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An Evaluation of Compressed Work Schedules and Their Impact on Electricity Use

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AN EVALUATION OF COMPRESSED WORK SCHEDULES AND THEIR IMPACT ON ELECTRICITY USE

THESIS

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AFIT/GCA/ENV/10-M01

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Abstract

As the largest energy consumer in the United States, the Department of Defense must consider all fiscally responsible means to improve energy efficiency. Budgetary and environmental concerns are a catalyst for numerous initiatives designed to reduce energy consumption. Congressional mandates outline the rate at which agencies must reduce facility energy use.

In this study, Monte Carlo simulation was used to compare electricity consumption, cost, and emissions produced under 5-day workweeks and compressed work schedules. The research provides energy managers a template for evaluating compressed work schedules as a means to improve energy efficiency.

The study found the relationship between the amount of electricity consumed on duty and non-duty days determines the effectiveness of compressed work schedules in improving energy efficiency. Electricity use in the test facilities on non-duty days was 72 to 90 percent of duty-day consumption. The resulting difference in electricity consumption, cost, and emissions was less than one percent when implementing compressed work schedules.

Compressed work schedules can incrementally improve energy efficiency for facilities with lower levels of electricity consumption on non-duty days. Therefore, energy managers will achieve greater gains in energy efficiency by improving the facilities themselves rather than focusing on the use of the buildings.

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This work is dedicated to my parents who taught me the value of education and to my wife whose understanding and support made this effort possible.

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AN EVALUATION OF COMPRESSED WORK SCHEDULES AND THEIR IMPACT ON ELECTRICITY USE

Chapter I. Introduction

The Department of Defense (DoD) occupies approximately 500,000 buildings and structures on 536 military installations worldwide (Andrew, 2009). The DoD is the single largest energy consumer in the United States as their facility energy usage accounts for approximately 63 percent of the federal total (Andrew, 2009). Annual facility energy spending exceeds $3.4 billion, representing over 13 percent of the Defense-wide operations and maintenance (O&M) budget obligation authority in FY2007 (Andrew, 2009). The portion of O&M funding allocated to energy consumption is even higher when removing the effect of the Global War on Terrorism from the operating budget; in FY2001, this figure equaled 23 percent prior to war-related O&M budget increases (Andrew, 2009). Government officials are motivated by budgetary and environmental concerns to seek ways in which to maximize energy consumption efficiency; all agencies are charged with the responsibility of reducing energy usage and demand.

The United States Air Force is responsible for the largest portion of DoD facility energy consumption at an annual cost of over one billion dollars (USAF, 2008). Air Force facilities are heavily dependent on fossil fuels to produce electricity (Lee, 2009). Efficient energy management is central to the Air Force's ability to combat rising energy costs and preserve taxpayers' dollars in order to support the personnel and weapons systems that allow the Air Force to complete the mission.

In 2007, General T. Michael Mosley signed Program Budget Decision 720, highlighting the extent of the Air Force's funding concerns as 40,000 Active Duty, Guard, Reserve, and civilian positions were eliminated over a three year period ending in FY2008 (Mosley, 2007). With this measure, the Air Force intended to self-finance the recapitalization and modernization of its aircraft, missile, and space inventories (Mosley, 2007). The decision identifies increased fuel costs as one factor leading to an "extremely tight budgetary climate" (Mosley, 2007:3). The Air Force clearly recognizes the efficient allocation of resources as critical to successfully fighting the Global War on Terrorism and navigating a changing global economic environment.

The $1 billion the Air Force allocates to facility energy consumption represents 15 percent of the $7 billion spent annually on energy use (USAF, 2008). Aviation fuel accounts for the greatest energy funding allocation (USAF, 2008). The cost to power Air Force facilities has risen nearly 35 percent from fiscal year 2002 to fiscal year 2007 while consumption has decreased by 11 percent, as seen in Figure 1.

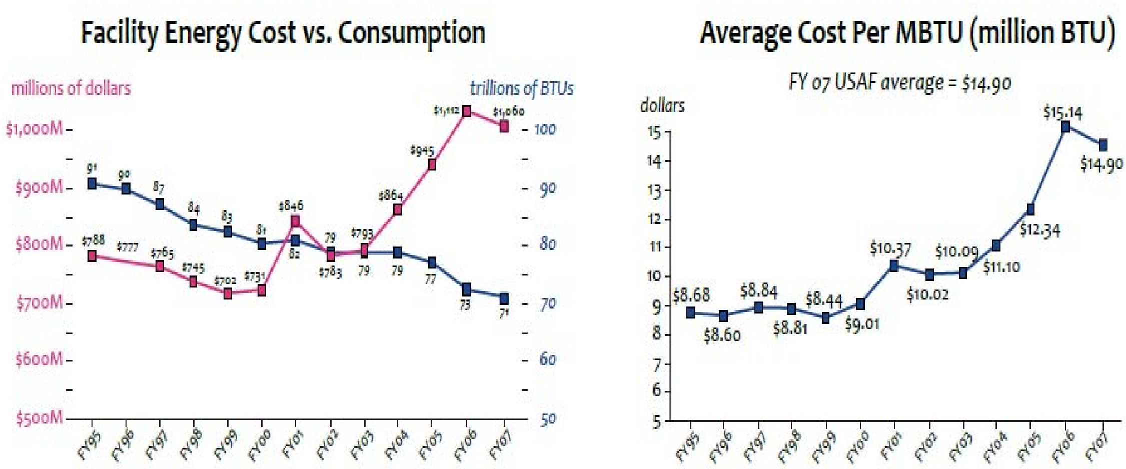


Figure 1. Facility Energy Cost vs. Consumption and Average Cost Per Million British Thermal Units (MBTU) (USAF, 2008)

Air Force facility energy consumption may be a relatively small portion of the DoD budget; however, internal agencies must consider every feasible cost saving measure given the DoD's current funding constraints. The amount of Congressional attention given to federal energy consumption supports this viewpoint. In order to decrease the reliance on fossil fuel driven electricity, the federal government mandated all agencies continue to reduce facility energy consumption per gross square foot by 30 percent by FY 2015 using FY 2003 as the baseline (Congress, 2009). Additionally, the cost of energy combined with the reliance on foreign oil suppliers has been identified as critical to national security in such legislation as the Energy Policy and Conservation Act of 1975 which outlined plans to "reduce vulnerability through several energy efficiency and renewable energy and conservation programs" (AGI, 2009:2). Efficiencies gained in energy consumption allow the DoD to better allocate limited resources to support global interests.

