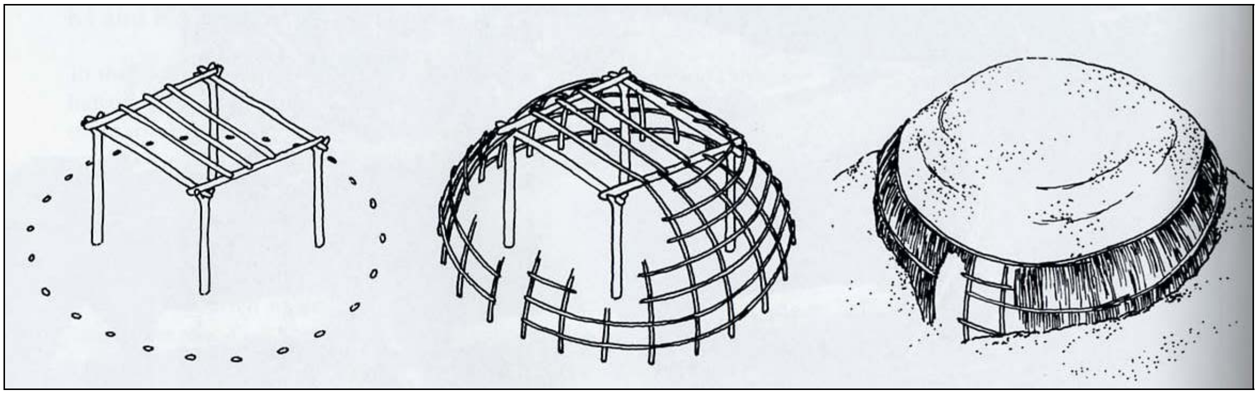


Figure 2.13. The Ki. The Ki was an extremely strong structure built of brush and mud (Nabokov, 1989).

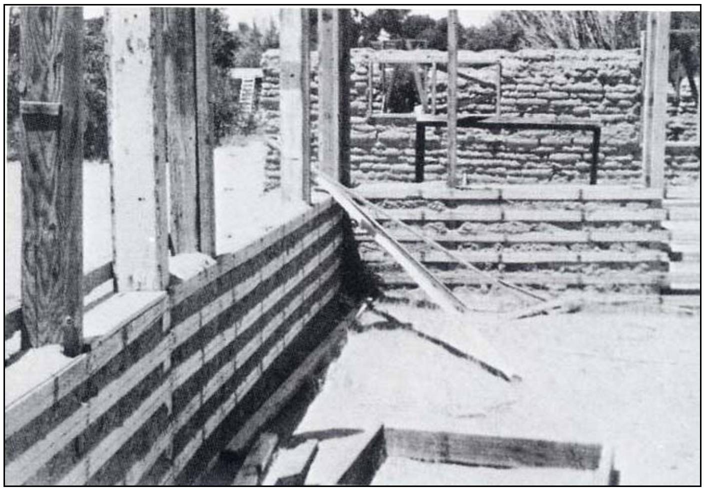


Figure 2.14. The Sandwich Wall. The sandwich wall was a hybrid of Native American and Spanish building techniques (Nabokov, 1989)

The icon of southwest Native American architecture is the pueblo. This construction technique was popular among several tribes and extensive networks of pueblos were built throughout the region. Because they were so effective, pueblo architectural traditions were resilient to foreign influence (Nabokov, 1989: 353). In fact, Spanish settlers often adopted some pueblo building characteristics in their dwellings (Nabokov, 1989: 367). As illustrated in Figure 2.15, the Anasazi nestled their dwellings beneath overhanging cliffs for protection from the elements as well as hostile enemies, and represented the most advanced network of civic construction in the region (Nabokov, 1989: 356). Early Anasazi shelters were semi-subterranean and included sunken hearths and sandstone slabs to deflect drafts from tunneled entries (Nabokov, 1989: 356). Eventually, the Anasazi started building completely above ground with shaped sandstone. Each unit was built adjacent to their neighbor to share a common wall and linear arrangements of rooms flanked a common plaza on all sides. Where possible, the rear façade of each unit was oriented towards the north while south façades were terraced to take advantage of solar exposure (Nabokov, 1989: 356). As building techniques improved with time, structures became more elaborate. At Pueblo Bonita, tapered walls of interlocking stonework reached up 35 feet and were built on top of trenched foundations filled with rubble and clay mortar for added stability (Nabokov, 1989: 362).

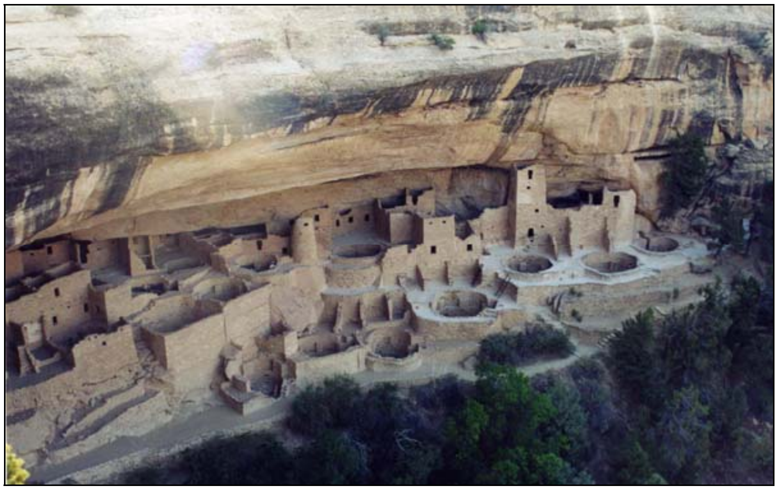


Figure 2.15. Cliff Dwellings. Anasazi cliff dwellings were sheltered from the desert sun and protected from enemies (Ballweg, 2005).

The availability of water played a crucial role in wall construction techniques. In the west, where water was scarce, walls were constructed mostly of stone, and adobe was reserved for mortar and plaster (Nabokov, 1989: 367). In the east where the Rio Grande provided a reliable source of water, the favored building material was the adobe block (Nabokov, 1989: 367). The two different building styles are illustrated below in Figure 2.16. Since adobe was vulnerable to weakening from moisture, special care had to be taken to divert precipitation away from the building façade. Low parapets were built around the edge of the roof and drain spouts penetrated the parapet to provide a specific path for water to drain (Nabokov, 1989: 370).

Figure 2.16. Pueblo Construction Materials. Pueblos were constructed of stone or adobe block depending on material availability (Ballweg, 2005).

Villages at Taos and Acoma are two successful pueblo communities. At Taos, clusters of family dwellings often reached five stories tall and maximized southern exposure during the cool winters (Nabokov, 1989: 384). The configuration of these dwellings also had security benefits with thick walls, roof access, and high-density, stacked units. The community of Acoma continues to demonstrate the resilience of pueblo construction as one of the oldest continuously occupied villages in the United States (Nabokov, 1989: 390). The walls are made of adobe brick built on fieldstone foundations and are seasonally renewed each August with a fresh coat of gypsum plaster (Nabokov, 1989: 394). The house-blocks are oriented to protect from westerly winds while exposing the terraced living areas to solar heating in the winter (Nabokov, 1989: 395). Like Acoma, dwellings at Zuni were terraced and divided by stepping wall extensions that doubled as stairs and provided shade (Nabokov, 1989: 399). The structures were also strategically orientated to shield from sandstorms, winter winds, and the hot summer sun (Nabokov, 1989: 399). Over the years, adobe has been replaced by concrete block, although traditions related to environmental response remain alive in the desert southwestern United States (Nabokov, 1989: 400).

These are only some examples of Native American architectural ingenuity. While applications of these concepts are tailored to specific regions, variations of the basic principles are found outside the southwest United States. The Arab cultures of the Middle East deserts also employed these concepts in their culturally specific way. It is not surprising that similarities between these two cultures are evident since many parallels can be made between them (Khalili, 2000: 96).

Middle East Arab Architecture:

The Arabs of the Middle East demonstrated advanced building designs prior to the discovery of petroleum and subsequent introduction of electricity and air conditioning to the region. Their principle concern was the need to mitigate the extreme heat produced by the relentless sun (King, 1998: 3). Therefore, creation of shade and capitalization of natural ventilation was critical (King, 1998: 10). Other environmental factors that needed to be addressed were precipitation that caused erosion and earthquakes that could reduce facilities to rubble. The various cultures of the Middle East responded to these factors in their own way based on their social systems and available materials. In locations where stone was available, it was preferred for its durability and resistance to moisture. However, mud was the main traditional building material due to its widespread availability (King, 1998: 10). Their architecture provided shelter from the sun with thick walls and long shadows; winds were tamed by a labyrinth of streets and wind catchers;

and they lived in tune with nature through a healthy respect of its power (Khalili, 2000: 120).

Stone construction was mostly limited to mountainous regions where the material was readily available. In areas where stone was not as abundant, it was used for foundation walls or for important structures. In the holy city of Makkah, stone was brought down from the nearby mountains (King, 1998: 96). Buildings were sturdy and most were three to four stories tall (King, 1998: 94). Sometimes, stone walls were constructed for the ground floor and the upper stories were constructed with baked brick (King, 1998: 92). In the highlands of the Arabian Peninsula, rough cut and dry-laid stone masonry was used to build towers as shown in Figure 2.17 (King, 1998: 108). Sometimes, the stone structures were built with their backs against the hillsides to help support the structure as well as provide some degree of physical security (King, 1998: 108). In the town of Fayfa', located in the Tihama Mountains of the Arabian Peninsula, stone was the only material used; presumably because water needed to build earth walls was too scarce to use for this purpose (King, 1998: 119). Here, the masons laid courses of roughly shaped stones that were stabilized with smaller ones wedged in the cracks, resulting in extremely thick and solid walls (King, 1998: 119). In the town of Jidda on the Red Sea coast, coral was cut into blocks and used as masonry. Teak wood courses were sometimes placed between courses of coral block for added stability and to help with erosion of the soft coral as shown in the bottom left corner of Figure 2.18 (King, 1998: 46). As a final layer of protection, the whole wall surface was rendered smooth with a thick layer of lime plaster (King, 1998: 46). In al-Diriya, flat limestone blocks were laid at a 45 degree angle in each course and fixed with mud mortar; after a leveling course of horizontally-laid stone was placed, another course of angled stone was often laid in the opposite direction to form a herringbone pattern (King, 1998: 159, 161). In the eastern province of Saudi Arabia, masonry units of cut sandstone or limestone were laid in beds of mortar and the exterior and interior surfaces were glazed with a waterproof plaster as shown in Figure 2.19 (King, 1998: 182, 183).

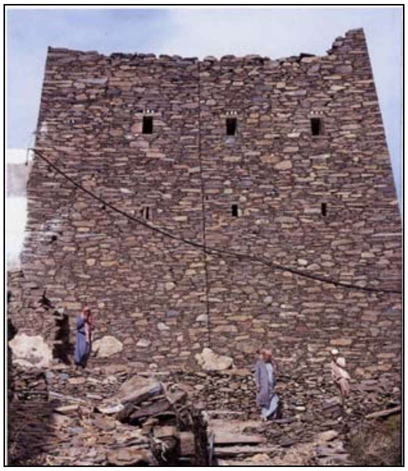


Figure 2.17. Stone Tower. Stone was the primary construction material in mountainous regions (King, 1998).

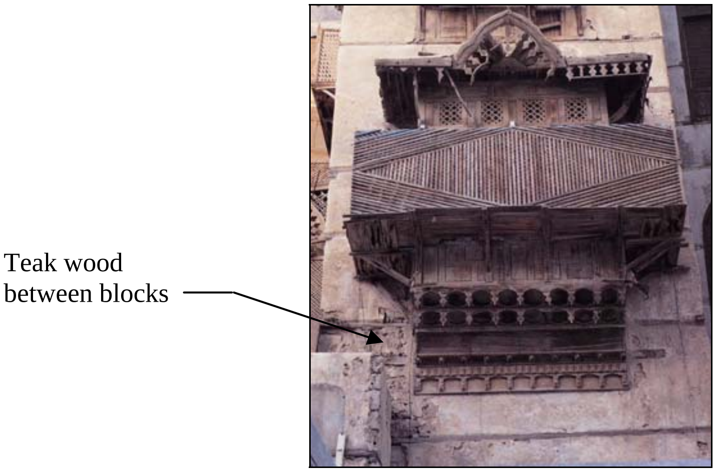


Figure 2.18. Plaster Erosion Control. Teak wood was placed between coral block and plastered over for erosion protection (King, 1998).

Figure 2.19. Protective Plaster Coating. Sandstone walls were rendered smooth with a protective plaster coating (King, 1998).

The use of mud as a building material was widespread in the Middle East due to its availability in almost every region; furthermore, its use can be traced back to the earliest recorded history of the region (King, 1998: 12). Because mud structures can be found in so many regions, each with their unique circumstances, the type of mud wall construction varied greatly (King, 1998: 12). Regardless of technique, the remarkable resilience of mud structures was demonstrated repeatedly. The town walls of al-Rass resisted continuous bombardment over a period of three months in 1817 and later, the walls of Ha’il withstood artillery in 1921 (King, 1998: 12). In addition to their proven strength, the most valuable quality of mud walls is their insulating quality (King, 1998: 12). Their thermal mass helps to moderate heat by absorbing solar radiation during the heat of the day and releasing it during the cool nights. However, mud buildings do have one nemesis--moisture. If the walls absorb water during the rainy season, they can become weak and collapse. In 1980, numerous structural failures after torrential rains prompted the Saudi Arabian government to forbid the use of mud in residential construction (King, 1998: 13). However, with regular maintenance including annual re-plastering of exterior surfaces, moisture penetration can be avoided and mud walls can maintain structural integrity (King, 1998: 12). Arabian Desert dwellers also recognized the benefit of additives, such as straw, for increased strength and durability (King, 1998: 13). Once the mixture was made, it was either placed in forms to make sun-dried bricks like those shown in Figure 2.20, or it was put to use immediately in walls constructed of continuous layers of packed mud (King, 1998: 13).

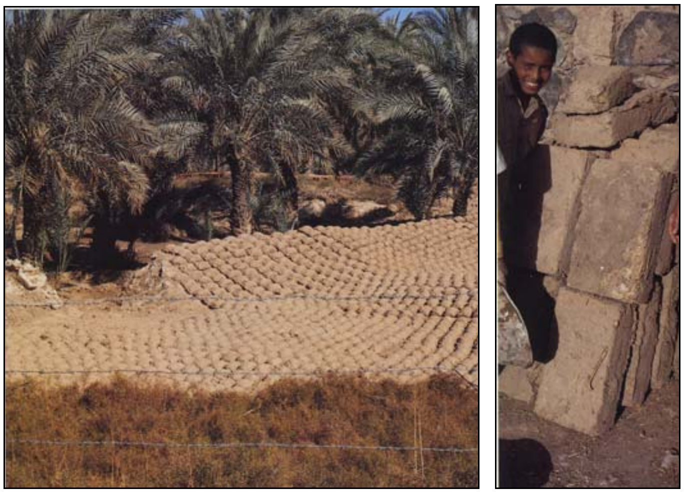


Figure 2.20. Adobe Blocks. Adobe blocks were dried in the sun before use as a building material (King, 1998).

While mud was the most widely used construction material for permanent structures in the Middle East, how it was used varied with each region and the final product had a distinctive appearance depending on its location. In the southwestern highlands of Saudi Arabia, the simple buildings of the town of Asir were mainly two- to three-stories tall with mud brick on stone foundations (King, 1998: 110). To help reduce the effects of erosion from rain, the builders inserted slanting slates that projected from the surface in horizontal bands usually 18-inches apart starting about half-way up the façade and continuing to the top as shown in Figure 2.21 (King, 1998: 110). Their purpose was to direct running water away from the face of the building (King, 1998: 111). The tops of the walls were often treated with triangular crenellations that also served the purpose of protecting from the deteriorating effects of water (King, 1998: 113).

Figure 2.21. Drip Edges. Slate projected from walls to direct water away from the façade (King, 1998).

In the area of Najran, the preference was for constructing with courses of mud rather than individual bricks. This technique, combined with a unique strategy for reducing wall erosion from rainfall produced the distinctive style shown in Figure 2.22 (King, 1998: 125). Each course was laid by compacting mud between wood formwork and was formed so that it projected slightly beyond the top of the lower course, creating a corrugated effect. For seismic stability, walls were also raked inward and courses were raised slightly where walls met in a corner to break the continuous cold joints between courses (King, 1998: 125).

Figure 2.22. Unique Regional Style. Modifications to control erosion and earthquake damage produced a unique style in Najran (King, 1998).

The need to mitigate the effects of the relentless desert sun drove development and integration of effective natural ventilation systems. The key components of the systems included shaded interior courtyards, carefully orientated and screened wall openings, and sometimes water retention devices for evaporative cooling. The courtyard acted as a central air shaft that supplied cool air to the rooms bordering it on each level. The wall openings were sized and placed to catch prevailing winds and were often screened to reduce the amount of sunlight that penetrated the sheltered interior realm. Often, cisterns were placed in the floors of the interior courtyards to capture rainfall for use as drinking water as well as evaporative cooling (King, 1998: 50). The partially demolished building in Figure 2.23 serves as a building section and illustrates some of these concepts. Sometimes, windcatcher towers, locally known as bad girr, rose above the main structure to catch fresh air and stronger breezes. Even mid-wall windcatchers were improved by the invention of baffles that excluded sunlight while permitting drafts to enter the interiors (King, 1998: 184). Figure 2.24 is a detail of how this system worked.

Figure 2.23. Building Section. The central courtyard serves as a central air plenum bordered by rooms on all levels (King, 1998).

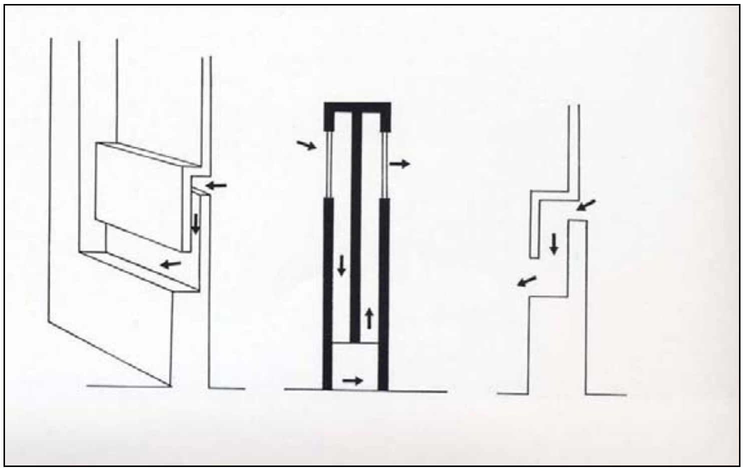


Figure 2.24. Windcatcher Detail. The improved windcatcher design permits air flow while blocking out the sun (King, 1998).

The Persians have long-understood the value of shade and its powerful effects of cooling. During the winter months, air temperatures could reach freezing levels. They capitalized on these cold months to produce ice for use in cooling during the scorching hot summers. They dug a deep trench on the north side of long walls and covered it with a low roof. The trench would fill with water that would freeze in the winter with the assistance of the shade provided by the roof and wall (Khalili, 2000: 33). The artist rendering shown in Figure 2.25 illustrates the main components of this system and how they worked.