Energy consumption has other peripheral consequences such as the release of harmful emissions into the environment. Power plants produce electricity by burning fossil fuels, resulting in the release of various pollutants such as sulfurous smog, nitrogen oxides, and carbon dioxides (Masters, 1998). Emissions are a source of great concern due to their contribution to "numerous health and environmental issues" (Brown, 2009:10). In an extreme case, air pollution caused 20 deaths and nearly 6,000 illnesses in Donora, Pennsylvania, over a 4-day period in 1948 (Masters, 1998). The impact of harmful emissions, however, is typically less pronounced. In the United States, experts estimate the number of excess deaths attributed to long-term exposure to air pollution to number several tens of thousands each year (Masters, 1998). Furthermore, emissions contribute to respiratory illnesses such as asthma, lung cancer, and decreased lung function (Brown, 2009).

The Clean Air Act demonstrates Congressional recognition of the emissions problem. The Act aims to reduce the impact of activities that contribute to the release of harmful pollutants into the environment, such as the generation of electricity through fossil fuel combustion. By decreasing the amount of electricity consumption, the DoD can effectively minimize the footprint its facilities leave on the surroundings. The Nellis Air Force Base solar photovoltaic system is an example of a governmental energy initiative with a positive environmental impact. By using solar power for a portion of the base energy needs, the Air Force estimates a reduction in carbon dioxide emissions of 24,000 tons annually, which is equivalent to removing 185,000 cars from the roadways (Whitney, 2007).

Budgetary and environmental concerns are a catalyst for numerous initiatives designed to reduce energy consumption, such as the aforementioned Nellis Air Force Base solar photovoltaic system. Improved building design, increased reliance on renewable energy technologies, and the creation of energy management steering groups are examples of incremental solutions to the energy problem. It is clear that there is no single "silver bullet" to reduce energy consumption. Any proposed energy conservation measure is subject to life-cycle cost analysis to ensure that only "projects with 10 year or less simple payback that fit within financial constraints [are] implemented" (IRTC, 2005:170).

Ideally, a proposed energy conservation measure requires little initial investment, produces results consistent with reduction goals, and has widespread applicability.

Federal agencies such as the State Government of Utah have considered compressed work schedules (CWS) as a means to reduce energy consumption by operating facility heating and cooling systems at minimal levels for longer consecutive periods. If effective, compressed work schedules could provide the DoD a low cost means to improve energy efficiency. Past research on CWS programs focus on employee perception of the work arrangement. The Department of Defense would benefit from a study quantifying the impact of compressed work schedules on energy consumption.

Research Objectives and Questions

This research is a quantitative evaluation of the ability of compressed work schedules to improve energy efficiency. This study provides energy managers a cost-driven evaluation of the CWS approach to reducing energy consumption. The results address Department of Defense budgetary and environmental concerns. Specifically, the study answers the following research questions.

1. Can the DoD reduce energy consumption in office facilities by adopting compressed work schedules?

2. Can the DoD reduce the emissions attributed to electricity consumption by adopting compressed work schedules?

3. Can the DoD reduce energy expenditures attributed to office facilities by adopting compressed work schedules?

4. What conditions are necessary to reduce energy consumption by adopting compressed work schedules?

Research Approach and Methodology

To accomplish the research objectives, this study adopts a four-part approach. First, two buildings located at Wright-Patterson Air Force Base (WPAFB) are selected as test facilities. Adjustments are made to metered electricity consumption data from the existing 5-day workweek schedules to reflect energy use with a 4-day compressed work schedule. Through Monte Carlo simulation, probabilistic models of electricity consumption are developed to compare energy use with various scheduling alternatives. The models account for random fluctuations in electricity consumption due to factors such as weather conditions and building occupation. Second, emission factors are applied to the consumption simulations to determine the effect schedule selection has on the environmental impact of DoD facilities. Third, cost factors for electricity use are used to determine the economic effects of various scheduling arrangements. Finally, through sensitivity analysis, the conditions necessary to reduce energy consumption by adopting compressed work schedules are identified.

Scope of the Research

Facilities occupied by office personnel working a traditional 5-day, 40-hour workweek are the most likely candidates to gain energy consumption efficiencies by adopting a compressed work schedule. Many DoD facilities, such as military hospitals, cannot alter existing schedules as they support missions requiring 24-hour operations. Therefore, this study will focus on DoD office buildings using the WPAFB test facilities as a case study.

DoD facility energy consumption consists of various sources to include electricity, natural gas, fuel oil, purchased steam, coal, and propane. The lack of metered facility energy data available limits this research as military installations commonly measure energy consumption at the installation level. The National Energy Conservation Policy Act requires all federal buildings to implement individual facility electricity metering by 2012 and natural gas and steam metering by 2016 (Congress, 2009). Facility electricity metering currently exists in limited quantities; this research will therefore focus on this single source of energy. Electricity is the most commonly used energy source and accounts for the greatest cost. In FY2007, electricity accounted for 48 percent of the Air Force energy requirement and nearly 67 percent of the energy budget as depicted in Figure 2.