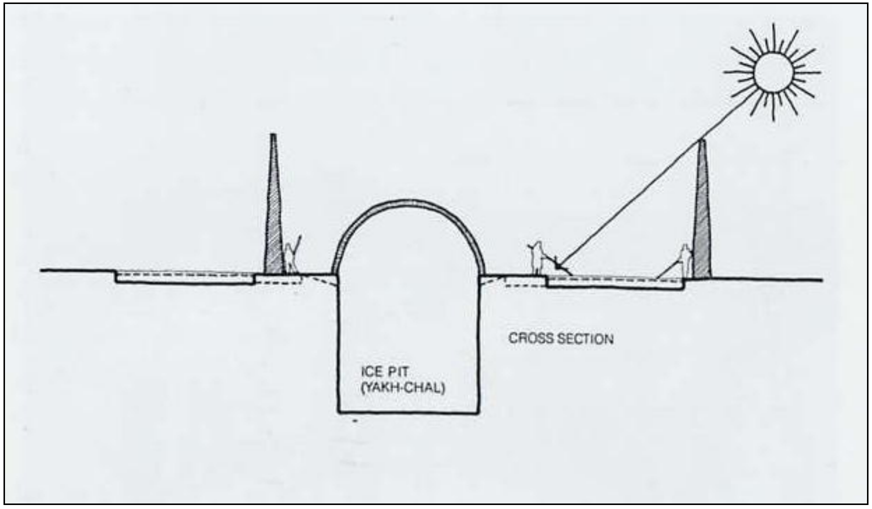


Figure 2.25. Creating Ice in the Desert. Persians constructed water collection pits in the shade to produce ice (Khalili, 2000).

Sadly, the time-tested and proven design strategies of Middle East indigenous architecture have been mostly forgotten. Earth structures with integrated natural ventilation systems have been replaced with steel framed or concrete masonry buildings, advocated by “technocrats” who mock old ways that boasted centuries-old ingenuity in favor of modern materials and methods imported from the west (Khalili, 2000: 136, 137). The result of building with these unfamiliar building materials has yielded great human tragedy in some cases. Although the materials can be incorporated into structures that are able to withstand seismic forces, poor workmanship due to hasty, uninformed construction produced death traps that crumbled in earthquakes (Khalili, 2000: 130). When a 7.7 magnitude earthquake leveled the city of Tabas, Iran in 1978, ancient domed structures built of adobe and clay were the only structures left standing amongst the rubble of steel structures with masonry curtain walls (Khalili, 2000: 131). The benefits of traditional architecture are numerous. It is simple, yet effective (Khalili, 2000: 154).

2.5 Architectural Design

Modern Earth Structures:

While building with earth is simple, it is a labor-intensive process and strict quality control must be administered to ensure stability and durability of the finished product (King, 1996: 57). In the U.S., earth is being used more frequently as a building material. Besides adobe, rammed earth is another popular earth-building technique. It is simply dense-compacted soil and has similar structural properties to concrete. Since its resurgence as a building material, numerous tests have been conducted on earth wall systems with favorable results. For example, compressive and shear tests indicate that rammed earth walls are stronger than hollow core concrete block or wood frame construction (Easton, 1996: 18). Where empirical testing hasn’t been accomplished, building inspectors have treated rammed earth like concrete and adobe like brick or concrete masonry unit construction (Elizabeth, 2005: 163). To reflect the results of recent testing and to provide guidance to designers and builders, new building codes have been written and old ones modified. In the fall of 1998, the International Conference of Building Officials devoted an entire issue of its national journal to alternative building materials, thereby solidifying their acceptance into the mainstream building community (Elizabeth, 2005: xix).

As the ultimate structural support for the facility, proper foundation design is critical. It must support and transfer all loads to the ground and serve as a moisture barrier between the wall and the ground (King, 1996: 41). It needs to be able to support the entire structure above in the event that the ground below sags under the enormous weight of the wall itself (King, 1996: 41). Several foundation systems are compatible with earth wall construction. The more common method is the standard poured-in-place, reinforced concrete wall. In developing countries, gravel and sand filled trenches are used to support earth walls and are just as effective (Elizabeth, 2005: 103). In fact, this system has been proven to isolate ground movement from the upper structure during earthquakes (Elizabeth, 2005: 103). This is important because seismic forces are significant in massive earth walls and is the main cause for earth wall collapse (King, 1996: 43). If a rigid foundation system like poured in place concrete is chosen, it must be securely connected to the upper walls through rebar and strapping (Easton, 1996: 77). Another major concern for earth wall foundation design is drainage. This is because moisture can cause significant structural degradation of earth walls if it is able to soak into them (Elizabeth, 2005: 95).

Earth walls come in many different forms including rammed earth and adobe (King, 1996: 9). As with any material, its composition will determine its strength. Earth wall systems take on the characteristics of the source material; therefore, earth walls of igneous soil, such as decomposed granite, tend to be stronger than those made from sedimentary rock (Easton, 1996: 87, 88). Furthermore, the ideal proportion of sand to clay is 70:30 (Easton, 1996: 88). Testing has shown rammed earth (compressive strength 3890 psi) to be stronger than adobe (compressive strengths between 200 and 800 psi) (King, 1996: 59 and Elizabeth, 2005: 74). Whether using rammed earth or adobe as the construction method, it is customary to add chemicals and natural additives to enhance strength and durability (King, 1996: 54). Natural additives include sand, straw and grasses while mineral additives include lime, asphalt emulsion and Portland cement (Elizabeth, 2005: 100). Portland cement is the strongest binder and its inclusion in the soil mixture makes a material called soil cement (King, 1996: 54, 57). Other soil mixture considerations that need to be carefully monitored include pH levels, the amount of moisture at the time of construction, and the amount of organic materials (King, 1996: 58).

In seismically active areas, structural reinforcement is the dominant concern (King, 1996: 63). This is because seismic loads are dynamic (King, 1996: 37). As with concrete, metal reinforcement has been proven to be an effective structural enhancement for earth walls to resist seismic loads (Elizabeth, 2005: 75). One method of adding steel reinforcement to monolithic earth walls is to build it into the formwork similar to the method used for poured in place concrete. Vertical reinforcement bars are mounted in formwork as shown in Figure 2.26 and horizontal reinforcement bars are laid at specified intervals as compacted earth fills the formwork. This is a very difficult process and involves careful planning as well as increased labor (King, 1996: 64). Recent tests have shown that synthetic fabrics or wire mesh sandwiching the earth walls and covered with plaster will also provide acceptable seismic integrity for adobe walls (Elizabeth, 2005: 75). In addition to the need for reinforcement, earth wall construction needs to comply with prescribed safety measures to ensure inherent stability. Building codes require maintaining certain height to thickness and unbraced horizontal length to thickness ratios (King, 1996: 42). In addition, size and location of wall penetrations are important to overall stability (King, 1996: 45). Some rules include: limiting the total length of wall openings to one-third the total wall length; extending lintels at least 24 inches past the sides of the openings, and limiting proportions of piers to no more than four times their width (King, 1996: 68). These proportions are illustrated below in Figure 2.27.

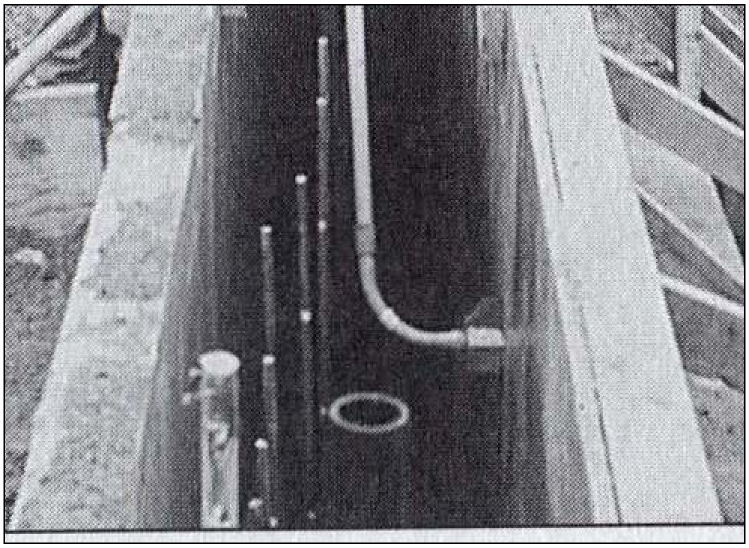


Figure 2.26. Steel Reinforcement in Formwork. Steel reinforcement bars are incorporated into monolithic earth walls for added strength (Elizabeth, 2005).

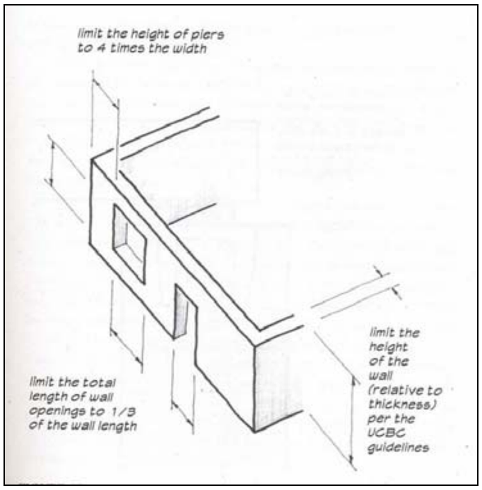
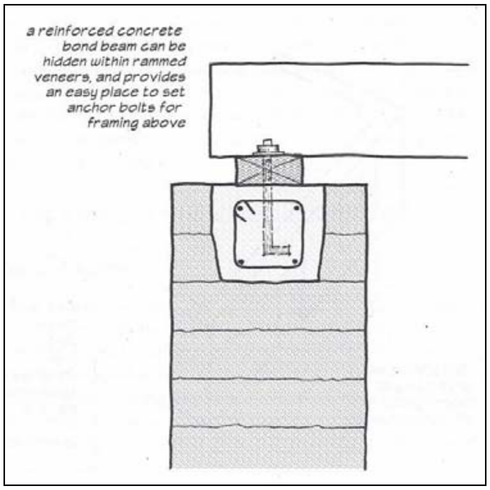


Figure 2.27. Wall Component Proportions. To ensure earth wall stability, certain wall proportions must be maintained (King, 1996).

The shape and configuration of walls and ceilings can also have an effect on structural integrity. Domes, arches, and vaults are types of structural components that were perfected by people in the Middle East centuries ago. Their inherent stability comes from the fact that they eliminate joints between the walls and the ceiling, forming a seamless whole (King, 1996: 42). Simple shapes and curved walls also offer increased stability over complex shapes and walls connecting at right angles (Elizabeth, 2005: 74).

To tie the wall structure to the roof, a bond beam is often required to cap the wall. The bond beam often takes the form of a monolithic, reinforced concrete layer at the top of the wall. A typical bond beam section is shown below in Figure 2.28. In some parts of the world such as Turkey, building inspectors require additional bond beams at the tops of windows and doors as well as at the bottom of windows (Elizabeth, 2005: 105). These bands circle the building and, in effect, act like the staves on a barrel to increase structural integrity in the event of an earthquake.



a reinforced concrete bond beam can be hidden within rammed veneers, and provides an easy place to set anchor bolts for framing above

Figure 2.28. Bond Beam Section. Building codes require a continuous bond beam in seismically active areas (King, 1996).

In addition to seismic considerations, walls also need to resist heat transmission. The benefit of massive earth walls is that they can store heat to help maintain a constant interior temperature. When the ambient temperature drops, the heat is released back into the room. This process of storing energy and releasing later is very similar to the function of a flywheel. However, in extended periods of heat or cold, the thermal flywheel effect becomes less valuable since it only serves to maintain the mean ambient temperature. Therefore, addition of insulation on the wall exterior compliments the thermal mass to create a very effective thermal regulation system (Elizabeth, 2005: 50).

The roof tops off the entire system. In seismically active areas, it works with the bond beam to transfer forces evenly throughout the structure (Easton, 1996: 185). It also serves as protection of the earth walls below that can be adversely affected if moisture is allowed to penetrate. Therefore, it must have sufficient overhang to direct any precipitation away from the walls (King, 1996: 58). Roof design can also help regulate solar exposure to influence interior temperatures as desired. As shown in Figure 2.29, deep eaves will permit winter sun to reach the surface of the walls due to the sun's low angle and block the high summer sun (Elizabeth, 2005: 52).

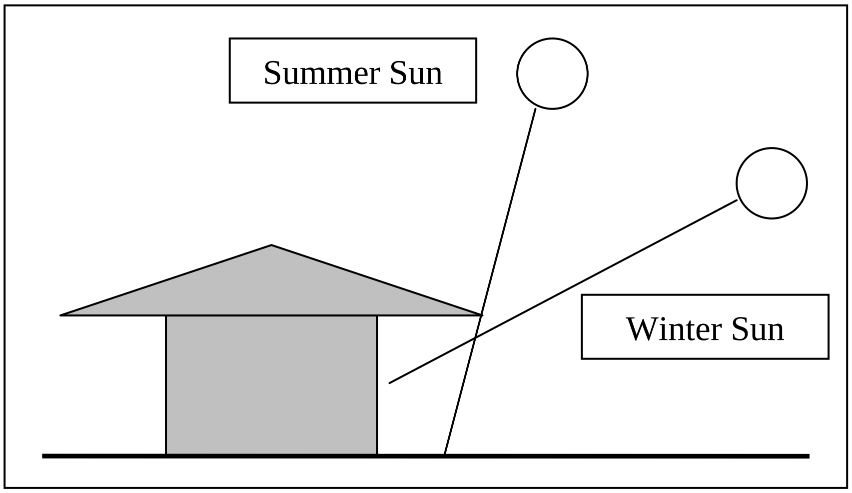


Figure 2.29. Deep Overhangs and Solar Exposure. Deep eaves can help seasonal control of sunlight on a building's façade.

Earth Structure Benefits:

Although earth is an effective thermal regulator, its performance as a construction material can be enhanced through other design principles such as those discovered by Native Americans and people of the Middle East. Shaded central courtyards create a thermal gradient that induces air flow (King, 1998: 210). The building's orientation also plays an important role in managing solar load as well as capturing prevailing breezes (Elizabeth, 2005: 55). Arbors and eaves can also help control solar heat loads and windcatchers can help collect breezes to circulate throughout the structure (Easton, 1996: 55, 31).

In the expeditionary environment, force protection is a major consideration that cannot be overlooked. Separation from the threat as well as intervening layers and material thickness all contribute to safety (AFP 10-219, Vol. 7, 2004). The very nature of earth wall construction, as well as the additional components that enhance its performance, provide opportunity for increased force protection. The thickness of the walls themselves offers a higher level of security from conventional threats over stick framed structures with curtain walls. Semi-subterranean structures can help with blast mitigation. In addition, by placing larger openings towards a shaded central courtyard to increase cooling potential also increases protection of personnel by placing vulnerable openings away from the threat. The interstice between a sacrificial panel and the facility it protects can perform double-duty as an air plenum.

For these reasons, indigenous architecture offers promise for effective response to all the various concerns addressed in the literature: environmental, cultural, and force protection. Through understanding vernacular techniques and pairing them with the most efficient applications of modern technology, it is possible to create buildings that respond to the demands imposed by these disparate issues (Easton, 1996: 46). These buildings can be as refined as we care to make them (Easton, 1996: 3). The overall design goal should be to integrate the various components that are part of building design so they work as a system supporting each other rather than isolated pieces (Elizabeth, 2005: 37).

III. METHODOLOGY

3.1 Research Objective Definition

The purpose of this research was to investigate the feasibility of employing indigenous architecture in the construction of new facilities to replace initial beddown assets in Middle East military outposts. The goals were to determine if these indigenous methods were more effective than the current standard of pre-fabricated metal buildings and to illustrate how traditional building techniques of desert cultures can be incorporated into a modern facility that meets the needs of the Air Force in an expeditionary environment. During the course of this research, answers to the following three questions were sought:

(1) What are the primary indigenous design concepts used to mitigate effects of harsh climates?

(2) What benefits can be gained from the use of indigenous architecture for replacement of WRM assets in the CENTAF AoR?

(3) How can traditional building techniques be translated to meet modern requirements?

3.2 Methodology Choice

With the goals in mind, the next step in the research process was to determine an appropriate methodology that will guide the process from the objective to conclusions (Yin, 2003: 20). In the field of social sciences, the traditional research methods include experiments, surveys, archival analysis, histories, and case studies (Yin, 2003 5). The selection of the appropriate method depends largely on three conditions including the type of question posed, the amount of control the researcher has over the events studied, and the relative time of the events studied (Yin, 2003: 5).

Another way to state the objective of this research was in the form of a "how" question. More specifically, "How can indigenous architecture be incorporated into expeditionary facility replacement projects?" This type of question is more suited to either a history or case study methodology (Yin, 2003: 5). The second criteria in choosing a research methodology is the extent of control over the events studied. Since the intent of this research was to determine how cultures traditionally responded to their environments through construction, there was no control over the events of interest. This also supported using a history or case study methodology (Yin, 2003: 5). The distinguishing factor between case studies and histories is the extent to which the research focuses on contemporary events (Yin, 2003: 5). This is where the determination got fuzzy. Although this research looked to the past as well as the present, the intent was to apply the results to contemporary situations. This indicated a case study as the proper methodology for this research. Further emphasizing the fit of case study research to this endeavor was this method's strength in looking at events within their natural context (Yin, 2003: 13).

3.3 Case Study Design

Like any credible research methodology, case studies follow a prescribed procedure (Yin, 2003: 15). Known as the design, this is the path that links the research questions to the conclusions (Yin, 2003: 20). There are five defining components of a case study design. They are the study's questions, the hypotheses, the units of analysis, the thought process linking data to conclusions, and the criteria used to make this link (Yin, 2003: 21).

As stated previously, the primary research objective was to investigate how indigenous architecture could be applied towards current expeditionary facility construction in the desert. Three sub-questions broke this main objective into focused areas of study. The first question asked, “What are the primary indigenous design concepts used to mitigate the effects of harsh desert climates?” It formed the foundation of this case study research. The product was a summary of the techniques employed by various desert dwelling cultures accompanied by a discussion of their similarities and differences. This was achieved through reading books by multiple authors that performed archival analysis on the different cultures and their traditional construction techniques and the results are contained within the literature review of Chapter 2. The information gained through this portion of the project was used to answer the remaining two questions and was summarized so other researchers could make their own interpretations.

The second question asked, “What benefits can be gained from the use of indigenous architecture for replacement of War Readiness Material (WRM) assets in the Middle East?” This question was intended to enumerate the benefits gained from indigenous architecture and compared these to the standard practice of using pre-fabricated metal buildings. This was accomplished through a comparative analysis of the two philosophies with regard to energy performance, force protection and fire safety characteristics, and procurement efforts. To compare energy performance, heat transfer calculations were performed for the wall sections of both types of construction. To compare force protection characteristics, the wall sections were described in terms of their effectiveness in withstanding forces from projectiles and high explosives as determined by tests recorded by the Department of Defense. Procurement efforts were analyzed for delivery time as well as cost. Values for the prefabricated metal building were derived from data of an actual project in Saudi Arabia while the figures for the earth structure were derived from data obtained through the literature review and the RS Means Construction Cost Manual. The product was a matrix illustrating the results.