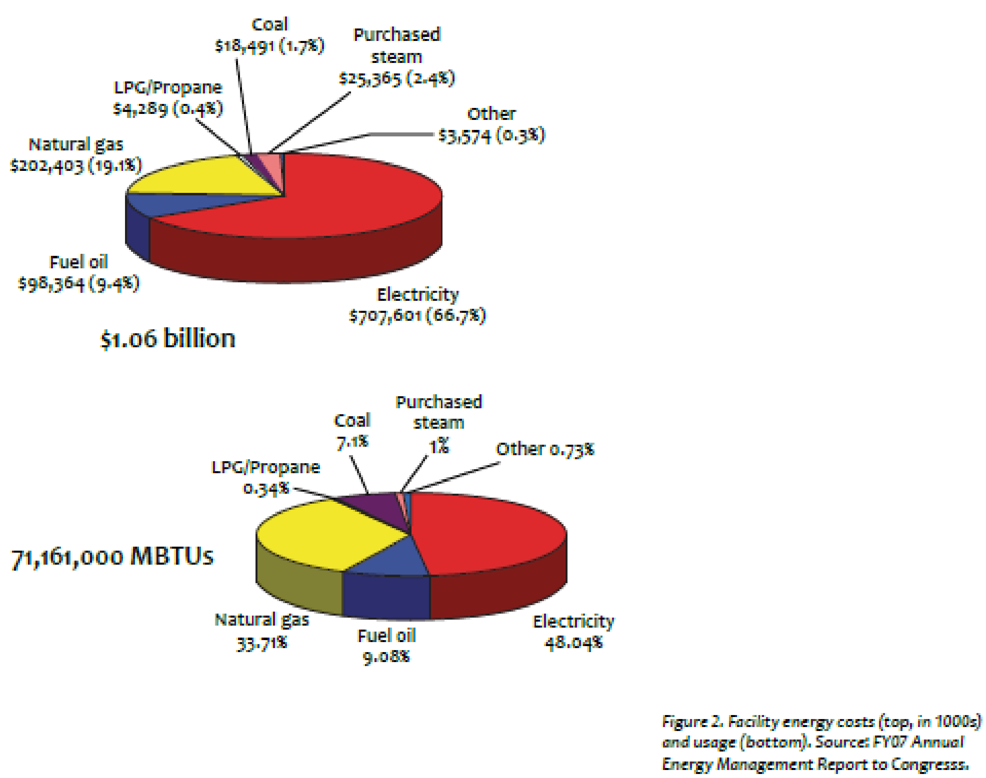


Figure 2. Facility Energy Use and Cost by Source (USAF, 2008)

Significance of the Study

The decision to alter an employee's existing schedule is one with many consequences. Installation commanders must consider the welfare of base personnel, the impact on the mission, compliance with established directives, and the financial implications associated with a scheduling change. It is incumbent upon base leadership to assess qualitatively the personnel and mission ramifications of deviating from the status quo. This study aims to aid the decision-maker by addressing the energy consumption mandates and financial consequences associated with scheduling decisions.

The research identifies the implementation of compressed work schedules as a potential means to improving energy efficiency. Compressed work schedules effectively reduce electricity consumption, emissions, and energy costs for office facilities under certain circumstances. Defining the conditions under which compressed work schedule will prove beneficial to the Department of Defense, thus empowering decision-makers to make a more informed judgment.

Thesis Overview

Chapter II provides a literature review presenting a summary of legislation pertaining to energy use and employee scheduling, discussion of various alternative work schedules, examples of CWS implementation, the evaluation of previous research, details regarding electricity consumption and cost, and an introduction to Monte Carlo simulation. Chapter III provides an overview of the methodology used to evaluate the ability of compressed work schedules to reduce Department of Defense energy consumption. Chapter IV presents the results from the simulation and sensitivity analysis. Finally, Chapter IV discusses the benefits of the study, limitations of the research, and areas for future research.

Chapter II. Literature Review

This chapter discusses the factors that have led numerous organizations to consider compressed work schedules as a means to meet energy usage goals and reduce O&M spending. The literature review establishes a baseline for the research by analyzing information from numerous sources. This chapter includes a summary of legislation pertaining to energy use and employee scheduling, discussion of various alternative work schedules, examples of compressed work schedule implementation, evaluation of previous research, details regarding facility electricity consumption and cost, and an introduction to Monte Carlo simulation.

Related Legislation

For nearly four decades, energy consumption has been at the forefront of Congressional and Executive legislation. In 1973, the United States chartered the Federal Energy Management Program (FEMP) to "reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites" (DOE, 2002:1). The FEMP continues to shape national energy-related legislation and conservation efforts. Mandatory energy performance standards for facilities are now a staple of the Federal Energy Management Program; the current energy reduction goals are detailed later in the chapter. The Executive Branch has also expressed interest in promoting work arrangements that are potentially beneficial to employees, such as compressed work schedules. The federal government must consider the merits of work scheduling changes that prove advantageous to employees and simultaneously improve energy efficiency. In this section, legislation pertaining to energy consumption and a memorandum regarding alternative work schedules is discussed.

Energy Policy and Conservation Act

In 1975, Congress passed the Energy Policy and Conservation Act (EPCA) following the Arab oil embargos (AGI, 2009). The main goal of the EPCA was to improve national security by reducing U.S. dependence on foreign oil suppliers. The EPCA commenced U.S. involvement in the International Energy Agency and mandated the creation of the Strategic Petroleum Reserve. The Act also outlined plans to “reduce vulnerability through several energy efficiency and renewable energy and conservation programs” (AGI, 2009:2). While not primarily designed to address facility energy consumption, the EPCA represents an important step in government involvement in energy usage.

National Energy Conservation Policy Act and Amendments

In 1978, Congress signed the National Energy Conservation Policy Act (NECPA) directing the Department of Energy to establish minimum energy performance standards for government facilities, which was previously a voluntary provision under the EPCA (Kubiszewski, 2008). The NECPA allocated $100 million for the retrofitting of federal and private buildings to improve energy efficiency (Kubiszewski, 2008). The NECPA displays the federal government’s dedication to responsible energy policy; subsequent amendments to the act enhance the impact of the legislation.

The first notable amendment is contained in the Deficit Reduction Act of 1985. This Act authorized agencies to enter into energy savings contracts of up to 25 years (Andrew, 2009), an important step in government collaboration with industry to reduce energy consumption. The Energy Policy Act (EPACT) of 1992 further defined energy reduction arrangements as Energy Savings Performance Contracts (ESPCs). The EPACT allowed agencies to enter ESPCs designed to improve energy efficiency in aging buildings and facilities with the stipulation that a given contract does not exceed 25 years and the resulting savings outweigh the investment (Andrew, 2009). Congress further strengthened the NECPA, requiring agencies to report annual energy consumption data for facilities. In 1988, the Federal Energy Management Performance Act amended the NECPA by requiring agencies to reduce facility energy consumption per gross square foot by 10 percent by FY1995 using FY1985 as the baseline (Andrew, 2009).

Recent Legislation

The United States continues to build on previous energy related legislation. Executive Orders and Acts signed under the William Jefferson Clinton and George Walker Bush administrations shape the nation's current efforts to improve energy efficiency. While the documents do not specifically address alternative work schedules, it is clear that any fiscally responsible initiative reducing energy consumption complies with the intent of the legislation.

Executive Order 13123

President Clinton signed Executive Order (EO) 13123, Greening the Government through Efficient Energy Management, on 3 June 1999. EO 13123 directed the federal government to provide the nation leadership by "significantly improving its energy management in order to save taxpayer dollars and reduce emissions that contribute to air pollution and global climate change" (Clinton, 1999:30851). The EO specifically mandated the installation of 20,000 solar energy systems at federal facilities by 2010 (Clinton, 1999).

President Clinton underscored the importance of EO 13123 by mandating agencies to submit annual reports; the President also encouraged organizations to submit budget requests to foster the implementation of energy-efficient initiatives. The annual scorecard provided the agencies a tool to evaluate the efficiency of their organization, a means of tracking progress toward the 2010 goals, and a basis for increasing funding levels for "green" initiatives. EO 13123 mainly focused on renewable energy as a means to achieve energy reduction goals and as an instrument in cost reduction (Clinton, 1999).

Energy Policy Act of 2005

In 2005, Congress signed the Energy Policy Act (EPACT). EPACT 2005 directed agencies to "develop, update, and implement a cost-effective energy conservation and management plan for all facilities administered by Congress to meet the energy performance requirements for Federal buildings" (Congress, 2005:605). EPACT 2005 amended the NECPA by requiring agencies to reduce facility energy consumption per gross square foot by 20 percent by FY2015 using FY2003 as the baseline (Congress, 2005). Table 1 displays the annual reduction requirements.

Table 1. Facility Energy Consumption Requirements of EPACT 2005 (Congress, 2005)

Fiscal Year	Percentage Reduction
2006	2
2007	4
2008	6
2009	8
2010	10
2011	12
2012	14
2013	16
2014	18
2015	20

EPACT 2005 also set requirements for increased electricity measurement and accountability by directing the installation of advanced meters in federal buildings by 1 October 2012 (Congress, 2005). This mandate provides energy mangers a means to obtain the detailed information necessary to improve electricity consumption efficiency. The individual metering of facilities is essential to compressed work schedule research, as this study attempts to quantify electricity usage only on appropriate buildings.

Energy Independence and Security Act of 2007

In 2007, Congress signed the Energy Independence and Security Act (EISA). The EISA amended the NECPA with more aggressive energy reduction goals for federal buildings, requiring agencies to reduce facility energy consumption per gross square foot by 30 percent by FY2015 using FY2005 as the baseline (Congress, 2007). The annual reduction requirements detailed in Table 2 represent the current figures energy managers are striving to achieve.

Table 2. Current Facility Energy Consumption Requirements (Congress, 2009)

Fiscal Year	Percentage Reduction
2006	2
2007	4
2008	9
2009	12
2010	15
2011	18
2012	21
2013	24
2014	27
2015	30

Current National Energy Conservation Policy Act

The NECPA is the driving force in the reduction of federal energy consumption. The most recent update to the NECPA occurred in January of 2008 with the following Congressional findings.

> (1) The Federal Government is the largest single energy consumer in the Nation;
>
> (2) the cost of meeting the Federal Government's energy requirement is substantial;
>
> (3) there are significant opportunities in the Federal Government to conserve and make more efficient use of energy through improved operations and maintenance, the use of new energy efficient technologies, and the application and achievement of energy efficient design and construction;
>
> (4) Federal energy conservation measures can be financed at little or no cost to the Federal Government by using private investment capital made available through contracts authorized by subchapter VII of this chapter [Chapter 91]; and
>
> (5) an increase in energy efficiency by the Federal Government would benefit the Nation by reducing the cost of government, reducing national dependence on foreign energy resources, and demonstrating the benefits of greater energy efficiency to the Nation. (Congress, 2009:2)

The NECPA acknowledges the extensive costs associated with the federal government’s energy usage and the national importance of improving energy efficiency. The NECPA provides organizations the ability to dictate the way in which the agencies will realize energy consumption mandates. The act includes discussion of potential solutions such as energy and water conservation measures in buildings, participation in the Environmental Protection Agency's "Green Lights" program, metering of energy use, and the designation of facility energy managers.

Expanding Family Friendly Work Arrangements in the Executive Branch

In 1994, President Clinton signed the Memorandum on Expanding Family-Friendly Work Arrangements in the Executive Branch. The document encourages federal agencies to offer employees "flexible family-friendly work arrangements, including: job sharing, career part-time employment, alternative work schedules, telecommuting and satellite work locations" (Clinton, 1994:1). The memorandum presents the belief that "broad use of flexible work arrangements to enable Federal employees to better balance their work and family responsibilities can increase employee effectiveness and job satisfaction , while decreasing turnover rates and absenteeism" (Clinton, 1994:1). The document gives clear support for alternative work schedule (AWS) programs based on the potential to positively affect employees. Significant reduction in energy usage with compressed work schedule implementation would certainly only strengthen the Presidential support. The following section discusses the scheduling options available to installation commanders.

Discussion of Alternative Work Schedules

Alternative work schedules (AWS) are present in any organization that allows its employees to work a schedule other than the traditional 8-hour day, 5-day workweek.

AWS options include flexible schedules and compressed work schedules; with all alternatives, full-time employees are required to work 80 hours in a bi-weekly period. This section discusses the various AWS options as defined by the Office of Personnel Management (OPM) and identifies the compressed work schedule (CWS) as the only viable consideration for energy usage analysis.

Flexible Schedules

The OPM identifies five flexible schedule models that allow for variation in the scheduling of employee work hours within established limits. Flexible schedules may allow individual employees to work less than 5 days per week, but still require personnel to occupy the office Monday through Friday. For this reason, flexible schedules are not the desired option when considering potential energy usage savings. The five flexible options are flexitour, gliding, maxiflex, variable day, and variable week schedules.

Flexitour options allow employees to select a starting and stopping time within the established flexible hours (GAO, 2004). Each employee performs the selected schedule for a pre-determined amount of time. For example, an organization may establish core hours of 1000 to 1500. Employees have the option of establishing arrival as early as 0630 hours and departure as late as 1830 hours, assuming a 30-minute lunch. An employee electing to work from 0630 to 1500 will do so until management authorizes the employee to alter the individual schedule.

The gliding schedule option is similar to flexitour in that employees can vary individual arrival and departure times around established core hours. Under gliding schedules, employees are not constrained to predetermined arrival and departure times as each individual works 8 hours in a given day (GAO, 2004). The gliding schedule option allows employees increased flexibility.

The maxiflex schedule establishes core hours for less than 10 days in a bi-weekly period, allowing employees to vary the number of days they work while maintaining 80 hours each period (GAO, 2004). The maxiflex arrangement provides scheduling flexibility, but does not establish uniform non-duty days. Employees have the option of working 5 days per week if desired.