The final research question was intended to investigate how traditional building techniques could be effectively incorporated in contemporary design to meet the needs of the Air Force in an expeditionary setting. Through architectural design, the information gained in the course of this study was synthesized to illustrate real-world application in the design of a typical administration facility answering to actual programmatic requirements.

3.4 Quality Assurance

The quality of any case study design is judged on four tests dealing with construct validity, internal validity, external validity, and reliability (Yin, 2003: 33). Construct validity exists when the tangible measurements accurately represent the concepts they are intended to represent (Schwab, 2005: 17). When working in the realm of social science, this requirement can be problematic; however, there are some tactics designed to facilitate this task. The three tactics are to use multiple sources of evidence, establish a chain of evidence, and to have key informants and peers review the research (Yin, 2003: 36). During the course of this research, all three tactics were implemented in order to establish construct validity. Numerous sources were sought for each component of the study, a database of notes was established and formatted so future researchers could easily find key information, and input was sought from interested parties and peers throughout the process.

Internal validity is present when there is a relationship between an independent variable and a dependent variable in a causal or explanatory study (Schwab, 2005: 14). Since this research does not deal with cause and effect, internal validity was not addressed for the purpose of this descriptive case study (Yin, 2003: 36).

External validity addresses the strength of generalizations outside the conditions of the study (Schwab, 2005: 19). For the purpose of this research, external validity was sought through investigation of multiple desert cultures in disparate parts of the world. The similarities noted between these different cultures provide credence to the generalizations made in this research.

The final test to measure research quality is reliability. A case study is reliable if errors and biases are minimized (Yin, 2003: 37). This, in part, is achieved when subsequent researchers can follow the steps taken during the research in question so it is helpful to explicitly list the steps taken during the course of the research (Yin, 2003: 38). The starting point of this research was to contact the CENTCOM Construction Management Office to establish a baseline for current policies regarding expeditionary military construction in the Middle East as well as gain an understanding of how the concept of indigenous architecture would be received. The second step was to collect and read primary documents related to military construction including those related to antiterrorism/force protection (AT/FP), fire safety, and facility hardening, in addition to general construction guidance. Sustainable design policy for the Air Force was then reviewed and followed by research of the natural building movement in the civilian sector. The foundation for the entire case study was conducted next through a thorough study of available texts and articles related to indigenous construction techniques of southwest Native Americans and desert cultures of the Middle East. With the bulk of the research accomplished, the indigenous construction techniques were summarized, a comparative analysis between pre-fabricated metal buildings and traditional building methods was conducted, and finally, an architectural design was drafted for a typical administration facility to tie all the research together.

3.5 Methodology Summary

The methodology of this case study could best be described as a hybrid of different techniques including a comparative analysis and architectural design with a sound foundation in a case study analysis. Since the case study involves investigation of two distinct cultures, Native Americans and Arabs, it is characterized as a multiple-case study (Yin, 2003: 39). The study of each of these primary cultures involved different tribes for both, breaking down the cases even further. Therefore, the more accurate description of this research is a multiple-case (embedded) or Type 4 design (Yin, 2003: 39). This is the strongest of the four possible types of case studies (Yin, 2003: 46). The logic being that when different cases yield similar results, it helps strengthen external validity (Yin, 2003: 53).

IV. RESULTS AND DISCUSSION

4.1 Introduction

The overall goal of this research was to determine the potential benefits of employing indigenous architectural concepts in the construction of facilities on expeditionary installations. This investigation was dependent on literature reviews that included official Department of Defense (DoD) documents as well as technical writings of recognized experts in the architectural and anthropological communities. The result was a consolidated description of key concepts regarding current DoD contingency construction policies as well as traditional construction practices of indigenous desert cultures. The culmination of this research was a schematic design intended to illustrate how modern requirements and technology can successfully integrate with time-tested traditional architecture to produce an effective facility in relation to force protection and inhabitant comfort.

Indigenous Architecture Summary:

The focus of this research involved the study of indigenous architecture and the first step in this endeavor was the investigation of traditional architecture of cultures indigenous to the extreme climates of the arctic and the desert to identify universal subsistence design concepts. Three major similarities were revealed: the use of thermal mass, building orientation with relation to the sun and prevailing winds, and the migration of building occupancy throughout the day to take advantage of solar load.

The next step was to identify refinements of indigenous design that were specific to desert climates, and therefore directly applicable to the current major theater of military contingency operations in the Middle East. The two cultures examined during this step were the Native Americans of the southwestern United States (U.S.) and the Arabs of the Middle East. Each of the key elements identified as part of their respective architectural styles were generalized into four broad categories: (1) environmental and cultural influence, (2) building material considerations, (3) control of solar radiation, and (4) natural ventilation.

Among the environmental and cultural influences, both cultures recognized water as a precious commodity. Communities were located near water sources if possible and, where water was particularly scarce, the use of adobe (one of the principle building materials of both cultures) was limited since it required the use of water to make the bricks and mortar. While both cultures understood the importance of water, they had different views on their relationship to the sun and the nature of their dwelling construction. The Arabs sought shelter from the sun (King, 1998: 10) while the Native Americans celebrated it. For example, the solid exterior walls of Arab dwellings served as a barrier between the harsh desert sun and the chambers that surrounded a cool, shaded courtyard (King, 1998: 210). In contrast, the Native Americans often placed openings to align with the position of the solstice sun or its position on other significant days (Nabokov, 1989: 363). The Arabs also built permanent structures of regular geometric shapes (King, 1998: 209), while the Native Americans viewed their dwellings as temporary and often added one structure adjacent to another in an organic growth pattern (Nabokov, 1989: 17).

Similarities between the cultures are more prevalent in the consideration of building materials. They both used adobe and rammed earth as a primary building material and often included semi-subterranean or subterranean dwellings in their building inventories due to their effectiveness in maintaining consistent interior temperatures. Since earth was the primary building material for both cultures, they also understood the importance of protection from moisture and the benefit of additives such as straw and animal dung to ensure structural integrity of their buildings. One major difference in this general category of building material considerations is the complexity of the structure. The Arabs embraced the use of arches and vaults for their inherent strength and beauty (King, 1996: 42), while the presence of similar structural components in Native American architecture is scarce.

The Native Americans and the Middle East Arabs also controlled solar radiation in similar ways. Some of the common methods included orientating their buildings to minimize exposure to the hot sun in late afternoon, incorporating architectural elements such as deep eaves to shade façades from the high midday sun, and occupying rooms in the house according to the time of day to take advantage of the migrating comfort zones due to solar load. The Arabs took solar control one step further than the Native Americans through the installation of elaborate screens on exterior wall penetrations (King, 1998: 184). These screens served to block out the harsh desert sun while permitting the entrance of cool desert breezes.

The Arabs also incorporated several advanced architectural elements that enhanced natural ventilation. They constructed windcatchers in the form of towers that rose above the surrounding structures to harness the desert breezes and filter them throughout the dwelling (Easton, 1996: 31). They also employed evaporative cooling by installing cisterns in the shaded building courtyards (Elizabeth, 2005: 47). These vats would collect precipitation during the rainy season. During the hot summer months, the water would evaporate, cooling the courtyard and its surrounding rooms. While the Arabs seemed to employ more sophisticated natural ventilation methods, both cultures used convection to ventilate their dwellings. When there was a temperature difference between warm, sunlit rooms and cool, shaded rooms, airflow would occur from the warm area to the cool area. This airflow resulted in natural ventilation (Easton, 1996: 31).

Table 4.1 is a summary of the presence of these concepts within the architecture of both cultures. Despite their location on separate continents, a remarkable number of similarities between the two were noted, giving credence to their designation within this research as key architectural elements for efficient buildings in desert environments.

Table 4.1. Indigenous Architecture Summary

Indigenous Architecture Concepts	*Middle East Arabs*	*Native Americans*
Environmental and Cultural Influence		
Water a precious commodity	√	√
Interior a sanctuary	√	
Organic growth/expansion		√
Temporary construction		√
Building Material Considerations		
Adobe and/or rammed earth	√	√
Subterranean structures	√	√
Protection from moisture	√	√
Additives to improve performance	√	√
Domes and/or vaults	√	
Control of Solar Radiation		
Screens	√	
Orientation	√	
Architectural elements	√	√
Occupied spaces according to time of day	√	√
Natural Ventilation		
Windcatchers	√	
Evaporative cooling	√	
Convection cooling	√	√

Basic Elements of the Sample Design:

The identification of common elements between the indigenous architecture of Native Americans and the Arabs of the Middle East highlighted their effectiveness. Three of these significant principles were identified for use in the sample design. They were: (1) insulated thermal mass in the form of thick earth walls, (2) natural ventilation, and (3) domes and vaults. In addition, one other element for the sample design was drawn from force protection literature from the Department of Defense. This element was the sacrificial panel (AFP 10-219, Vol. 7, 2004: 35). A detailed description of each of these elements follows.

Insulated Thermal Mass: Insulated thermal mass combines the temperature regulating benefit of thermal mass with insulation to help separate extreme outdoor temperatures from the inhabited interior of a dwelling. Thick, dense walls constructed of earth effectively regulate interior temperature by storing heat within their mass when the ambient temperature is higher than the temperature of the wall itself. This heat is released when the ambient air temperature is cooler than the wall temperature. The overall effect is to reduce interior temperature fluctuations while exterior temperature fluctuations may be drastic (Elizabeth, 2005: 50). Figure 4.1 illustrates this concept.

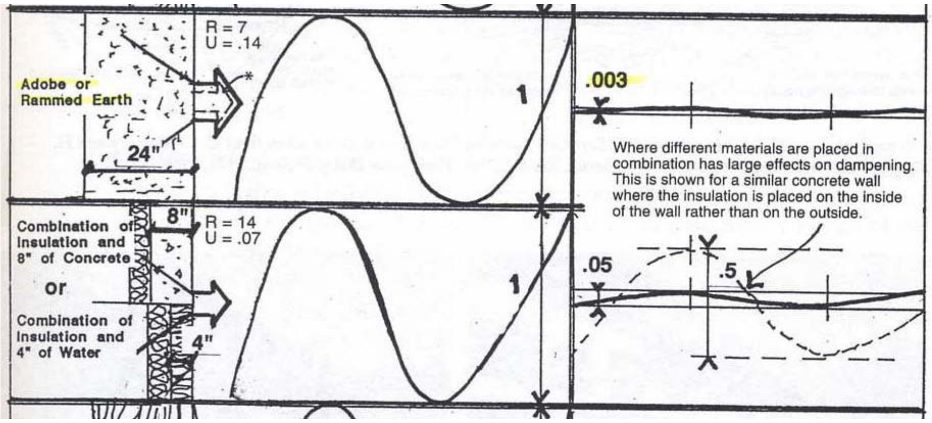


Figure 4.1. Effect of Thermal Mass on Temperature Fluctuations. Under certain conditions, earth mass can regulate interior temperature fluctuation to just 0.003 degrees Fahrenheit for every one degree change on the exterior. Addition of insulation decreases the temperature fluctuation even more (Elizabeth, 2005).

In extreme climates, the ability to maintain the interior temperature fluctuation within the human comfort zone (65 to 80°F) is threatened because over time, the wall temperature will approach the mean ambient air temperature (Easton, 1996: 36). For example, in Baghdad, Iraq, the average 24-hour temperature for the months of June, July, and August is 33.7 °C (92.7 °F) (World Climate, 2006). Under prolonged exposure to these high temperatures, the wall's core temperature will eventually reach 33.7°C. As a result, the interior temperature fluctuations will be above the human comfort zone. The addition of insulation to thermal mass will help to maintain interior temperatures within the comfort zone during extended periods of extreme heat or cold.

Natural Ventilation: There are several methods to take advantage of natural air circulation. Two that were popular in traditional architecture of the Middle East included the use of windcatchers and convection ventilation. Windcatchers harness natural breezes and channel them through the facility to help circulate air, thereby cooling interior spaces (Easton, 1996: 31). A windcatcher is illustrated in Figure 4.2. Convection ventilation results from the temperature difference between cool, shaded interior courtyards and the exposed, hot exteriors of the building. As the heat moves through the gradient, a breeze is created and the courtyard serves as a plenum for the air flow (Easton, 1996: 31). This concept is illustrated in Figure 4.3.

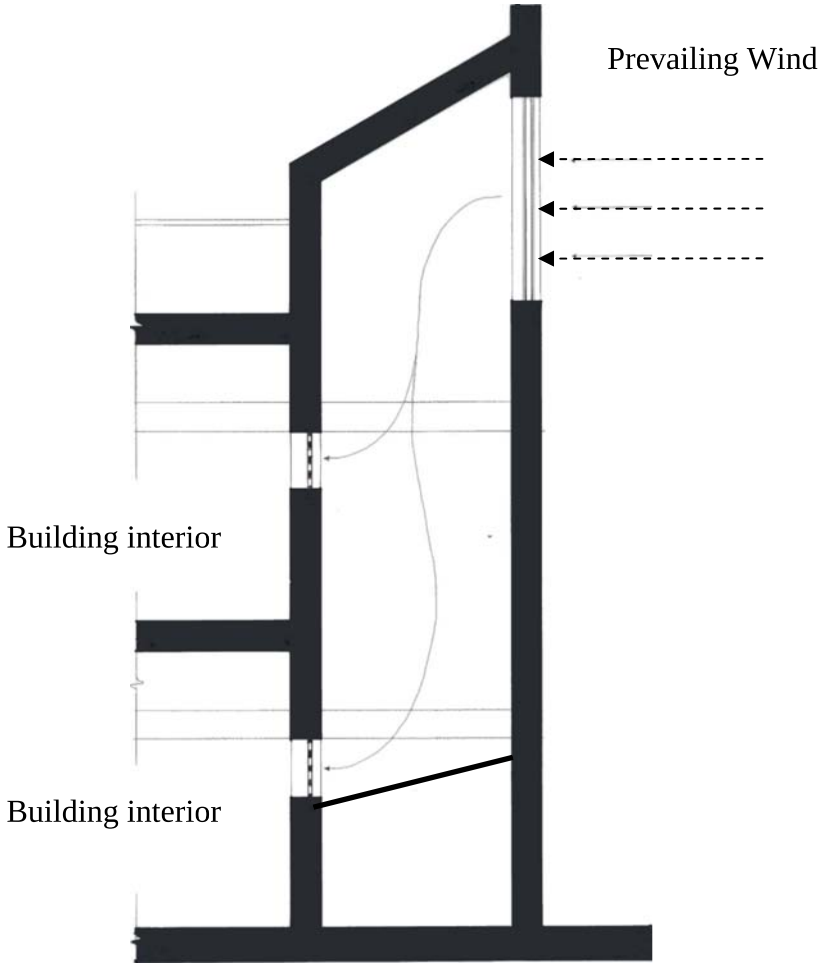


Figure 4.2. Windcatcher. The windcatcher rises above the surrounding structure and captures and deflects breezes to help circulate air within the building.

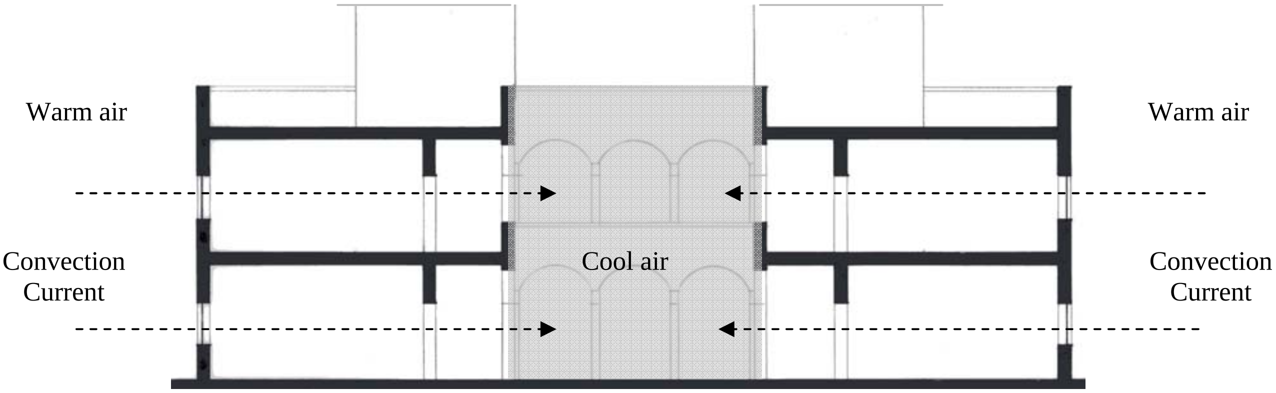


Figure 4.3. Convection Ventilation. The temperature difference between the cool air in the shaded courtyard and the hot air of the exposed exterior creates a convection current of air flow that can be used to ventilate the building.

Domes and Vaults: Domes and vaults were perfected in traditional Middle Eastern architecture and are recognized for their inherent strength and beauty (King, 1996: 42). Their resilience to external forces has been proven many times as they have often remained standing after major earthquakes, while surrounding post and beam buildings with masonry curtain walls were reduced to rubble (Khalili, 2000: 131). Their structural strength lies in their geometry. By creating a seamless transition from wall to ceiling, loads are uniformly distributed through compression (Elizabeth, 2005: 109). A typical barrel vault is illustrated in Figure 4.4.

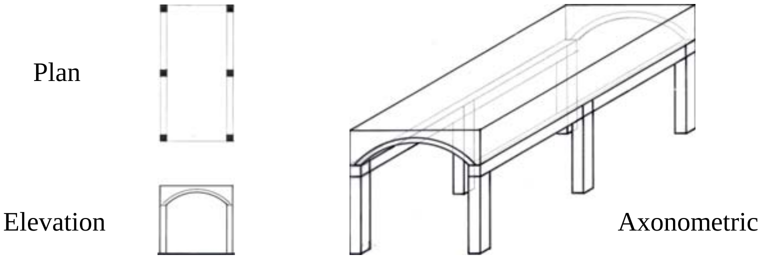


Figure 4.4. Barrel Vault Plan, Elevation, and Axonometric Drawings. The barrel vault is a simple, but very strong structural element.

Sacrificial panel: A sacrificial panel is a force protection measure designed to protect the primary structure of a facility through the construction of an exterior curtain wall. This wall is non-structural and its purpose is to absorb the force of an explosion or projectile through its destruction. By serving this function, the sacrificial panel reduces the potential for spalling or breaching of the interior wall (AFP 10-219, Vol. 7, 2004: 11). The sacrificial panel is illustrated in Figure 4.5.