The variable day schedule allows employees to adjust individual arrival and departure times around core hours as long as the individual works 40 hours in each week of the bi-weekly period. Employees can vary the number of hours worked in a given day within established limits (GAO, 2004). For example, an organization may establish core hours of 1000 to 1500 and stipulate that no individual work more than 10 hours in a given day. An employee may choose to work 5 hours on Monday, 10 hours per day Tuesday through Thursday, and 5 hours on Friday to complete the 40-hour workweek.

The variable week schedule allows employees to adjust individual arrival and departure times around core hours as long as the employee works 80 hours in each bi-weekly period. Unlike the variable day schedule, employees have the option of working less than 40 hours in one week of the bi-weekly period. Employees can vary the number of hours worked in a given day within established limits (GAO, 2004).

Compressed Work Schedules

Compressed work schedules mandate that employees work less than 10 days in each bi-weekly period. A CWS can resemble flexible work schedule options, but differ by establishing uniform non-duty day(s). This research is based on the implementation of the CWS. The most commonly accepted CWS structures are the 4-day workweek and the 5-4/9 plan (explained below); 3-day workweeks are possible, but are not common enough for consideration in this research. CWS programs are the only viable option for energy savings because of the non-duty day(s) they provide.

The 4-day workweek requires all employees to work 10-hour days with three non-duty days each 7-day week of the bi-weekly pay period. For this research, Monday through Thursday workweeks were assumed under the 4-day workweek schedule. The 5-4/9 plan requires employees to work eight 9-hour days and one 8-hour day in a bi-weekly period. For this research, a 5-4/9 schedule in a given bi-weekly period is assumed to consist of 9-hour days Monday through Thursday of week one, an 8-hour workday on Friday of week one, 9-hour days Monday through Thursday of week two, and a non-workday on Friday of week two.

Examples of Compressed Work Schedule Implementation

Air Force Implementation

The use of alternative work schedules is not a new concept across the Air Force and other government agencies. Hill AFB experimented with a CWS in 1991; base leadership modified the practice to flexible scheduling in 1995 because of negative reactions from customers who felt the non-work days were detrimental to the level of service provided. Tinker AFB implemented a CWS for a portion of base personnel in October of 2009; however, since units working under traditional and flexible schedules share the facility, significant energy savings are not expected.

Keesler AFB currently operates under a 5-4/9 CWS originally employed in 1995. The Wing Commander requested the Air Force Audit Agency conduct a review of the

CWS in 2009. The audit indicates that Keesler AFB failed to realize the estimated utility related savings; however, other efficiencies due to the scheduling change exist. In 2007, the cost savings totaled an estimated $47 thousand, 39 percent of the anticipated $121 thousand value (AFAA, 2009). The audit states the following:

> AETC personnel overestimated utility savings by assuming consumption would be significantly reduced on non-work days by turning down air conditioners and shutting off lights. However, forecasters did not account for factors such as mold growth in buildings and mission essential personnel working the 'down Friday,' requiring buildings to remain fully air-conditioned. (AFAA, 2009:3)

A portion of Keesler AFB units abandoned the CWS in favor of a traditional 8-hour a day, 5-day a week work schedule. It is clear that units wishing to implement a CWS must balance customer needs and peripheral concerns with potential energy and cost savings. Widespread acceptance of CWS is difficult, as a culture change must occur to realize the full magnitude of potential savings.

Utah State Government Implementation

The State of Utah implemented a 4-day workweek for 80 percent of its state employees in August of 2008 with mixed-results; the CWS involves 17,000 employees who occupy 1,000 buildings across the state (Copeland, 2009). Utah realized a 10 percent reduction in energy consumption, translating to approximately $500,000 in cost savings by declaring every Friday a non-work day (Gehrke, 2009a). Increased levels of energy awareness contribute to the savings as employees turn off utilities when not in use (Kessler, 2009). The governor's office originally projected $3 million in cost savings; however, gas prices and utility rates unexpectedly decreased in 2008 (Gehrke, 2009a).

The State of Utah will continue to utilize compressed work schedules for the majority of its state employees; however, the Department of Motor Vehicles will open for

11 hours on Fridays, citing decreased customer service. Officials estimate this change will cost the state $500,000 and negate the cost savings experienced in 2008 (Gehrke, 2009b). The need to balance energy efficiency with customer service is a common theme for organizations considering compressed work schedules.

Utah energy managers hope the CWS will help the state reach its goal of a 20 percent reduction in energy use by 2015 (Copeland, 2009). States such as Florida, South Carolina, Wisconsin, Illinois, Michigan, and New York are considering similar CWS implementation in order to realize comparable savings (Copeland, 2009). It is unclear if these states will reconsider a scheduling change having seen the Utah results.

Previous Research

Previous research regarding alternative work schedule implementation focuses on employee performance and well-being rather than associated energy usage savings. Researchers have evaluated categories such as job satisfaction, organizational performance, work-family conflict, and reductions in time away from work through surveys and regression analysis. The majority of studies found AWS to have a positive impact in the eyes of employees regarding the aforementioned categories. However, employees report increased difficulties regarding fatigue, meeting customer needs, and meeting with co-workers as problematic under AWS arrangements. Therefore, organizations considering CWS implementation must weigh these factors in the decision-making process. However, the body of survey-driven research is non-conclusive and should not be generalized to organizations across the Air Force.

This section contains a review of previous studies to develop a general understanding of personnel concerns involved in the implementation of AWS programs.

However, this study will focus only on potential energy savings associated with CWS in the research. It is important to note that survey-driven studies measure individual perceptions of scheduling effects on the various categories, and therefore may not adequately reflect changes in performance due to a scheduling change.

Defense Manpower Data Center Study

In April of 1997, the Defense Manpower Data Center issued Report Number 96-017, Survey on Alternative Work Schedules in the Office of the Under Secretary of Defense for Personnel and Readiness. The study allowed Personnel and Readiness (P&R) employees to adopt flexible or compressed work schedules in order to evaluate the impact on employee satisfaction, organizational performance, reduction in time away from work, and the potential disadvantages of the AWS. The researchers used electronic surveys for the data collection. “Based on respondents’ reports, 33.7 percent of P&R personnel were participating in the AWS program. Less than 22 percent of eligible respondents chose not to participate, and 44.4 percent of individuals were not allowed to participate” (DMDC, 1997:iii).