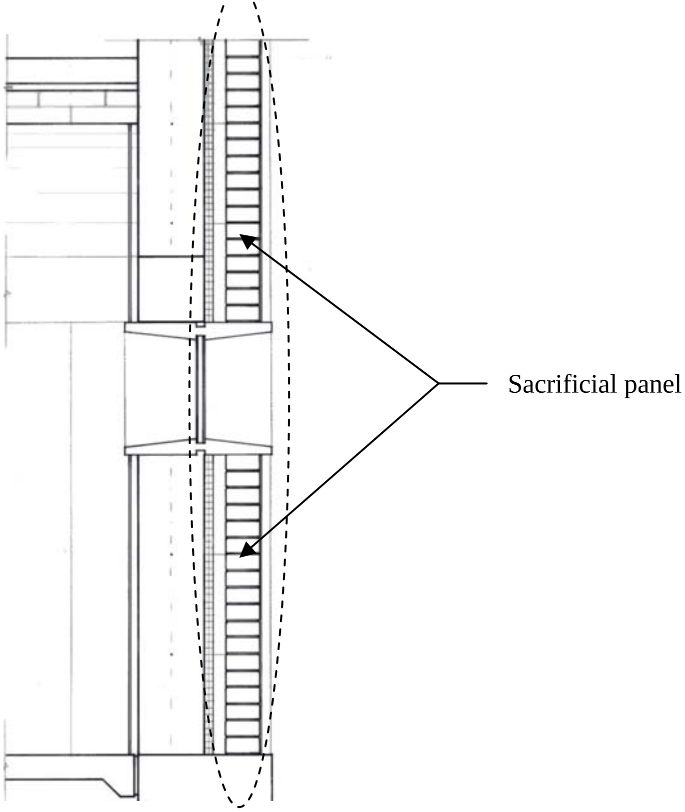


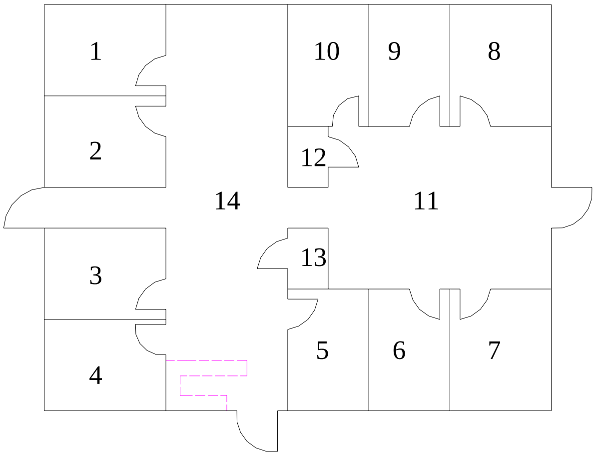
Figure 4.5. Sacrificial Panel. The exterior curtain wall of adobe bricks serves as a protective layer to reduce the spalling potential of the interior wall.

4.2 Sample Design

The design provided with this research is schematic and intended to illustrate the application of general principles of successful indigenous design concepts, including the primary elements listed above, without getting into the specifics of detailed programmatic requirements that would normally be addressed in a complete design. However, in order to provide enough of the salient requirements to make an effective comparison, general information was considered such as the required square footage of the housed functions. A series of aircrew offices for KC-135, EA-6B, F-16, and F-15 flight operations plus their life support functions are the focus of this design. The program requirements were borrowed from a project at Prince Sultan Air Base in Saudi Arabia to replace old trailers with new ones in the winter of 2001. The general requirements for each facility are provided below, and the program for the indigenous design facility is a combination of all these requirements.

<u>KC-135 Flight Operations</u>:

To house this operation, the original project specified a 185 SM (2000 SF) trailer with designated rooms as shown in Figure 4.6.

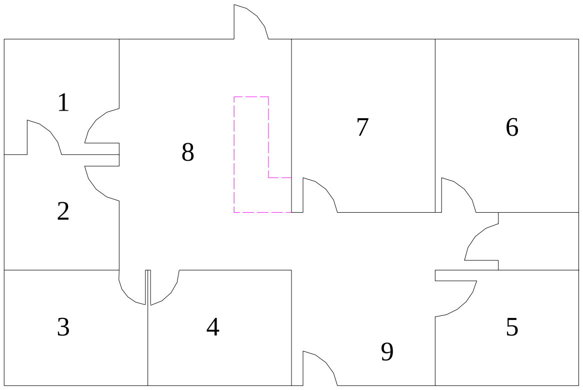


1. Mission Planning 10 SM (100 SF)
2. Mission Planning 10 SM (100 SF)
3. Mission Planning 10 SM (100 SF)
4. Mission Planning 10 SM (100 SF)
5. Boom Chief Office 9 SM (100 SF)
6. First Shirt's Office 9 SM (100 SF)
7. Commander's Office 11 SM (120 SF)
8. Director of Operations Office 11 SM (120 SF)
9. Admin. and Flight Records 9 SM (100 SF)
10. Crew Communication Rm. 9 SM (100 SF)
11. Operations Room 33 SM (350 SF)
12. Communications Closet 2 SM (20 SF)
13. Storage Room 2 SM (20 SF)
14. Lounge 44 SM (480 SF)

Figure 4.6. KC-135 Flight Operations. The KC-135 Flight Operations trailer was specified to be a 40 ft. by 50 ft. or 2,000 SF structure.

EA-6B Flight Operations:

To house this operation, the original project specified a 140 SM (1500 SF) trailer with designated rooms as shown in Figure 4.7.

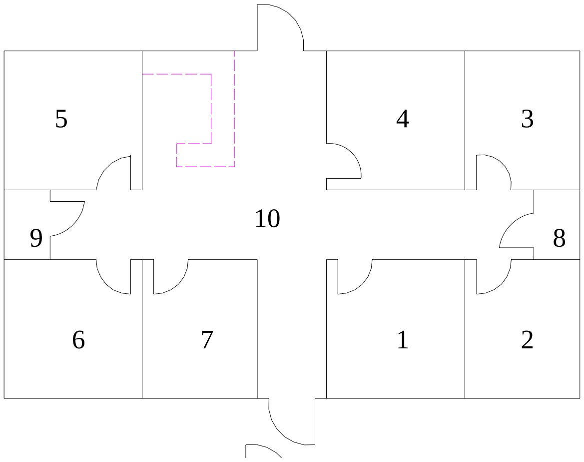


1. Commander’s Office 9 SM (100 SF)
2. Executive Officer’s Office 9 SM (100 SF)
3. Admin./Logistics Office 11 SM (120 SF)
4. Hinge Lounge/SIPR Rm. 11 SM (120 SF)
5. JOPA/PWTP Study Rm. 11 SM (120 SF)
6. Safety/NATOPS Rm. 16 SM (300 SF)
7. Operations Rm. 16 SM (180 SF)
8. Ready Rm./SDO Desk 28 SM (300 SF)
9. Charts/Planning Rm. 11 SM (120 SF)

Figure 4.7. EA-6B Flight Operations. The EA-6B Flight Operations trailer was specified to be a 30 ft. by 50 ft. or 1,500 SF structure.

F-16 Flight Operations:

To house this operation, the original project specified a 140 SM (1500 SF) trailer with designated rooms as shown in Figure 4.8.

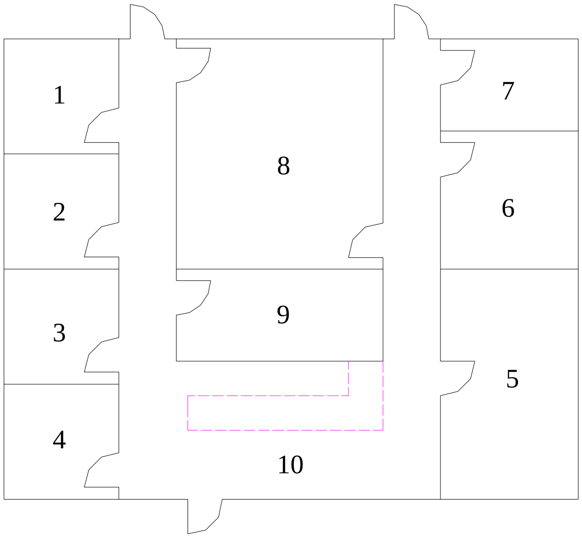


1. Commander’s Office 13 SM (140 SF)
2. Director of Opertions Office 11 SM (120 SF)
3. Planning Room 11 SM (120 SF)
4. Flt. CC/Trng./Stds and Eval. 13 SM (140 SF)
5. Briefing Room 13 SM (140 SF)
6. Briefing Room 13 SM (140 SF)
7. Scheduler’s Room 11 SM (120 SF)
8. Storage Room 4 SM (50 SF)
9. Storage Room 4 SM (50 SF)
10. Operations Desk/Lobby 3.5 SM (40 SF)

Figure 4.8. F-16 Flight Operations. The F-16 Flight Operations trailer was specified to be a 30 ft. by 50 ft. or 1,500 SF structure.

F-15 Flight Operations:

To house this operation, the original project specified a 185 SM (2000 SF) trailer with designated rooms as shown in Figure 4.9.

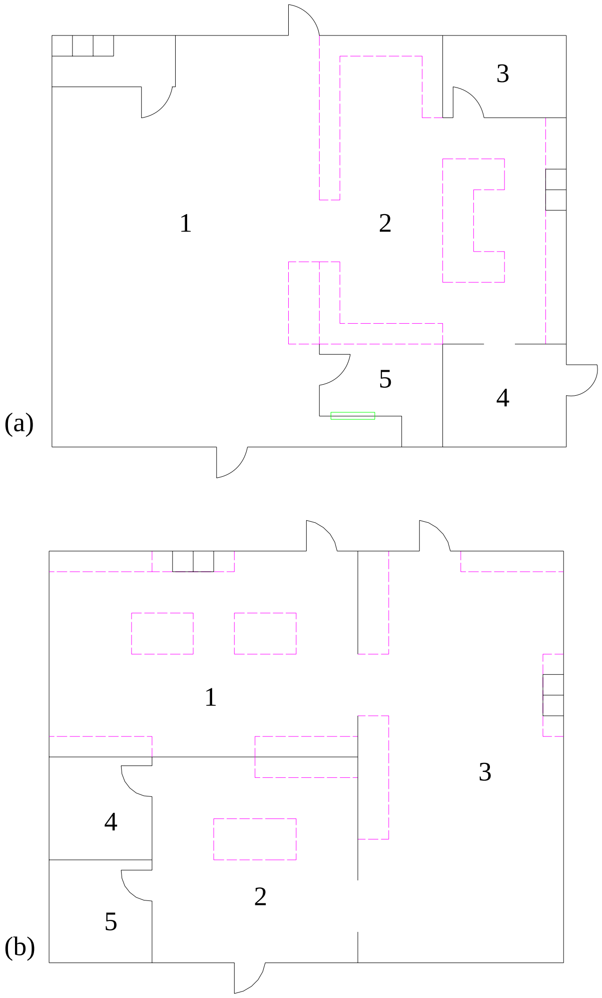


1. Mission Planning Rm. 9 SM (100 SF)
2. DACT Briefing Rm. 9 SM (100 SF)
3. Mission Planning Rm. 9 SM (100 SF)
4. Director of OPS Office 9 SM (100 SF)
5. Scheduling Room 22 SM (240 SF)
6. Commander’s Office 13 SM (140 SF)
7. Storage Rm. 9 SM (100 SF)
8. Main Briefing Rm. 33 SM (360 SF)
9. Intelligence Office 16 SM (180 SF)
10. OPS Desk/Lobby 26 SM (280 SF)

Figure 4.9. F-15 Flight Operations. The F-15 Flight Operations trailer was specified to be a 40 ft. by 50 ft. or 2,000 SF structure.

Life Support:

To house this operation, the original project specified two each 185 SM (2000 SF) trailers with designated rooms as shown in Figure 4.10 (a) and (b).



(a)

1. Locker Rm. w/ Laundry 102 SM (1100 SF)
2. Work Area w/ Counters 61 SM (660 SF)
3. Office 9 SM (100 SF)
4. Common Area 11 SM (120 SF)
5. Armory 9 SM (100 SF)

(b)

1. Work Area I w/ Counters 56 SM (600 SF)
2. Work Area II w/ Counters 37 SM (400 SF)
3. Locker Rm. w/ Laundry 74 SM (800 SF)
4. Superintendent's Office 9 SM (100 SF)
5. Storage Rm. 9 SM (100 SF)

Figure 4.10 (a) and (b). Life Support. Both Life Support trailers were specified to be 40 ft. by 50 ft. or 2,000 SF structures.

<u>Operations Town Site Plan</u>:

All facilities for the original project were located on a rectangular site with rough dimensions of 168 meters by 76 meters (550 feet by 250 feet). The long axis was orientated north to south. These dimensions and site orientation were used for the site plan of the consolidated program of the indigenous design. The original site with new and existing trailers is illustrated in Figure 4.11.

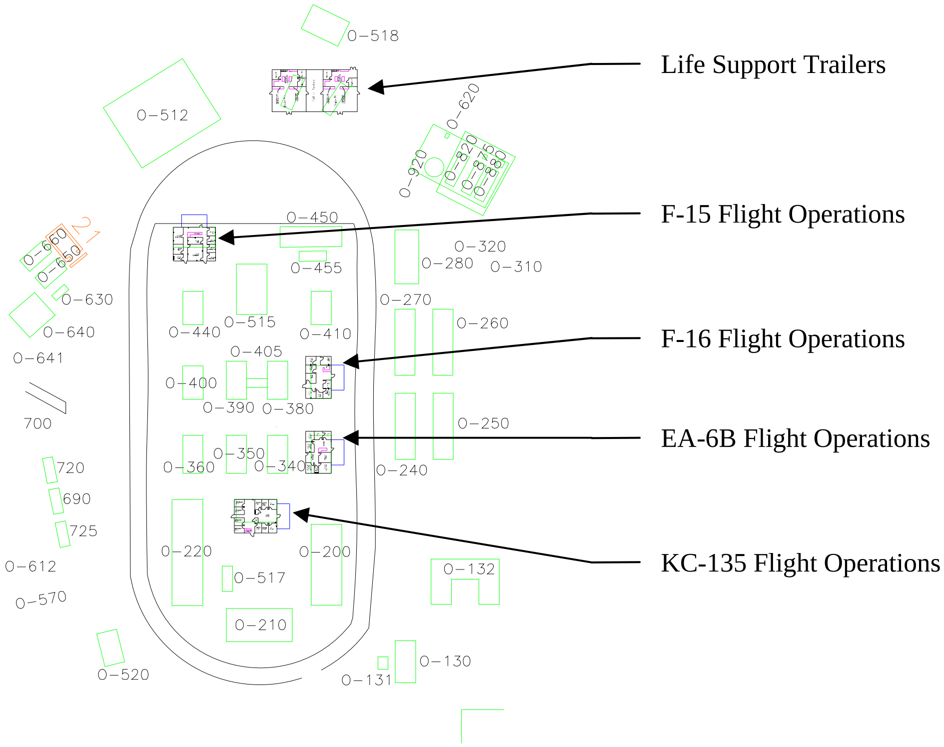


Figure 4.11. Operations Town Site Plan. The Operations Town trailers were located on a rectangular site.

Overall Design:

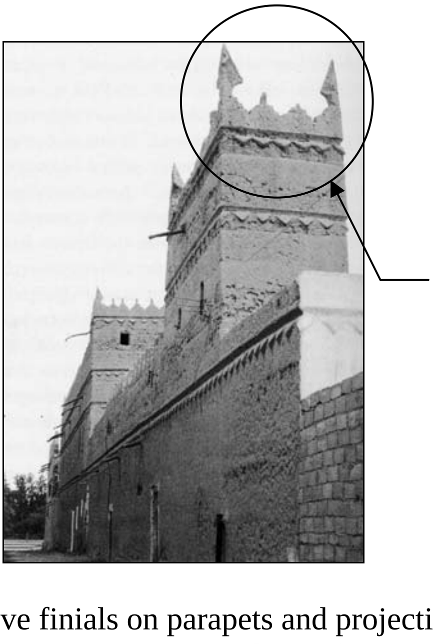
The design objectives included providing a safe, energy-efficient work space for five different flying operation offices. Therefore, the primary structure is composed of reinforced concrete piers and bond beams while the infill is composed of load-bearing, reinforced rammed earth walls. The concrete piers are vertical structural members that support the barrel vaults and separate the rammed earth and adobe panels at the end of each vault. The bond beams form bands around the entire structure at each floor level and act like the staves on a barrel to hold the entire structure together under seismic lateral forces. The four flying operation offices flank the central courtyard in two-storey wings. The life support offices are housed in a two-storey wing on the back side of the courtyard. The compound is entered through the front side of the courtyard by a gate shown in Figure 4.13 that can be closed and monitored for extra security. Vertical circulation is provided by a stair tower shown in the floor plans of Figures 4.13 through 4.15 on each corner of the courtyard.

The layout is based on a modular four meter grid for ease of construction. The primary structural elements are centered on the grid and separate the exterior façade into bays. Each bay is covered by a barrel vault for added strength. The bays also facilitate repair of the walls should they be damaged in an attack by making a clear separation between wall sections. Only those sections with damage will need to be repaired.

The monolithic earth construction provides some inherent force protection due to its ability to resist small arms projectiles as well as moderate blast forces. In addition, the first floor of the life support wing is protected by a berm to provide additional protection for people in the compound. The exterior walls have a limited number of doors and small, operable, mylar-covered windows to permit air circulation and penetration of daylight to the interior spaces. The result is a fortified wall around the complex. In the event of a structural fire, firefighters can access all rooms from the courtyard which can be entered through the main gate or by exterior doors at the base of all the stair towers. Furthermore, compartmentalization of each office space reduces the risk of fire spread. The reinforced masonry construction is resistant to heat-induced stresses on load-bearing capacity, making the structure more likely to be salvaged in the event of a structural fire.

To facilitate air circulation throughout the compound, the stair towers rise above the rest of the structure and double as windcatchers to harness desert breezes. The central courtyard also serves as a cool, shaded area and a plenum to help circulate air to all the rooms that flank it. The barrel vaults also help funnel air from the courtyard to the inner portions of the office.

The final goal of the design was to make it identifiable to the local culture through the use of indigenous materials and traditional construction practices. The complex plans and elevations are prismatic in nature like much of the traditional Middle Eastern architecture. Other architectural elements that are tied to local tradition include the barrel vaults and a relatively solid exterior that shields the compound’s interior from the harsh desert sun as well as from the view of those on the outside. In addition, parapet-topping finials and projections on the façade, like those shown in figure 4.12, are common to Middle East traditional architecture. They serve to channel erosion-causing rain water away from the plaster that covers the adobe walls. Floor plans, elevations, and building sections are illustrated in Figure 4.13 through Figure 4.19.



Finials and façade projections

Figure 4.12. Finials. Decorative finials on parapets and projections from the façade also serve to draw water away from erosion-sensitive plaster (King, 1998: 117).

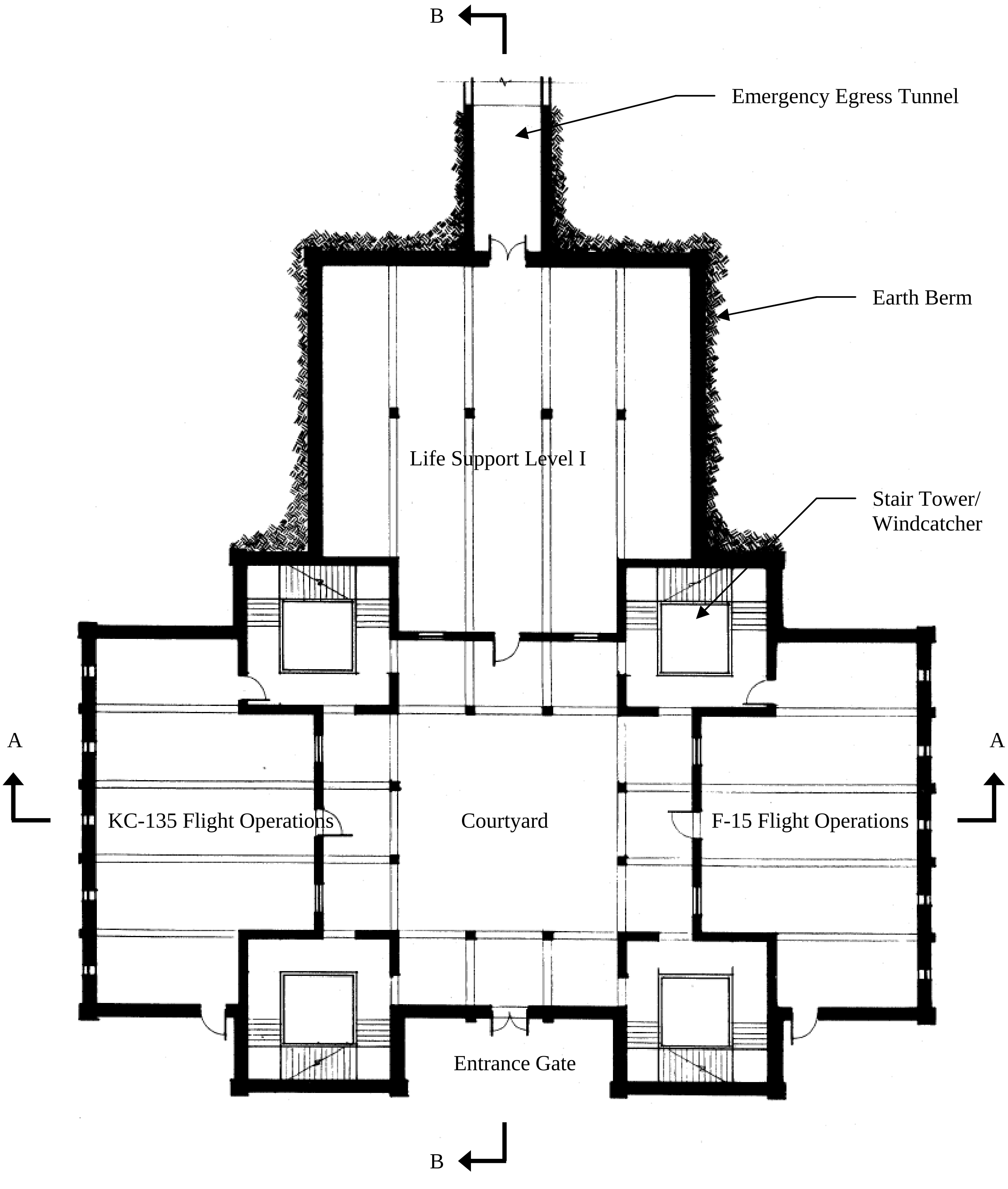


Figure 4.13. First Floor Plan. The first floor of the complex houses the KC-135 Flight Operations office on the left flank, the F-15 Flight Operations Office on the right flank, and the first level of Life Support functions on the back side of the central courtyard.

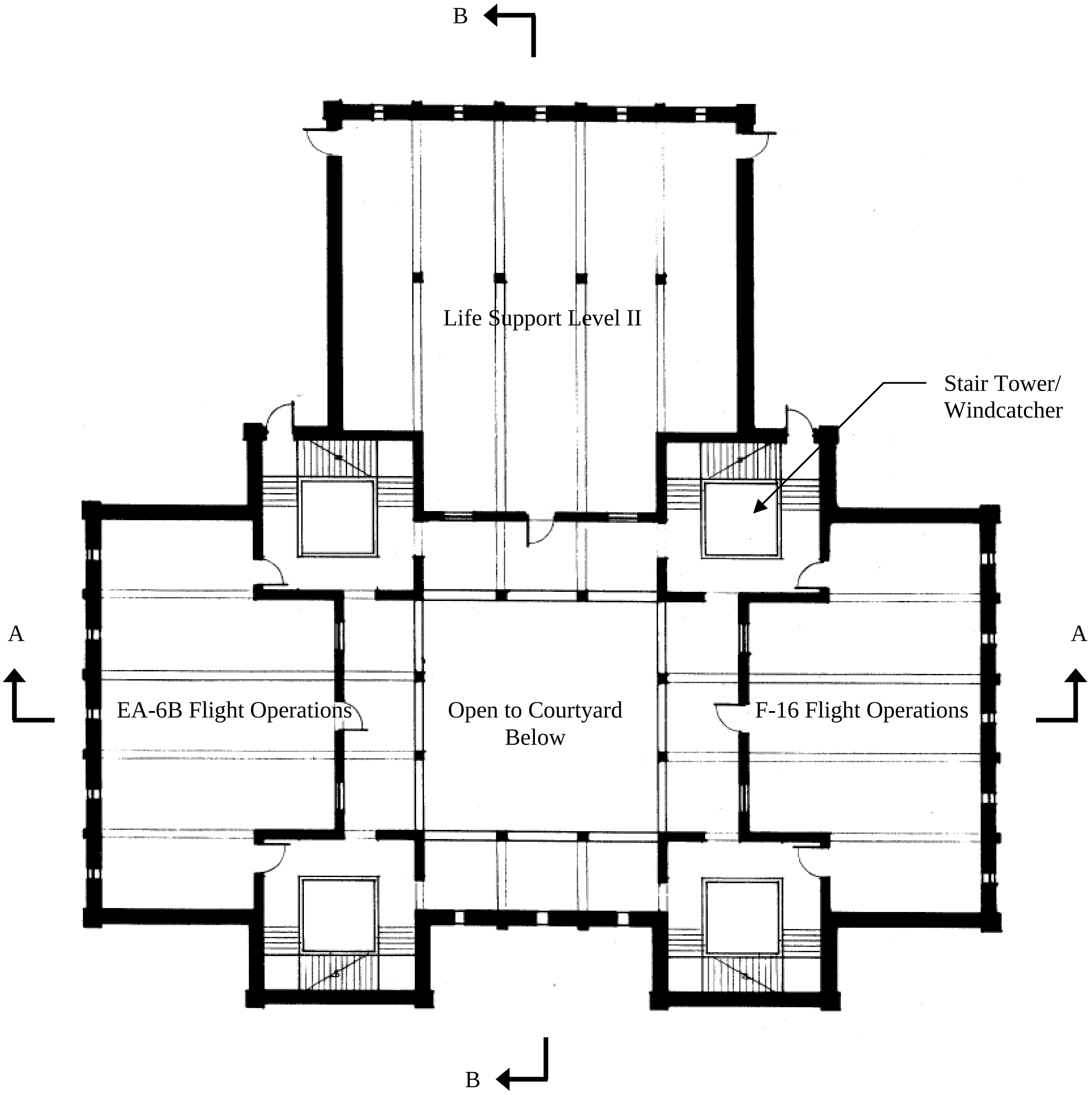


Figure 4.14. Second Floor Plan. The second floor of the complex houses the EA-6B Flight Operations office on the left flank, the F-16 Flight Operations Office on the right flank, and the second level of Life Support functions on the back side of the central courtyard.

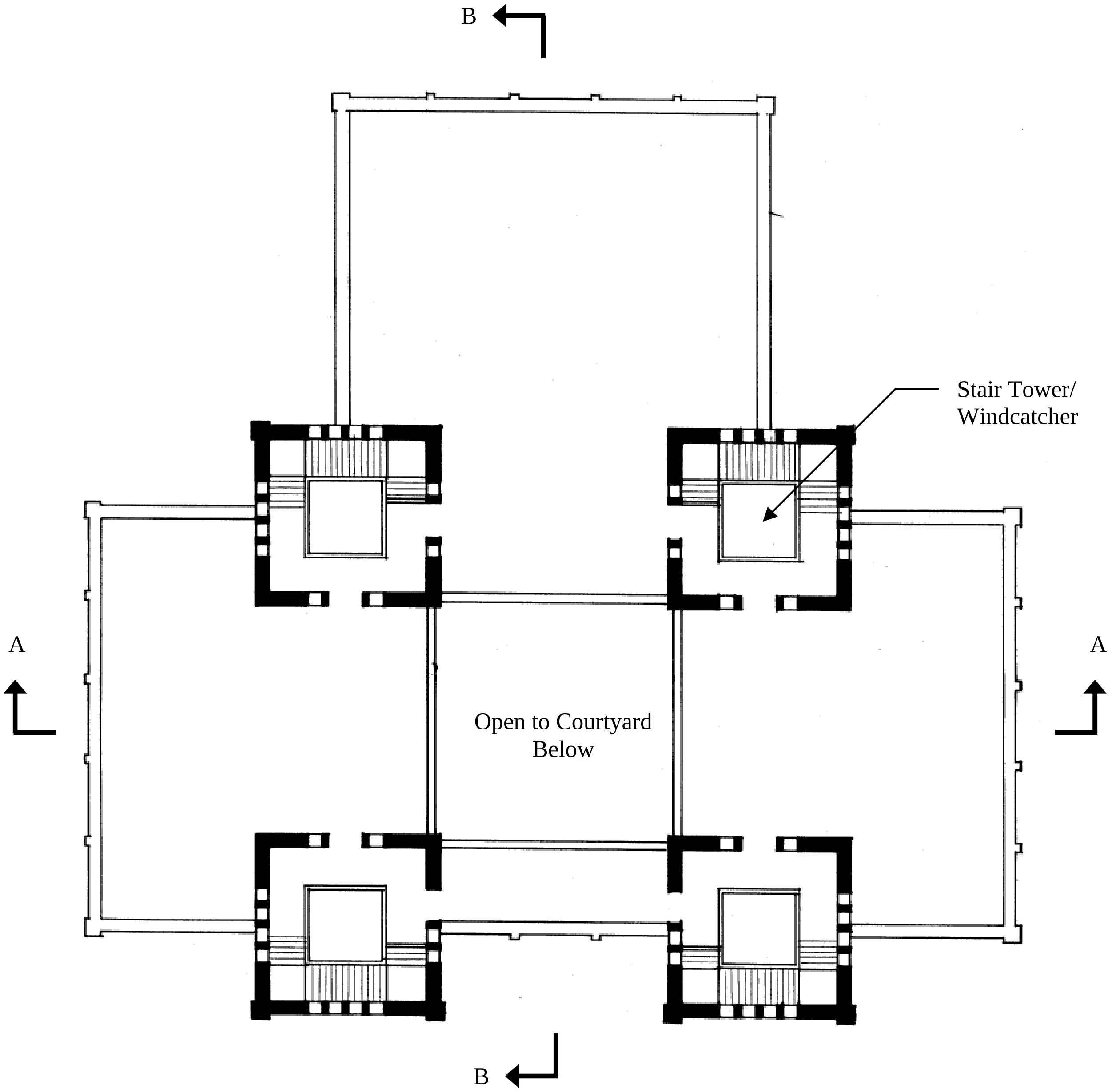


Figure 4.15. Roof Level Plan. The stair towers extend above the roof-tops of the complex wings to serve as windcatchers. The roof can also be accessed by these towers.

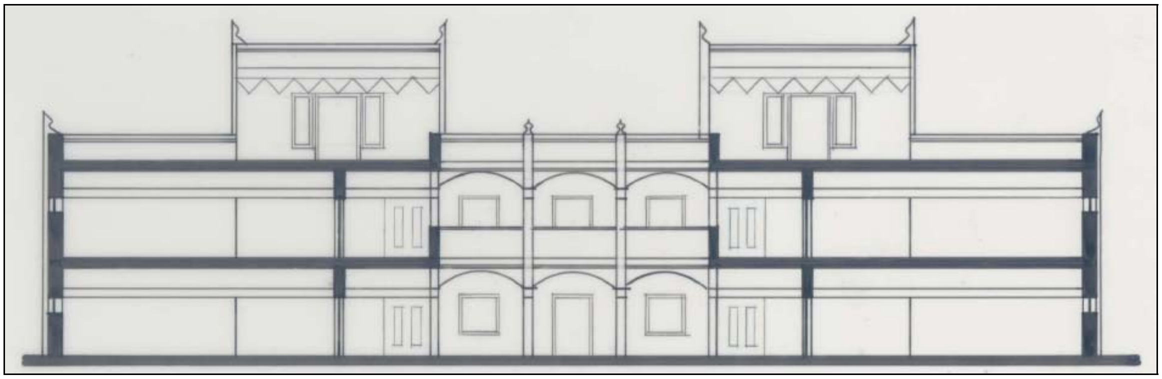


Figure 4.16. Transverse Building Section (A-A). The section shows how each space connects to the central courtyard.

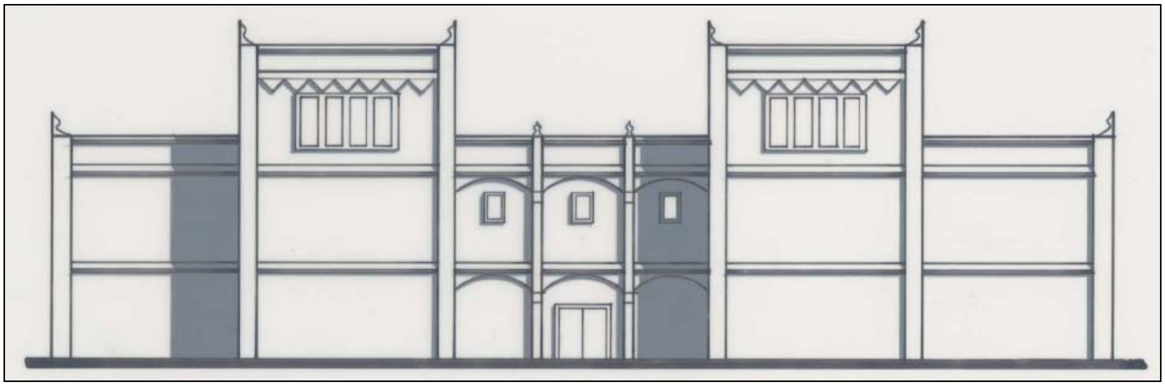


Figure 4.17. Front Elevation. The exterior elevation shows the fortified walls and some of the characteristic architectural elements of Middle Eastern traditional design.

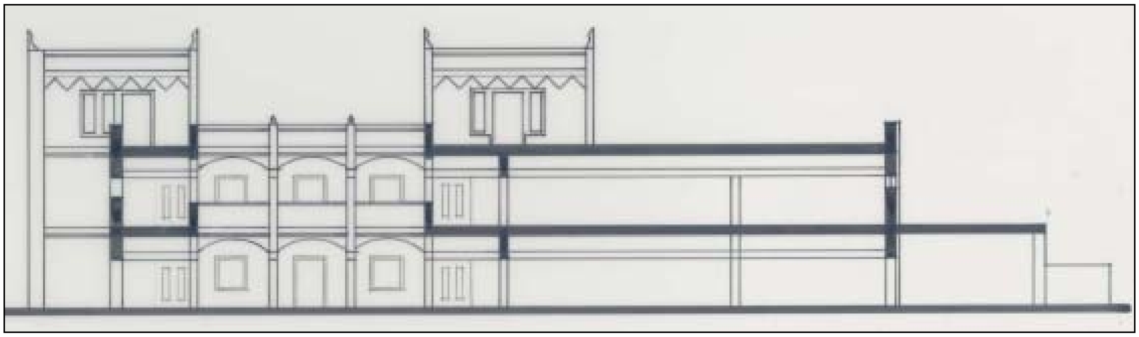


Figure 4.18 Longitudinal Building Section (B-B). Another view of the interior components of the complex and how they relate to the central courtyard.

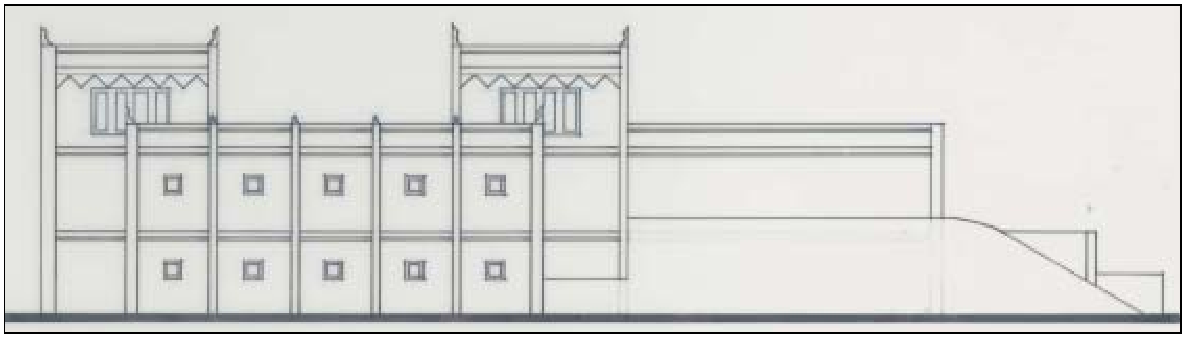


Figure 4.19. Side Elevation. This side elevation shows the small, mylar-covered windows as well as the earth berm that surrounds the first level of the Life Support area.

4.3 Comparison of the Building Techniques

For the purpose of this research, a schematic design was produced to show, in general, how indigenous building concepts could be applied. Because the design was very basic, the construction technique was evaluated against the prefabricated metal building with regard to only the exterior envelope. In other words, the costs of provisions for utilities and other detailed components were not considered. The comparison begins with a description of the two wall assemblies and follows with analysis in regards to energy performance, force protection, fire safety, and procurement.

Construction Descriptions:

The typical prefabricated metal building wall section is 200 millimeters (mm) thick. The main structural components are 160 mm metal studs. The exterior is sheathed with 4 mm plywood and clad with 0.6 mm steel siding. The interior walls are sheathed with 15 mm gypsum board. The wall cavity is filled with 40 kilogram per cubic meter (kg/m^3) rock wool insulation. Figure 4.20 illustrates this construction.

The prefabricated metal building wall section is compared against a rammed earth wall section with an exterior adobe sacrificial panel. The main structural component of this system is a 400 mm rammed earth wall with steel reinforcement. This wall is sandwiched between a geotextile fabric on each face. The geotextile fabric is a woven material that can be used to contain any spalled material in the event that the wall is subjected to an explosive blast (AFP 10-219, Vol. 7, 2004: 66). The interior surface is given a finished appearance with 15 mm gypsum board attached to 40 mm furring strips. The exterior of the rammed earth wall is clad with 50 mm rigid insulation. The sacrificial panel is 200 mm thick and constructed of adobe brick with an exterior surface of erosion-resistant adobe plaster. A 125 mm gap is maintained between the exterior face of the rammed earth wall and the interior face of the adobe sacrificial panel as a buffer space to protect the primary wall in the event that the exterior adobe panel is destroyed in an explosion. This wall construction is illustrated in Figure 4.21.