The researchers identified the need for the study stating that the majority of previous research had “been completed in the private sector and there is little research related to personal preference in government AWS programs” (DMDC, 1997:4). The study reported that the AWS had a positive impact on employee satisfaction as “88 percent of AWS participants reported that the effect on morale was favorable. In addition, over 90 percent of the managers reported that the program had a favorable effect on their subordinates’ morale” (DMDC, 1997:67). The study reported AWS having a slight positive impact on organizational performance as “nearly 58 percent of managers reported that the effect of AWS on their subordinates' job performance was either favorable or very favorable" (DMDC, 1997:68). The report highlighted office communication and employee availability for meetings as the major internal disadvantages of the AWS program. The study reported a reduction in time away from work as "AWS participants reported that sick leave (46.5 percent of AWS participants), annual leave (42 percent), other leave (23 percent), and overtime use (14.3 percent) decreased as a result of the AWS program" (DMDC, 1997:69). It is important to note, and is conceded in the report, that the results were based on employee responses and therefore reflect individual perceptions of the measured categories.

Review of Public Personnel Administration Study

Facer and Wadsworth (2008) studied city government employees from a small growing community in the west. The focus of the research was on work-family balance, workweek experience, and job satisfaction. The authors compare the survey results of employees working a 4-10 CWS against employees working a traditional 8-hour per day, 5-day workweek. Individuals provided responses on a 1 to 5 Likert-type scale.

The authors constructed the work-family balance questions based on role conflict theory, which, according to a 1964 Kahn et al. study, "suggests that participation in one role makes it difficult to participate simultaneously in an additional role because of the potentially conflicting expectations from these different roles" (Facer and Wadsworth, 2008:167). The authors concluded that the CWS employees have lower levels of work-family conflict than those employees working a traditional schedule. Statistical significance was evident in four of the six related survey items. The authors referred to a 1997 Glass and Estes study which suggested that work-family conflict influences employee perception of productivity and job satisfaction and “high levels of work-family conflict are related to decreased productivity, absenteeism, and turnover” (Facer and Wadsworth, 2008:175).

The authors determined that the overall workweek experience was greater with the CWS. The CWS arrangement ranked higher in all categories surveyed to include the following: productivity, experiencing inefficiencies, access to childcare, and citizen access (the authors do not provide a formal definition for this category). The authors determined that overall job satisfaction is higher with the CWS. The items for this portion of the survey included the following: satisfied with job, intend to look for another job, satisfied with pay and benefits, and I like working for the city. Only the last line item was determined to be statistically significant.

Journal of Applied Psychology Study

Goodale and Aagaard (1975) surveyed a large multinational accounting corporation consisting predominately of older, white-collar workers. The corporation employed a 4-day, 38-hour work schedule with rotating days off for individual employees. “This meant that an employee had a different day off each week with the days off following in sequence over a 5-week cycle” (Goodale and Aagaard, 1975:34). Their research was similar to the aforementioned studies as 70 percent of employees reported a favorable view of the flexible schedule.

The researchers reported negative findings to include increased worker fatigue, difficulties in meeting customers’ needs, and problems in meeting with co-workers with the AWS. The population of the survey was 474 employees; the researchers identified the sub-groups examined as adequate for meaningful comparisons. Age is reported to factor into the perception of the AWS with younger workers (25 to 34 years and under 25 years) responding more favorably to the schedule (Goodale and Aagaard, 1975). Position in the company played a role in the response as 53 percent of the 40 supervisors felt the flexible schedule had a detrimental effect on their work area; only 13.9 percent of supervisors were able to take their day off regularly (Goodale and Aagaard, 1975). However, the researchers found no significant fluctuations in company productivity measures. The researchers conclude,

> Such a work schedule seems questionable in a setting where (a) employees must meet and work in groups, (b) customer service is provided 5 days a week, (c) supervisors feel the need to be available during all work hours, and (d) a majority of employees are relatively old. (Goodale and Aagaard, 1975:38)

Canadian Psychology Journal Study

Armstrong-Stassen (1998) studied alternative work arrangements and their effect on the Canadian workforce. The author draws similar conclusions to the previously mentioned studies. Compressed work schedules are identified as having a positive effect on employees, particularly in the categories of personal life and leisure. The author reports mixed results for overall job satisfaction.

Unlike the Goodale and Aagaard (1975) study, increased customer service was identified as a benefit of compressed work schedules. The author suggested that compressed work schedules are not appropriate in all circumstances as, “Jobs that are highly stressful or require a high level of vigilance may be unsuitable for 10-hour or 12-hour work days because of fatigue and the potential of increased injuries and accidents” (Armstrong-Stassen, 1998:116).

Previous Research Conclusion

Previous research on alternative work schedules reveals the difficulties that decision-makers face when selecting a scheduling arrangement. Employee perception of alternative work schedules is primarily favorable; however, complications do exist. Research regarding categories such as organizational performance and customer satisfaction proved to be inconclusive. For the Department of Defense, compressed work schedules must be evaluated with careful consideration of the effects on personnel and the mission. Therefore, it is incumbent on installation commanders and lower-levels of management to rely on personal judgment before the implementation of a compressed work schedule. The following sections address the quantitative aspect of scheduling decisions.

Electricity Consumption

To effectively manage an energy conservation program, the Institute of Electrical and Electronics Engineers (IEEE) states that it is necessary to "establish the existing pattern of electrical usage and to identify those areas where energy consumption could be reduced" (IEEE, 1991:725). This section details the devices that drive the consumption of electricity in office facilities. The utilization rate and inherent efficiency of a given device determines the energy needed to support the device, referred to as the load. Naturally, energy managers reduce the consumption of electricity by either using a device less or using devices that are more efficient; compressed work schedules aim to achieve the former. The typical load groups and examples of classes of electrical equipment, as defined by the IEEE, are listed below.