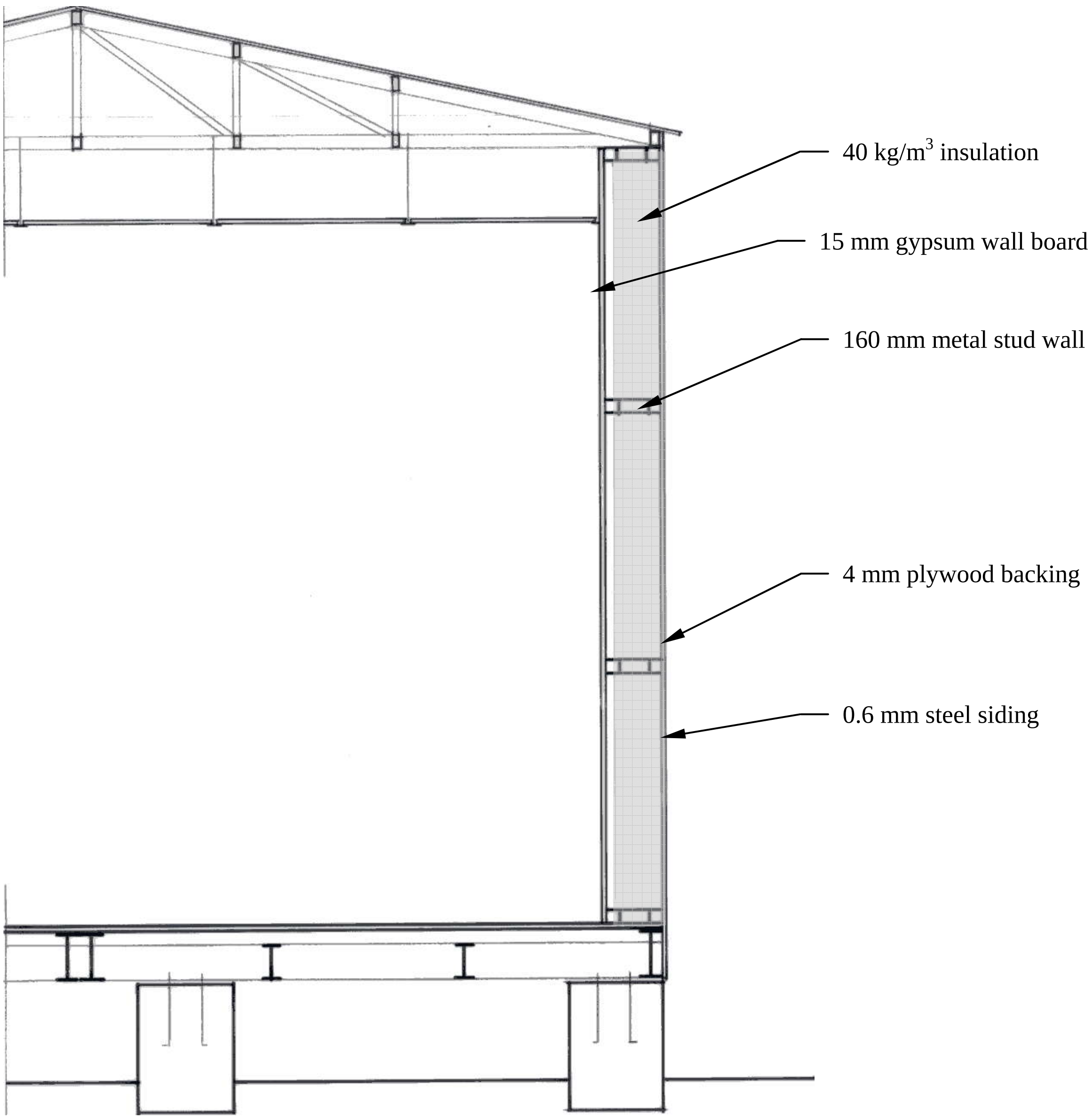


Figure 4.20. Prefabricated Metal Building Wall Section. The prefabricated metal building is a light construction and designed to be transportable.

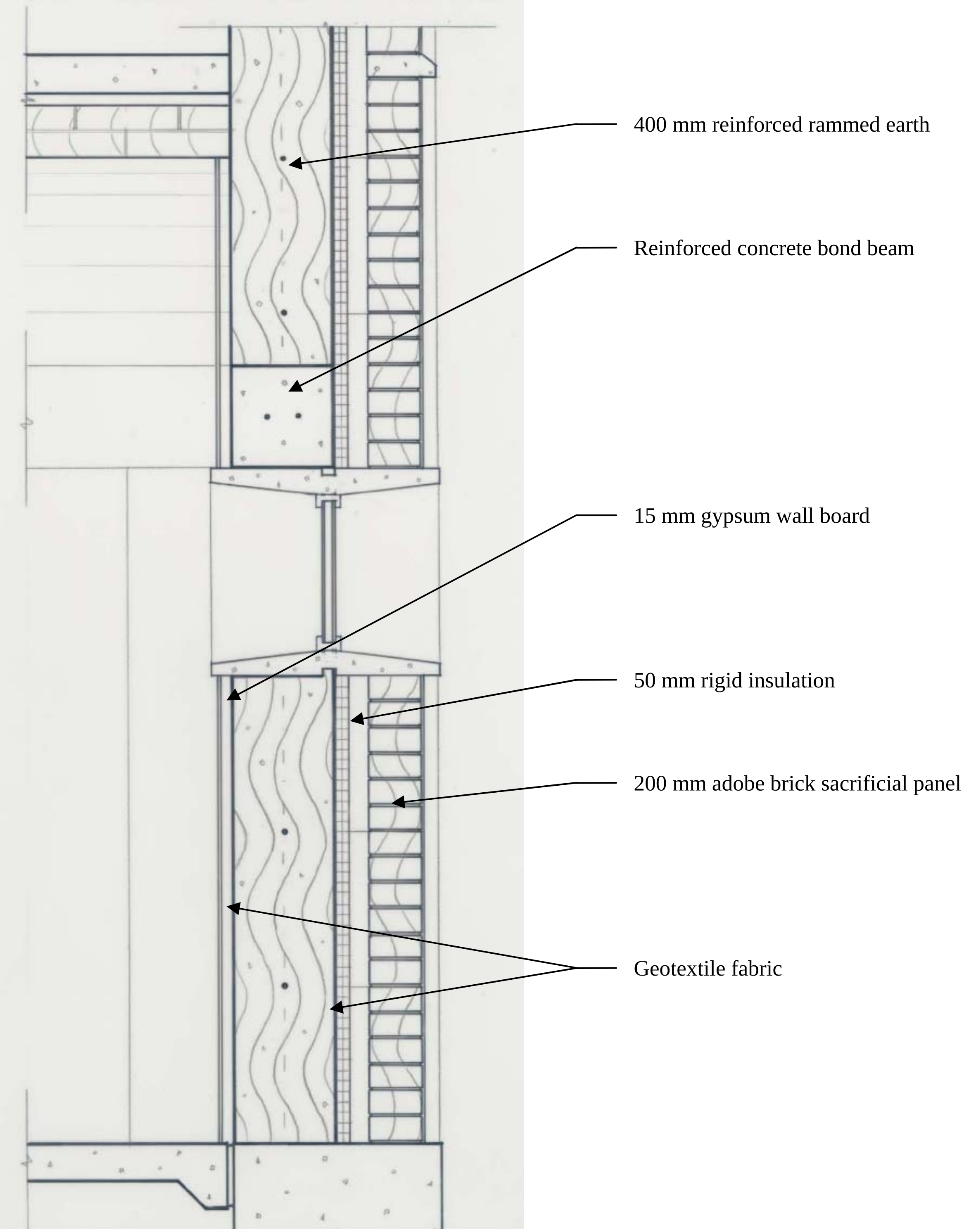


Figure 4.21. Monolithic Earth Wall Section. The earth wall section has a deep profile and results in a permanent structure.

Energy Performance:

The following equation was used for heating and cooling load calculations:

$$q = UA(\Delta T)$$

where q = heat transfer rate, U = overall heat transfer coefficient (Btu.in. / h.ft2.°F), A = the sample wall area (SF), and ΔT = the temperature difference between the selected interior design temperature and the exterior design temperature (°F). In order to calculate the overall heat transfer coefficient (U), the thermal resistance (R) value was calculated for each material and its thickness in the wall section. These values were totaled to give the total R-value at furring and the total R-value between furring. The reciprocal of the total R-value gives the U-value. Typically, wall furring occurs at 20 percent of the wall surface and the remaining 80 percent of the wall surface is between furring. The corresponding U-values were multiplied by those percentages and summed to give the overall U-value.

Heat transfer calculations for both of the wall assemblies indicated that the sample designs have roughly the same insulation qualities. Design temperatures were used for Ad Dawhah, Qatar, with a summer design temperature of 115°F and a winter design temperature of 43°F (ASHRAE, 1997: 26.45). The interior design temperature was 72°F. Under these conditions, the summer cooling heat transfer rate for the prefabricated metal building was calculated to be 211 British Thermal Units (BTUs) per hour while the same rate for the rammed earth structure was calculated to be 216 BTUs per hour. This is a difference of only 5 BTUs per hour in favor of the prefabricated metal building. The winter heating mode calculations were even closer. Here, the heat transfer rate for the prefabricated metal building was determined to be 142 BTUs per hour while the calculations for the rammed earth structure yielded a heat transfer rate of 146 BTUs per hour; a difference of 4 BTUs per hour in favor of the prefabricated metal structure. Considering the approximate nature of the R-values used for these calculations, these heat transfer rates are essentially the same. The calculations are detailed in Appendix A.

These calculations did not take into account the dampening effect provided by the thermal mass of the rammed earth wall. Heat is absorbed in the walls and stored during periods of high cooling loads and released when cooling loads drop (Easton, 1996: 35). This is in contrast to the metal stud walls that facilitate direct transmission of heat from one side to the other. It should also be noted that a more accurate heat transfer rate calculation in cooling mode would have accounted for the transient difference in solar load due to changing sun exposure throughout the day by using a cooling load temperature difference (CLTD) or similar calculation method (McQuiston, 1994: 8.1). However, CLTD values could not be found for the subject wall assemblies; therefore, a straight temperature difference was used. Furthermore, since the focus of this design was the wall section, heat transfer calculations were performed only for transmission through the walls and did not include heat transfer through the roof of either design.

Other aspects of the indigenous design that would improve the relative comfort of the building inhabitants include the use of windcatchers, convection ventilation, and evaporative cooling. Each of these design elements helps to condition the air through natural processes and do not expend electricity to do so.

Force Protection:

Material mass is an effective protective barrier against small arms projectiles and explosive devices. For this reason, the monolithic earth walls of the indigenous design are inherently more effective against impact from projectiles and the effects of blast pressure from high explosives. The 400 mm (approximately 16 in.) thick reinforced rammed earth walls have similar structural characteristics to reinforced concrete and can withstand a wide array of conventional weapons including small caliber machine gun fire, mortars, rockets, and even a 1,000 pound bomb detonated 50 feet away (AFP 10-219, Vol. 7, 2004: 11). In contrast, the 0.6 mm thick aluminum siding on a 4 mm plywood backing of the prefabricated metal trailer provides comparably little protection against the same threats. In order to compensate for this shortcoming, large concrete barriers are often placed around this type of metal structure.

Fire safety:

The three major fire safety concerns of a designer are life safety, property protection, and continuity of operations (NFPA, 1981: 5-2). The first concern, life safety, refers to the protection of the building's occupants who must be safeguarded from the products of combustion including heat, smoke, and toxic gasses (NFPA, 1981: 5-3). Since both designs in this comparative analysis have gypsum board for a finished interior wall surface, life safety concerns related to the products of combustion would be the same.

While the products of combustion in the two sample structures were the same, significant differences in the major structural components yielded major concerns for property protection and, therefore, continuity of operations. Property protection refers to the survivability of the building under the intense heat of a fire and continuity of operations refers to the ability to continue occupancy of the structure after a fire has occurred (NFPA, 1981: 5-3). Statistically, few deaths occur from structural failure because occupants usually have time to evacuate the facility or they are overcome by inhalation of smoke and toxic gasses before this happens (NFPA, 1981: 5-3).

However, structural failure is a concern for firefighters and it is also an important factor in determining whether the facility must be replaced. In studies of the effects of major structural fires on reinforced concrete and steel, reinforced concrete survived with very little, if any, strength reduction (Bailey, 2006). The only concern is when the surface material spalls and water comes in contact with the super-heated internal steel reinforcing bars. This might reduce the ductility of the reinforcement bars and, therefore, cause concern for the building’s structural integrity (NCSCCMI, 1994: 4). Since reinforced rammed earth is comparable to reinforced concrete, its performance is expected to be similar. In contrast to concrete, structural steel members showed signs of significant stress, if not complete failure, under the same fire-induced conditions (Bailey, 2006: 5). Therefore, a fire in a prefabricated metal trailer would be expected to lead to questionable structural integrity. Under this circumstance, the facility would need to be demolished and replaced.

Procurement:

In the original project delivery timeline at Prince Sultan Air Base, each prefabricated metal Operations Town trailer was expected to take a total of 65 days to construct including 45 days at the manufacturing plant in Rhyad, Saudi Arabia and 20 days on site to place the structure and complete the interior finishes. While the contractor was able to work on more than one trailer at the manufacturing plant, trailer delivery had to be drawn out because new trailers were to be placed on the same site as the facilities they were replacing. Occupants were required to move out of their old facility and into a temporary office space while their old trailer was removed and the new one was set in place. The total delivery time for all six trailers was anticipated to be seven months; however, if the shell game was not necessary, the entire project could possibly have been delivered in half the time, or three to four months.

In contrast, the construction timeline for the indigenous structure was calculated to be a more time-consuming process. The indigenous design includes approximately 2,615 SM (28,150 SF) of rammed earth walls. A good crew with machinery can complete 300 square feet of wall per day (Easton, 1996: 108). At this rate, it would take approximately 94 days to complete the rammed earth walls of the structure. For adobe, one person can lay up to 20 SM of single brick thickness wall per day (Elizabeth, 2005: 92). Therefore, a crew of four people can construct the 2,050 SM of adobe sacrificial panels in 26 days. For the double-thick adobe brick vaults, a different four person crew can complete the 2,112 SM of work in 53 days at a rate of 10 SM per day. Assuming the vaults and sacrificial panels can be constructed at the same time, the vault work becomes the critical path for adobe work. Therefore, adding 53 days of adobe construction to the 94 days of rammed earth construction gives a total of 147 days or five months for earth wall and vault construction. This is slightly longer than the delivery time of the prefabricated metal trailers.

In addition to delivery time, the other major procurement consideration was cost. The government estimate for the prefabricated metal trailers was slightly more than 500,000 dollars in January of 2001. According to inflation rate tables published by the Secretary of the Air Force Financial Management and Comptroller office, the U.S. Air Force raw inflation index for 2001 military construction was 0.914 (SAF, 2006).

Therefore, the equivalent project cost in 2006 dollars was 547,046 dollars. Force protection enhancements were not included in the original project; however, the combined cost to install "T-wall" blast protection panels, like the one shown in Figure 4.22, was estimated at 142,800 dollars using current price data. Therefore, the total cost for the trailers plus force protection enhancements was estimated at 690,000 dollars. The estimated cost for construction of the indigenous design was approximately 1,170,000 dollars. Material costs for the rammed earth and adobe walls were not included because soil conditions in the region favor the possibility of quarrying suitable material consisting of 70 percent sand and 30 percent clay from the construction site (Elizabeth, 2005: 87). The cost calculations for both facility types are detailed in Appendix B. These calculations consider only initial cost and do not consider life cycle costs. Historical evidence has shown that earth structures can last for a century if not longer (King, 1996: 8). Metal buildings, on the other hand, have a much shorter life span. The metal trailers of the replacement project at Prince Sultan Air Base in Saudi Arabia were only ten years old. Assuming this lifespan, the earth structure could pay for itself in ten years without considering its inherent energy saving advantages.

Figure 4.22. "T-Wall" Blast Protection Panels. Reinforced concrete panels are a popular method of providing moveable blast protection for facilities in the Middle East (Harshbarger, 2006).

After a cursory analysis, determination of the best building system for construction of permanent replacement facilities at main operating bases in the Middle East was not definitive. Selection of the best building system depends largely on the value placed on each of the primary considerations of energy performance, force protection, fire safety, and procurement time and cost.

V. CONCLUSIONS

5.1 Overview

In the course of this research, noted similarities between indigenous architecture of southwestern Native Americans and Arabs of the Middle East highlighted effective design elements for sustainable design in a hot, arid desert climate. Some of these elements were incorporated into a notional design of an Air Force flying operations office complex on a main operating base in the Middle East (Al Udeid Air Base, Qatar) and this design was evaluated in terms of energy performance, force protection, fire safety, and procurement time and cost. The results were then compared to the same aspects for a prefabricated metal building. The complete process was a hybrid of different techniques including a comparative analysis and architectural design with a sound foundation in a case study analysis. The two building systems are illustrated in the wall sections shown in Figure 5.1.

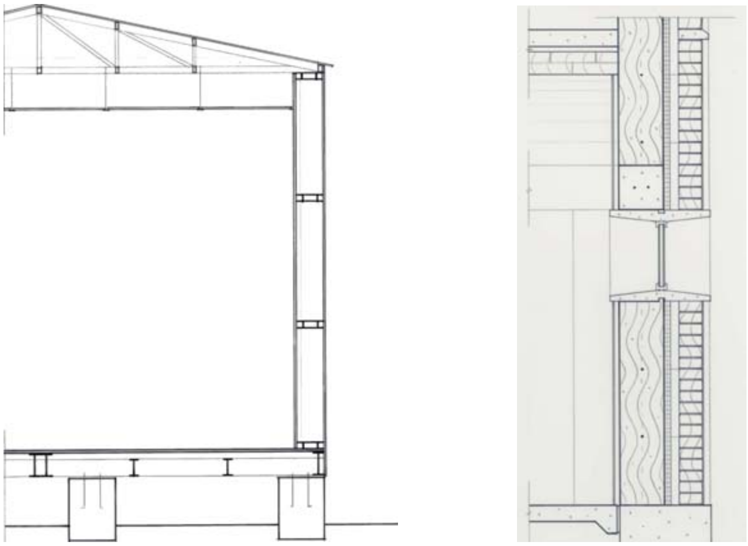


Figure 5.1. Building Systems. The prefabricated metal building and monolithic earth wall building systems were the subject of comparative analysis in this research.

Both construction techniques have benefits and detractors and the overall best option depends on the aspects that are most important to the decision maker. Table 5.1 summarizes the comparison between the metal and earth building systems. A check mark indicates the best option for each consideration.

Table 5.1. Building System Comparison Summary

Building System Comparison Summary		
Energy Performance (Heat Transfer)		
	142.09 BTUs per Hour	√
	145.88 BTUs per Hour	
Force Protection (Resilience vs. Conventional Weapons)		
	Little to none	
	Most conventional small arms and up to 1000 lb bomb	√
Fire Protection (Potential for Structural Damage)		
	High	
	Low	√
Procurement Cost ($)		
	$690,000	√
	$1,170,000	
Procurement Time (Months)		
	3-4 months	√
	5 months	
Replacement Frequency (Years)		
	10 years	
	100 years	√

5.2 Characteristics, Benefits, and Disadvantages

Characteristics:

Indigenous architecture incorporates time-tested techniques to respond to the challenges of the local climate. Simple concepts such as thermal mass, windcatchers, and convection ventilation draw upon natural forces to alter the built environment to meet human demands for comfort and safety. By using materials from the site, such as earth, to construct the thermal mass, the building’s tie to the site is strong. In addition, earth structures are an effective and proven construction technique in desert regions. At one time, earth structures were found in almost every region of the world and were constructed with numerous techniques such as adobe and rammed earth. With proper maintenance, earth structures can last for centuries despite exposure to powerful environmental forces such as dust storms, extreme temperature fluctuations and occasional heavy rain.