(1) Lighting: Interior (general, task, exists, and stairwells), exterior (decorative, parking lot, security), normal, and emergency

(2) Appliances: Business and copying machines, receptacles for vending machines, and general use

(3) Space Conditioning: Heating, cooling, cleaning, pumping, and air-handling units

(4) Plumbing and Sanitation: Water pumps, hot water heaters, sump and sewage pumps, incinerators, and waste handling

(5) Fire Protection: Fire detection, alarms, and pumps

(6) Transportation: Elevators, dumbwaiters, conveyors, escalators, and moving walkways

(7) Data Processing: Desktop computers, central processing and peripheral equipment, and uninterruptable power supply (UPS) systems, including related cooling

(8) Food Preparation: Cooling, cooking, special exhausts, dishwashing, disposing, etc. [Not Applicable for this study]

(9) Special Loads: For equipment and facilities in mercantile buildings, restaurants, theaters, recreation and sports complexes, religious buildings, terminals and airports, health care facilities, laboratories, broadcasting stations, etc. [Not Applicable for this study]

(10) Miscellaneous Loads: Security, central control systems, communications, audio-visual, snow melting, recreational or fitness equipment, incinerators, shredding devices, waste compactors, shop or maintenance equipment, etc. (IEEE, 1991:75)

According to data collected by the United States Energy Information Administration (EIA), nearly 70 percent of electricity consumption in commercial buildings results from lighting and space conditioning (EIA, 2008). The EIA obtained this data in a 2003 study combining data collected in the Commercial Buildings Energy Consumption Survey and building energy simulations provided by the Facility Energy Decision Screening system. It is important to note that the IEEE categorizes office facilities as commercial buildings (IEEE, 1991). Figure 3 depicts the total electricity consumption by use in commercial buildings.

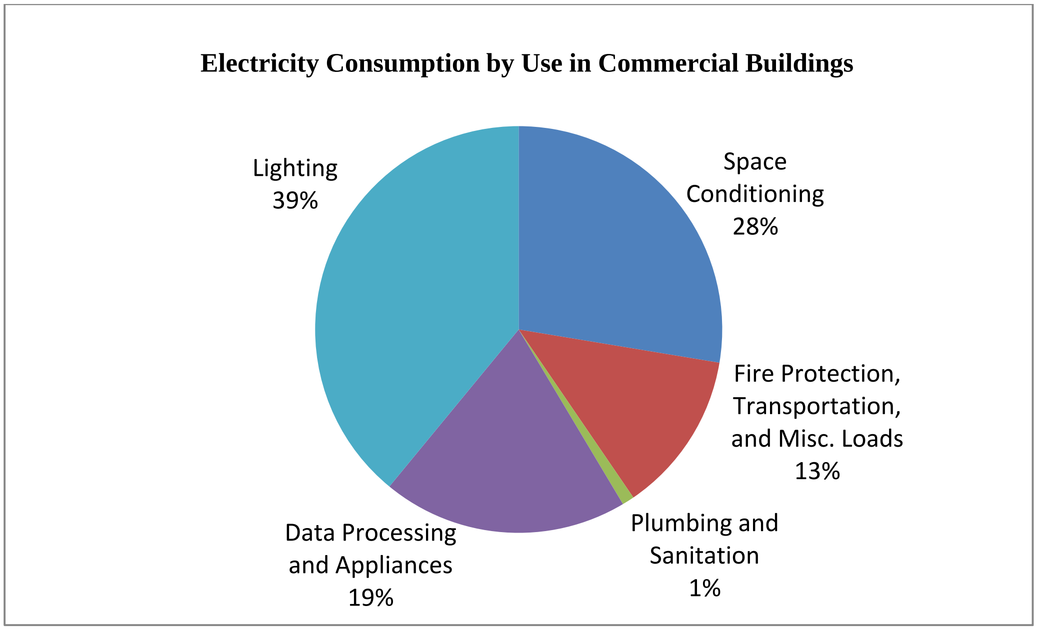


Figure 3. Total Electricity Consumption by Use in Commercial Buildings (EIA, 2008)

Energy managers can reduce facility electricity consumption by addressing the given building's load profile, which is defined as "the graphic representation of the demand load, usually on an hourly basis, for a particular day" (IEEE, 1991:67). Naturally, the aforementioned electrical utilization devices consume the most energy during business hours when personnel occupy a given building. Figure 4 displays a generic load profile for an office building. Electricity consumption is relatively low outside of the normal operation hours. Energy managers activate systems in the morning to prepare the building for occupancy, thereby increasing energy consumption. The use of electricity remains relatively constant throughout the business hours. Another transition period occurs at the end of the day as operations cease, returning the building to its non-duty load profile.

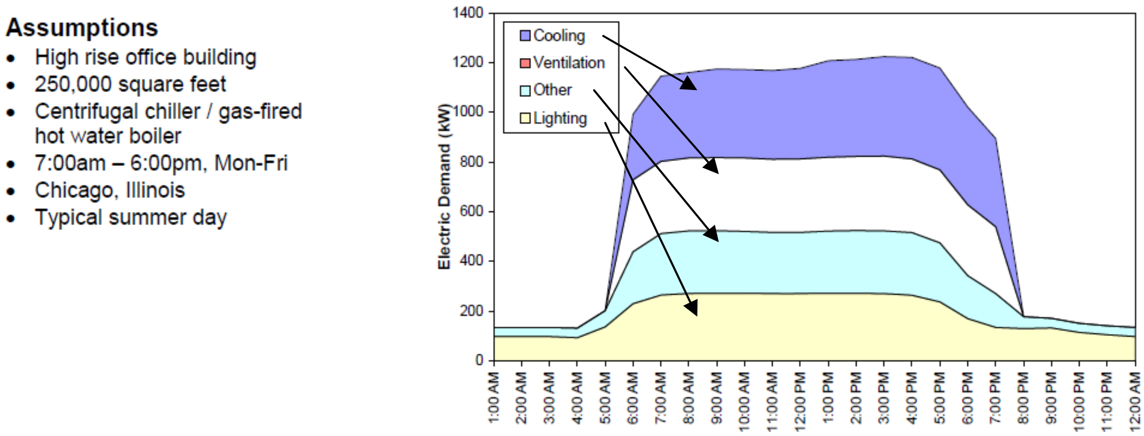


Figure 4. Generic Office Building Load Profile (EIA, 2008)

Compressed work schedules provide the capability to alter a building's load profile, thus affecting energy consumption. By adopting a compressed work schedule, Monday through Thursday electricity consumption will escalate due to the increased duration of the business day. Electricity consumption on Friday will decrease to the Saturday and Sunday non-business day levels. If the energy savings achieved on the Friday non-business day outweigh the increased levels generated Monday through Thursday, the total electricity requirement for the facility is reduced.

Electricity Cost

In the previous section, the relationship between facility load profiles and energy consumption is discussed. It is important to note that energy providers base the cost of electricity on use (consumption) and the rate of use (demand), often referred to as peak demand charges (Holtz, 1990). For WPAFB, peak demand is calculated based on the highest level of electricity consumption (kW) in a 30-minute period for a given month.