Benefits:

The benefits of indigenous design are numerous. Once constructed, their inherent climate-regulating properties can reduce supporting infrastructure as well as operating costs. Because permanent indigenous buildings often involve the construction of mass walls, they also have inherent force protection characteristics that are invaluable to military personnel in dangerous environments. Masonry and earth structures are also advantageous to fire safety since the primary construction materials are non-combustible and are also resistant to heat-induced structural stress. Finally, by definition, indigenous design is identifiable by the local community. The built form can have a powerful association for people. By using local materials and labor and employing these in a manner that produces a structure that the indigenous people can relate to, that association can be very positive. This process also bolsters the local economy. In the end, the facility will be something the local people are proud to have in their area and improve receptiveness of buy-back by the host government when U.S. forces vacate the facility.

Disadvantages:

The benefits of indigenous design come with a high initial cost. When these concepts were initially developed, human labor was cost-effective and craftsmanship was prevalent. Today, value is placed on rapid procurement at the lowest initial cost and very little consideration is paid to life cycle costs. Although indigenous design can incorporate mechanization in some of the associated construction processes, it is still labor-intensive. Furthermore, it requires a labor force skilled in traditional construction methods that may be difficult to find and hire. Since skilled manual labor now comes at a premium cost, this drives the capital cost of this type of building above the price of contemporary building methods. Indigenous construction is also time consuming, and therefore not suited to an environment where rapid changes dictate flexibility such as a military expeditionary installation. In addition, current Department of Defense (DoD) construction policy prohibits permanent facility construction at most expeditionary locations in the Middle East. Main operating bases (MOBs) are the only exception and they are in their infancy in terms of development in the Middle East. Therefore, the time and cost of indigenous designs make them an unlikely choice in that environment.

5.3 Limitations

The application of this investigation's findings is limited to a cursory look at the problem of selecting the best construction method for semi-permanent to permanent facilities on expeditionary installations. Political, cultural, and financial situations as well as dynamic operational demands make the decision very complicated and worthy of a detailed analysis into each of those aspects. The bulk of the information presented in this research is qualitative in nature. Therefore, its interpretation is subjective, although application of proper case study methodology and rudimentary supporting quantitative calculations helped lend credence to the findings. In addition, no clear winner was revealed in the comparative analysis between the metal and earth walled structures. Both options had their benefits over the other. For example, if initial cost was significantly more important in a decision-maker's criteria, the metal building would most likely be the preferred option. However, if inherent force protection characteristics were the most important, the earth walled structure might prevail. The lack of readily available quantitative data also limited the evaluation of force protection characteristics of the construction methods. Since earth construction has only recently seen resurgence, very few laboratory tests have been conducted.

5.4 Future Research

The research presented in this endeavor was primarily based on the study of existing technical and anthropological literature. The consolidated results are a broad-brush look at each of the major considerations for building a permanent facility in a military expeditionary environment: energy performance, force protection, fire safety, and procurement. Future research opportunities exist for a separate detailed, qualitative analysis of each factor. The benefit of such research is highlighted by the fact that because the use of earth as a building system has only recently seen a resurgence, very little laboratory testing has been conducted to determine its properties as a building material.

Energy Performance:

The heat transfer calculations presented in this report were very basic and considered only heat transfer through the wall. Further study of energy performance characteristics of the comprehensive structure would provide a better picture for the decision maker. A detailed energy performance analysis would include heat transfer calculations for the entire building envelope, not just the wall section. It would also include a quantitative analysis of the potential benefits of natural ventilation achieved through the use of windcatchers and convection ventilation. These results could be translated to the amount of energy saved and subsequently to costs required to produce that energy.

Force Protection:

Laboratory testing is required to definitively determine the effectiveness of earth wall systems against force protection threats such as small arms fire and explosive blasts from improvised explosive devices or mortars. The findings in this report were derived from test results of comparable construction assemblies because no data specific to rammed earth or adobe could be found. Some specific areas of study could include determining the optimal thickness of rammed earth walls or the optimal amount of steel reinforcement needed to resist the forces of an explosive blast. The Air Force Civil Engineer and Services Agency at Tyndall Air Force Base, Florida, has expressed an interest in this subject; however, funding has not been obtained for testing (Rutland, 2005).

Fire Safety:

Similar to explosive blast testing, data for fire safety of earth wall systems was scarce and conclusions in this report were based on testing done on comparable systems such as reinforced concrete. A more detailed analysis of the effects of interior fires on the structural integrity of earth walls is needed. Testing of reinforced concrete indicated that the amount of spalling depended partly on the density of the concrete. High density concrete was more likely to spall than normal concrete because expanding water vapor was not able to escape through the material (Kodur, V.R, 1988: 3). Extensive spalling can have detrimental effects on structural integrity. Because rammed earth is a highly compacted material, spalling might be a significant factor in an interior fire.

Procurement:

Further research is also possible in the area of procurement. For example, a study of the local-market availability of a labor force educated in earth wall construction is needed. While this type of construction was prevalent throughout the Middle East and can still be seen in historic structures in the region, it is considered a lost art due to the importation of concrete masonry and prefabricated metal building construction systems to the region.

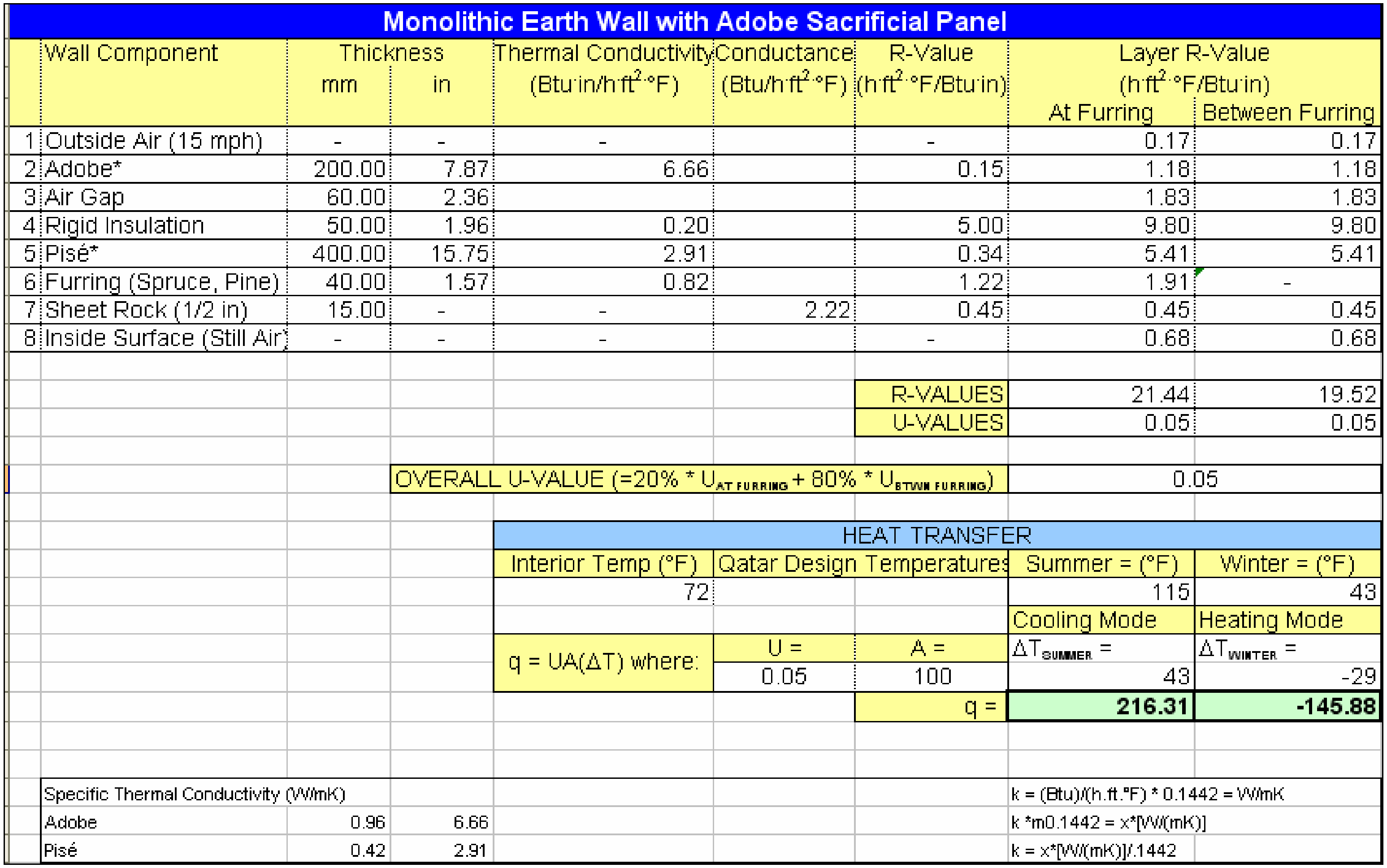
In addition, construction times and costs were derived predominantly from western literature. These factors may take on considerably different values when local work forces and suppliers are used. Therefore, another avenue for future research could be investigating these factors in a Middle East market and using those true values to determine the associated procurement cost and time.

Value Focused Thinking:

Finally, a value focused thinking (VFT) analysis would provide an objective approach for determining the appropriate building system question. Since no apparent overall winner was revealed with the qualitative investigation, a VFT analysis is necessary. Quantitative decision analysis factors in the decision maker’s values for each of the decision factors and assigns weights to these factors along with scores for the relative qualities. In order to conduct this type of analysis, more definitive values will need to be achieved for each of the considerations than those presented in this report.

5.5 Conclusion

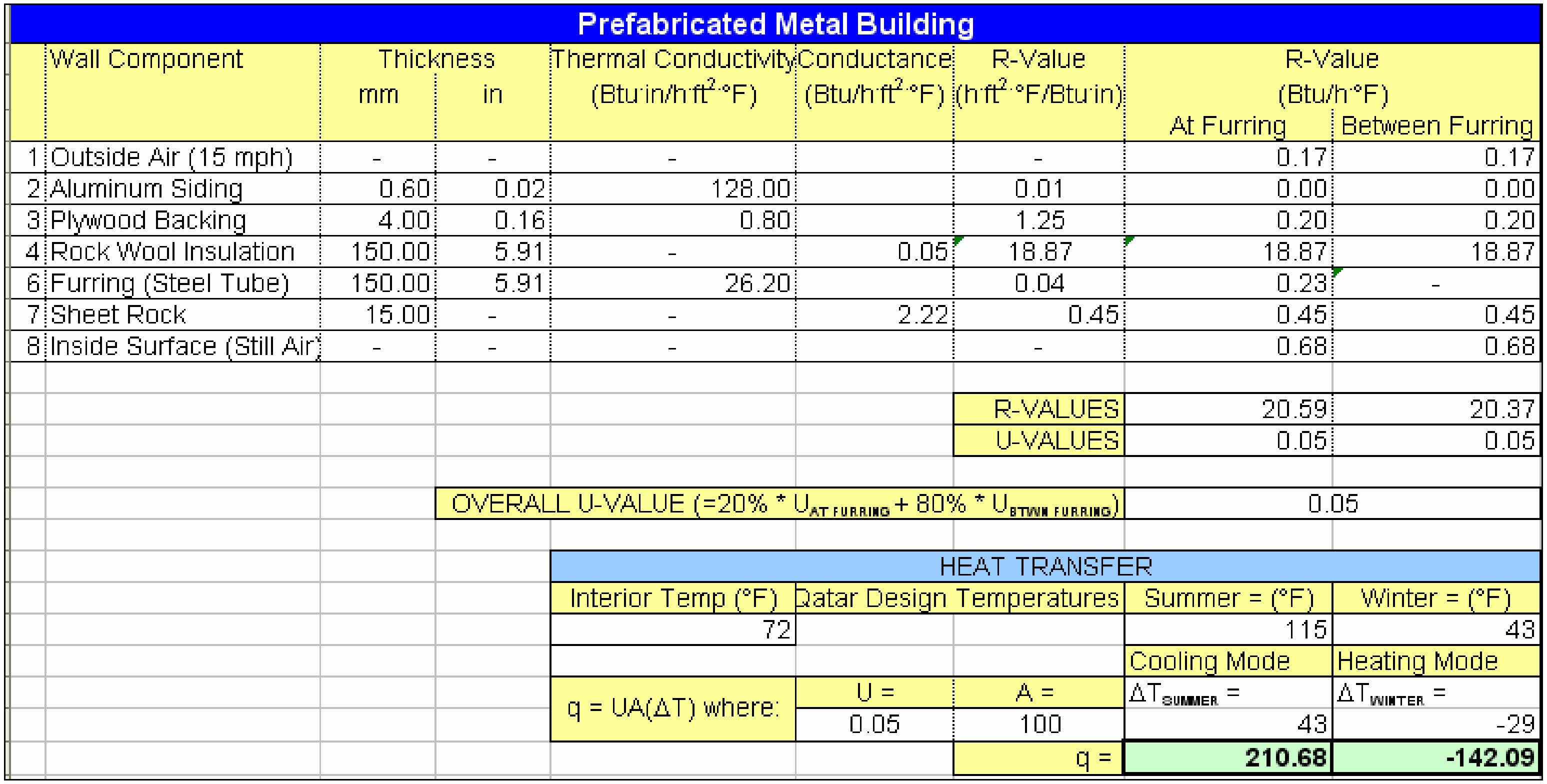
The choice of the optimum permanent building system in an expeditionary environment is very complicated and requires a more detailed investigation. However, the results of this study indicate that indigenous architecture has promise and warrants consideration. It has inherent efficient energy performance and favorable fire safety and force protection characteristics, although these are achieved at the cost of increased procurement time and at a high initial cost.   The time-tested techniques are not only proven to be effective in response to the harsh, local climate, they are also perceived favorably by the local people over imported construction techniques. With the potential of an extended presence in the Middle East, a small indigenous footprint is an important consideration that might help ease strained relations with our host countries. The benefits of indigenous architecture have the potential to improve the built environment for expeditionary installations.



Monolithic Earth Wall with Adobe Sacrificial Panel

	Wall Component	Thickness		Thermal Conductivity	Conductance	R-Value	Layer R-Value	
		mm	in	(Btu·in/h·ft^2·°F)	(Btu/h·ft^2·°F)	(h·ft^2·°F/Btu·in)	(h·ft^2·°F/Btu·in)	
							At Furring	Between Furring
1	Outside Air (15 mph)	-	-	-		-	0.17	0.17
2	Adobe*	200.00	7.87	6.66		0.15	1.18	1.18
3	Air Gap	60.00	2.36				1.83	1.83
4	Rigid Insulation	50.00	1.96	0.20		5.00	9.80	9.80
5	Pisé*	400.00	15.75	2.91		0.34	5.41	5.41
6	Furring (Spruce, Pine)	40.00	1.57	0.82		1.22	1.91	-
7	Sheet Rock (1/2 in)	15.00	-	-	2.22	0.45	0.45	0.45
8	Inside Surface (Still Air)	-	-	-		-	0.68	0.68
						R-VALUES	21.44	19.52
						U-VALUES	0.05	0.05
			OVERALL U-VALUE (=20% * $U_{\text{AT FURRING}}$ + 80% * $U_{\text{BTWN FURRING}}$)				0.05	
				HEAT TRANSFER				
				Interior Temp (°F)	Qatar Design Temperatures		Summer = (°F)	Winter = (°F)
				72			115	43
							Cooling Mode	Heating Mode
				q = UA(ΔT) where:	U =	A =	ΔT_{SUMMER} =	ΔT_{WINTER} =
					0.05	100	43	-29
						q =	**216.31**	**-145.88**
	Specific Thermal Conductivity (W/mK)						k = (Btu)/(h.ft.°F) * 0.1442 = W/mK	
	Adobe	0.96	6.66				k *m0.1442 = x*[W/(mK)]	
	Pisé	0.42	2.91				k = x*[W/(mK)]/.1442	

(ASHRAE, 1997)



Prefabricated Metal Building

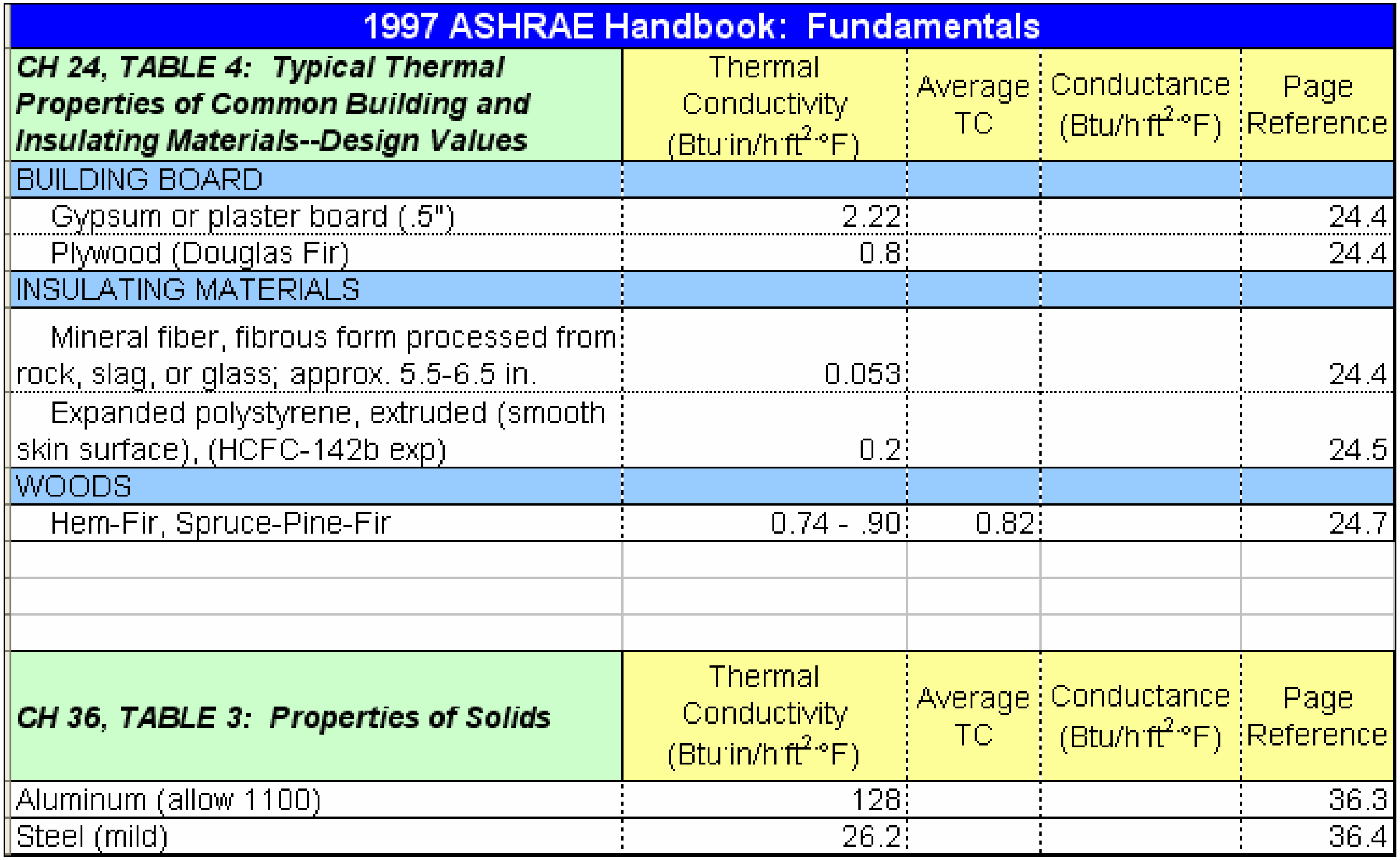
	Wall Component	Thickness mm	Thickness in	Thermal Conductivity (Btu·in/h·ft^2·°F)	Conductance (Btu/h·ft^2·°F)	R-Value (h·ft^2·°F/Btu·in)	R-Value (Btu/h·°F) At Furring	R-Value (Btu/h·°F) Between Furring
1	Outside Air (15 mph)	-	-	-		-	0.17	0.17
2	Aluminum Siding	0.60	0.02	128.00		0.01	0.00	0.00
3	Plywood Backing	4.00	0.16	0.80		1.25	0.20	0.20
4	Rock Wool Insulation	150.00	5.91	-	0.05	18.87	18.87	18.87
6	Furring (Steel Tube)	150.00	5.91	26.20		0.04	0.23	-
7	Sheet Rock	15.00	-	-	2.22	0.45	0.45	0.45
8	Inside Surface (Still Air)	-	-	-		-	0.68	0.68
						R-VALUES	20.59	20.37
						U-VALUES	0.05	0.05

OVERALL U-VALUE (=20% * $U_{AT\ FURRING}$ + 80% * $U_{BTWN\ FURRING}$) 0.05

HEAT TRANSFER

Interior Temp (°F)	Qatar Design Temperatures		Summer = (°F)	Winter = (°F)
72			115	43
			Cooling Mode	Heating Mode
q = UA(ΔT) where:	U =	A =	ΔT_{SUMMER} =	ΔT_{WINTER} =
	0.05	100	43	-29
		q =	**210.68**	**-142.09**

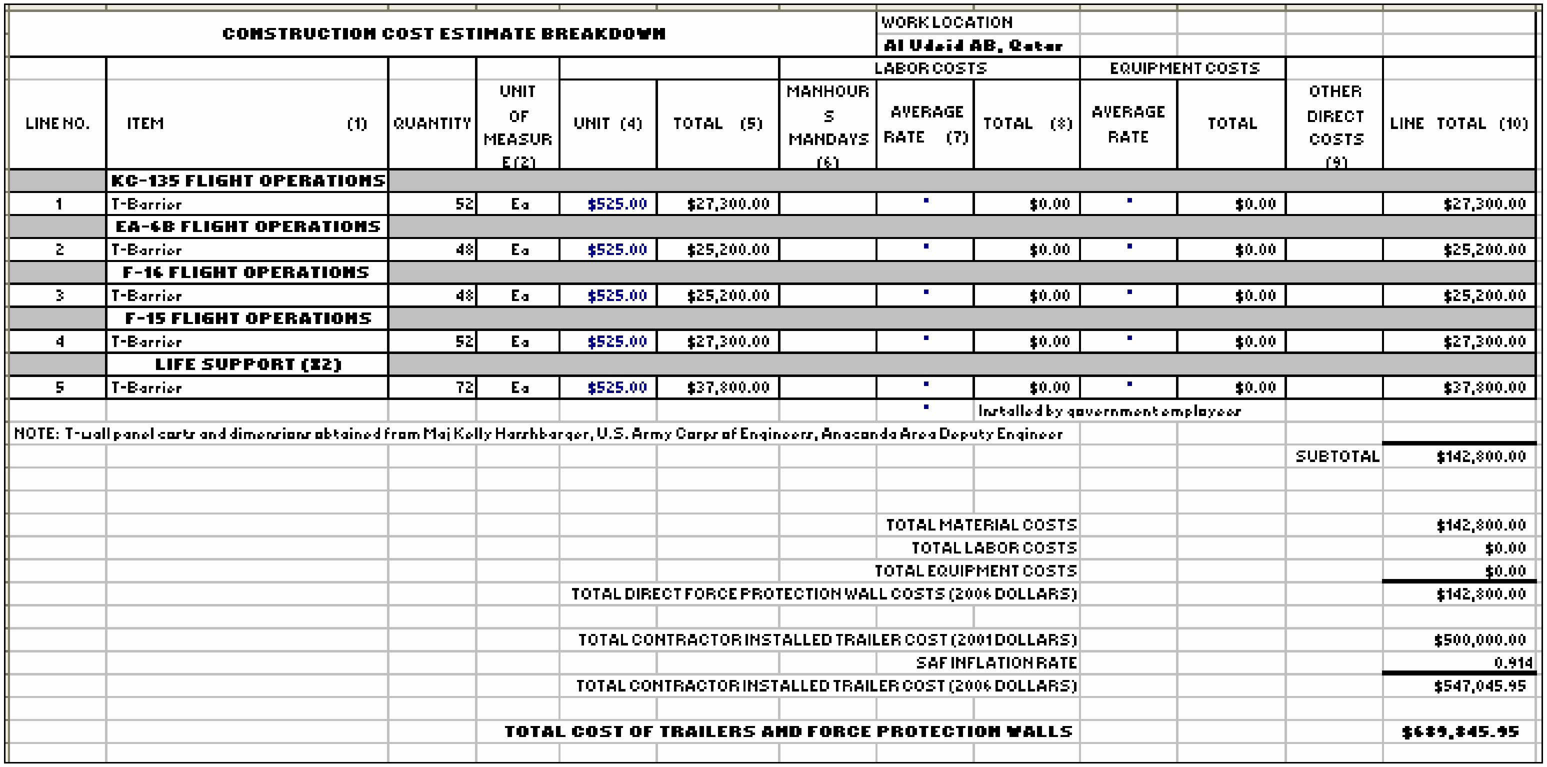
(ASHRAE, 1997)



1997 ASHRAE Handbook: Fundamentals				
CH 24, TABLE 4: Typical Thermal Properties of Common Building and Insulating Materials--Design Values	Thermal Conductivity (Btu·in/h·ft^2·°F)	Average TC	Conductance (Btu/h·ft^2·°F)	Page Reference
BUILDING BOARD				
Gypsum or plaster board (.5")	2.22			24.4
Plywood (Douglas Fir)	0.8			24.4
INSULATING MATERIALS				
Mineral fiber, fibrous form processed from rock, slag, or glass; approx. 5.5-6.5 in.	0.053			24.4
Expanded polystyrene, extruded (smooth skin surface), (HCFC-142b exp)	0.2			24.5
WOODS				
Hem-Fir, Spruce-Pine-Fir	0.74 - .90	0.82		24.7
CH 36, TABLE 3: Properties of Solids	Thermal Conductivity (Btu·in/h·ft^2·°F)	Average TC	Conductance (Btu/h·ft^2·°F)	Page Reference
Aluminum (allow 1100)	128			36.3
Steel (mild)	26.2			36.4

(ASHRAE, 1997)

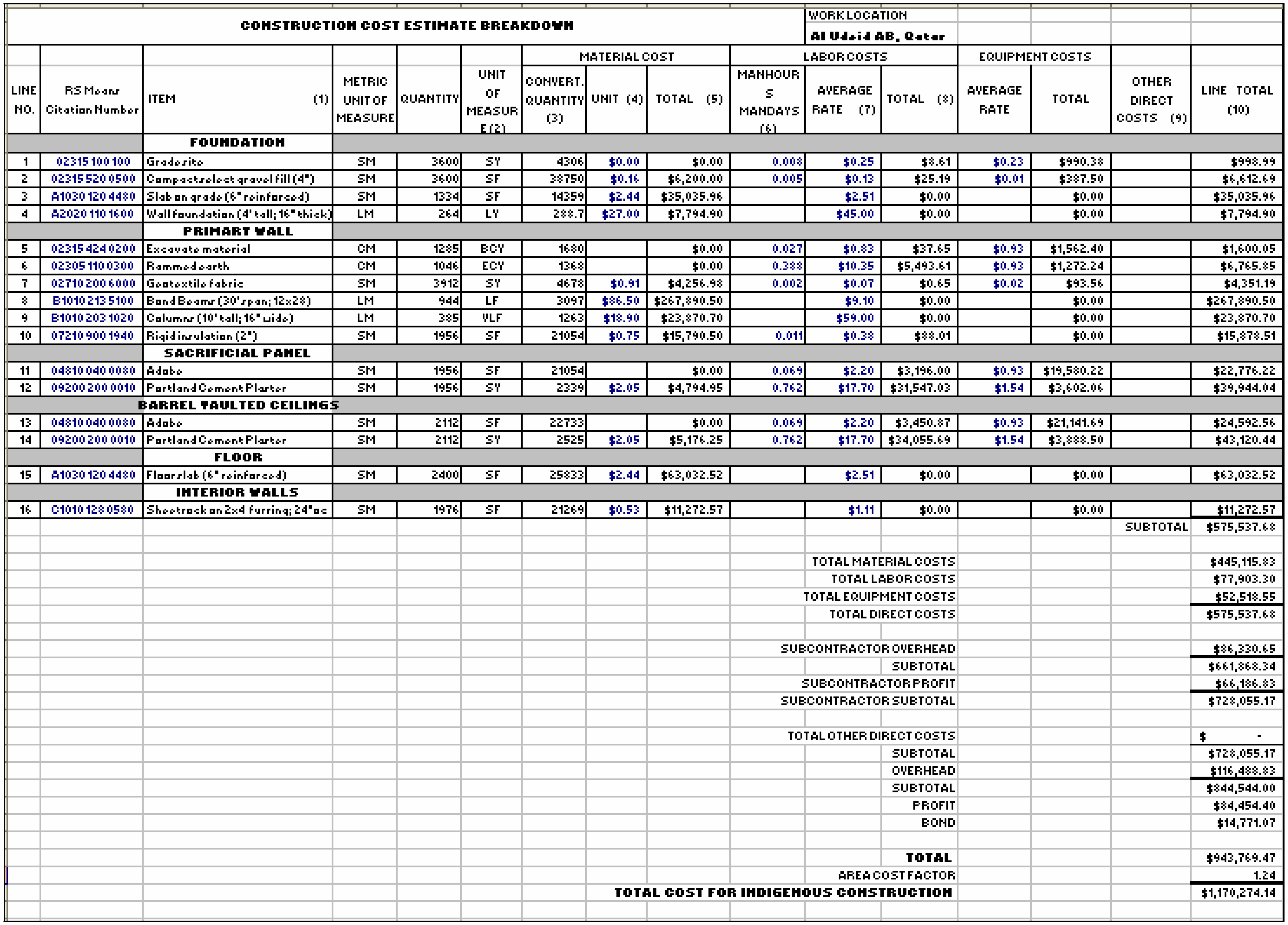
Appendix B



CONSTRUCTION COST ESTIMATE BREAKDOWN							WORK LOCATION					
							Al Udaid AB, Qatar					
						LABOR COSTS			EQUIPMENT COSTS			
LINE NO.	ITEM (1)	QUANTITY	UNIT OF MEASURE (2)	UNIT (4)	TOTAL (5)	MANHOURS MANDAYS (6)	AVERAGE RATE (7)	TOTAL (8)	AVERAGE RATE	TOTAL	OTHER DIRECT COSTS (9)	LINE TOTAL (10)
	KC-135 FLIGHT OPERATIONS											
1	T-Barrier	52	Ea	$525.00	$27,300.00		▪	$0.00	▪	$0.00		$27,300.00
	EA-6B FLIGHT OPERATIONS											
2	T-Barrier	48	Ea	$525.00	$25,200.00		▪	$0.00	▪	$0.00		$25,200.00
	F-16 FLIGHT OPERATIONS											
3	T-Barrier	48	Ea	$525.00	$25,200.00		▪	$0.00	▪	$0.00		$25,200.00
	F-15 FLIGHT OPERATIONS											
4	T-Barrier	52	Ea	$525.00	$27,300.00		▪	$0.00	▪	$0.00		$27,300.00
	LIFE SUPPORT (X2)											
5	T-Barrier	72	Ea	$525.00	$37,800.00		▪	$0.00	▪	$0.00		$37,800.00
							▪	Installed by government employees				
NOTE: T-wall panel costs and dimensions obtained from Maj Kelly Harshbarger, U.S. Army Corps of Engineers, Anaconda Area Deputy Engineer												
											SUBTOTAL	$142,800.00
								TOTAL MATERIAL COSTS				$142,800.00
								TOTAL LABOR COSTS				$0.00
								TOTAL EQUIPMENT COSTS				$0.00
								TOTAL DIRECT FORCE PROTECTION WALL COSTS (2006 DOLLARS)				$142,800.00
								TOTAL CONTRACTOR INSTALLED TRAILER COST (2001 DOLLARS)				$500,000.00
								SAF INFLATION RATE				0.914
								TOTAL CONTRACTOR INSTALLED TRAILER COST (2006 DOLLARS)				$547,045.95
								TOTAL COST OF TRAILERS AND FORCE PROTECTION WALLS				**$689,845.95**

(Harshbarger, 2006)

Appendix B



CONSTRUCTION COST ESTIMATE BREAKDOWN

WORK LOCATION

Al Udeid AB, Qatar

LINE NO.	RS Means Citation Number	ITEM (1)	METRIC UNIT OF MEASURE	QUANTITY	UNIT OF MEASURE (2)	MATERIAL COST			LABOR COSTS			EQUIPMENT COSTS		OTHER DIRECT COSTS (9)	LINE TOTAL (10)
						CONVERT. QUANTITY (3)	UNIT (4)	TOTAL (5)	MANHOURS MANDAYS (6)	AVERAGE RATE (7)	TOTAL (8)	AVERAGE RATE	TOTAL		
		FOUNDATION													
1	02315 100 100	Grade site	SM	3600	SY	4306	$0.00	$0.00	0.008	$0.25	$8.61	$0.23	$990.38		$998.99
2	02315 520 0500	Compact select gravel fill (4")	SM	3600	SF	38750	$0.16	$6,200.00	0.005	$0.13	$25.19	$0.01	$387.50		$6,612.69
3	A1030 120 4480	Slab on grade (6" reinforced)	SM	1334	SF	14359	$2.44	$35,035.96		$2.51	$0.00		$0.00		$35,035.96
4	A2020 110 1600	Wall foundation (4' tall; 16" thick)	LM	264	LY	288.7	$27.00	$7,794.90		$45.00	$0.00		$0.00		$7,794.90
		PRIMARY WALL													
5	02315 424 0200	Excavate material	CM	1285	BCY	1680		$0.00	0.027	$0.83	$37.65	$0.93	$1,562.40		$1,600.05
6	02305 110 0300	Rammed earth	CM	1046	ECY	1368		$0.00	0.388	$10.35	$5,493.61	$0.93	$1,272.24		$6,765.85
7	02710 200 6000	Geotextile fabric	SM	3912	SY	4678	$0.91	$4,256.98	0.002	$0.07	$0.65	$0.02	$93.56		$4,351.19
8	B1010 213 5100	Bond Beams (30' span; 12x28)	LM	944	LF	3097	$86.50	$267,890.50		$9.10	$0.00		$0.00		$267,890.50
9	B1010 203 1020	Columns (10' tall; 16" wide)	LM	385	VLF	1263	$18.90	$23,870.70		$59.00	$0.00		$0.00		$23,870.70
10	07210 900 1940	Rigid insulation (2")	SM	1956	SF	21054	$0.75	$15,790.50	0.011	$0.38	$88.01		$0.00		$15,878.51
		SACRIFICIAL PANEL													
11	04810 040 0080	Adobe	SM	1956	SF	21054		$0.00	0.069	$2.20	$3,196.00	$0.93	$19,580.22		$22,776.22
12	09200 200 0010	Portland Cement Plaster	SM	1956	SY	2339	$2.05	$4,794.95	0.762	$17.70	$31,547.03	$1.54	$3,602.06		$39,944.04
		BARREL VAULTED CEILINGS													
13	04810 040 0080	Adobe	SM	2112	SF	22733		$0.00	0.069	$2.20	$3,450.87	$0.93	$21,141.69		$24,592.56
14	09200 200 0010	Portland Cement Plaster	SM	2112	SY	2525	$2.05	$5,176.25	0.762	$17.70	$34,055.69	$1.54	$3,888.50		$43,120.44
		FLOOR													
15	A1030 120 4480	Floor slab (6" reinforced)	SM	2400	SF	25833	$2.44	$63,032.52		$2.51	$0.00		$0.00		$63,032.52
		INTERIOR WALLS													
16	C1010 128 0580	Sheetrock on 2x4 furring; 24"oc	SM	1976	SF	21269	$0.53	$11,272.57		$1.11	$0.00		$0.00		$11,272.57
														SUBTOTAL	$575,537.68
										TOTAL MATERIAL COSTS					$445,115.83
										TOTAL LABOR COSTS					$77,903.30
										TOTAL EQUIPMENT COSTS					$52,518.55
										TOTAL DIRECT COSTS					$575,537.68
										SUBCONTRACTOR OVERHEAD					$86,330.65
										SUBTOTAL					$661,868.34
										SUBCONTRACTOR PROFIT					$66,186.83
										SUBCONTRACTOR SUBTOTAL					$728,055.17
										TOTAL OTHER DIRECT COSTS					$ -
										SUBTOTAL					$728,055.17
										OVERHEAD					$116,488.83
										SUBTOTAL					$844,544.00
										PROFIT					$84,454.40
										BOND					$14,771.07
										TOTAL					$943,769.47
										AREA COST FACTOR					1.24
										TOTAL COST FOR INDIGENOUS CONSTRUCTION					$1,170,274.14

(Balboni, 2006) and (Waier, 2005)

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VITA

Major Matthew B. Hutchings graduated from Parkview High School in Springfield, Missouri in 1988. He entered undergraduate studies at the University of Kansas in Lawrence where he graduated with a Bachelor of Architecture degree in 1993. He was commissioned through the Detachment 280 AFROTC.

He has had four prior assignments including the 28th Civil Engineer Squadron at Ellsworth AFB, South Dakota; the 354th Civil Engineer Squadron at Eielson AFB, Alaska; the 99th Civil Engineer Squadron at Nellis AFB, Nevada; and the Directorate of the Civil Engineer, Headquarters Air Force Reserve Command at Robins AFB, Georgia. He has deployed to Soto Cano AB, Honduras; Al Jaber AB, Kuwait; and Prince Sultan AB, Saudi Arabia. In 2004, he entered the Graduate School of Engineering and Management at the Air Force Institute of Technology. Upon graduation, he will be assigned to the 13th Space Warning Squadron at Clear AFS, Alaska.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The purpose of this research was to improve the effectiveness of facility design and construction for expeditionary installations in the Middle East. Specifically, this thesis sought to answer three research questions addressing current military construction policies as well as historical design of desert-dwelling cultures, a comparison of current construction assemblies with indigenous design, and synthesis of indigenous design techniques with modern materials, techniques, and requirements. The research questions were answered through a comprehensive literature review, rudimentary quantitative analysis, and architectural design. The research indicated the feasibility of incorporating indigenous design into facility construction on expeditionary installations to improve building performance and force protection.

The culmination of this effort was the development of a schematic design to illustrate how indigenous design principles could be employed to provide a typical administrative facility in answer to real world programmatic requirements.

15. SUBJECT TERMS

Indigenous architecture, rammed earth, thermal mass, natural ventilation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Ellen C. England, Lt Col, USAF (ENV)
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