More than 80 percent of utility rate schedules within the United States and nearly 100 percent outside the country bill according to consumption and demand (Holtz, 1990).

The peak demand billing system clearly limits the effectiveness of compressed work schedules to reduce energy costs. Suppose, for example, a building with a utility rate structure of $0.025 per kWh of electricity consumption and $13.00 per kW for peak demand. Assume a 10 percent reduction in electricity consumption by adopting a compressed work schedule, resulting in 450,000 kWh consumed with 4-day workweek schedule instead of the original 500,000 kWh consumed with a 5-day workweek schedule. The consumption costs savings totals $1,250 ($11,250 as opposed to $12,500); however, the peak demand remains unchanged at 600 kW, resulting in a $7,800 demand charge. Therefore, in this example, a 10 percent reduction in electricity consumption reduces electricity costs only 6.1 percent. In future chapters, the actual cost savings associated with simulated energy consumption and demand data are examined.

Monte Carlo Simulation

Many companies use Monte Carlo simulation (MCS) to evaluate and structure business decisions. For example, "General Motors, Proctor and Gamble, Pfizer, Bristol-Myers Squibb and Eli Lilly use simulation to estimate both the average return and the risk factor of new products" (Microsoft, 2009:2). The Monte Carlo method allows decision-makers to solve various mathematical problems by introducing uncertainty to the known parameters of a given process (Sobol, 1975). The MCS output represents approximate values of the process within the observed parameters; the output is provided within a statistical distribution of likely outcomes (Sobol, 1975).

In this research, Monte Carlo simulation is used to estimate the effect a scheduling change will have on electricity consumption and cost. The Monte Carlo method involves the following four steps:

(1) Define a domain of possible inputs

(2) Generate inputs randomly from the domain using a certain specified probability distribution

(3) Perform a deterministic computation using the inputs

(4) Aggregate the results of the individual computations into the final result. (QFinance, 2010)

The available metered electricity usage data represents a point-estimate of future consumption values. Relying solely on a given point-estimate fails to account for random variations due to such factors as weather and building occupancy on a given day. The Monte Carlo method is appropriate for "any process whose development is affected by random factors" (Sobol, 1975:10). MCS introduces uncertainty into the model, thus accounting for chance fluctuations in energy consumption. The results of this study are presented probabilistically according to the simulation outputs.

Chapter Summary

This chapter details the factors that have led numerous organizations to consider compressed work schedules as a means to meet energy usage goals and reduce O&M spending. This study considers the legislation dedicated to improving energy efficiency in the Department of Defense to include EPCA 1975, NECPA 1978, EO 13123, EPACT 2005, EISA 2007, and NECPA 2008. Presidential support for alternative work schedule arrangements is present in the Memorandum on Expanding Family-Friendly Work Arrangements in the Executive Branch. Significant reduction in energy usage with compressed work schedule implementation would strengthen Presidential support for alternative scheduling arrangements.

The Department of Defense is aware of alternative scheduling arrangements such as flexible or compressed work schedules; examples of CWS implementation exist within the DoD and state government level. Previous research regarding alternative work schedules focus on employee perception of the scheduling arrangement regarding categories such as employee satisfaction, organizational performance, reduction in time away from work, work-family balance, and workweek experience. This research complements the qualitative studies with a quantitative assessment of the potential impact of CWS implementation on electricity consumption.

This chapter discusses the electrical utility devices that contribute to energy consumption and presents the cost of electricity as a function of consumption and demand. Finally, the Monte Carlo method is identified as a means to introduce uncertainty to the electricity consumption modeling of various work schedule arrangements. A detailed discussion of the methodology used in this study is provided in the next chapter.

Chapter III. Methodology

This chapter describes the methodology to determine the effects of scheduling on electricity consumption, emissions levels, and energy costs for Department of Defense office facilities. The methodology for this study is divided into four primary parts. Monte Carlo simulation is used to model existing electricity consumption data in Part I. The effect of schedule selection on the environmental impact of DoD facilities is determined in Part II. The economic effects of various scheduling arrangements are calculated by the application of utility rates to the simulated electricity consumption and demand figures in Part III. Finally, sensitivity analysis is performed in Part IV to establish a range of possible outcomes given changes to critical inputs; in addition, the conditions most conducive to achieving energy efficiency through compressed work schedules are defined.

Part I: Electricity Consumption

As discussed in the literature review, 5-day schedules include traditional and flexible work arrangements. Compressed work schedules include 4-10 and 5-4/9 options. The first part of this section compares electricity consumption under traditional 5-day, flexible, and 4-10 compressed work schedule arrangements; 5-4/9 CWS options are detailed in Appendix A. The electricity usage figures computed in Part I were used to evaluate the associated environmental impacts and economic effects of the various scheduling alternatives in Parts II and III.

Step 1: Select Test Facilities

This study was based on two office buildings located at Wright-Patterson Air Force Base, referred to as "Building A" and "Building B." The test facilities serve as a proxy for energy use in office buildings across the Department of Defense. These facilities were selected based on two factors. First, the nature of operations contained within the buildings potentially allow the tenant units to adopt compressed work schedules. The test facilities house office-type operations with primary building occupation occurring Monday through Friday during daylight hours. The absence of 24-hour operations and regularly scheduled weekend duty requirements make these facilities potential candidates for compressed work schedules.

The second factor leading to the selection of the test facilities was the availability of electricity consumption data. Each building is equipped with the advanced metering devices required by the National Energy Conservation Policy Act, which provide electricity usage in half-hour increments. Electricity consumption was measured and computed in kilowatt-hours (kWh). This research consists of usage figures from the period of 1 June 2008 through 30 May 2009, allowing for the analysis of the data by seasons as listed in Table 3.

Table 3. Definition of Seasons

Season	Summer	Fall	Winter	Spring
Start Date	1 June 2008	1 September 2008	1 December 2008	1 March 2009
End Date	31 August 2008	30 November 2008	28 February 2009	31 May 2009

Step 2: Adjust Data to Reflect Consumption under Compressed Work Schedules

The energy use data available consisted of 48 daily electricity meter readings from each test facility, totaling over 35 thousand readings for a year's time. The load profile for a given facility is dependent on the hours of operations. Electricity consumption remains relatively low during non-duty hours. Transition phases occur between the non-duty and peak demand periods when the buildings are at the highest levels of occupation. Figure 5 depicts the load profile for Building B for an average workweek under a traditional schedule in the winter season.

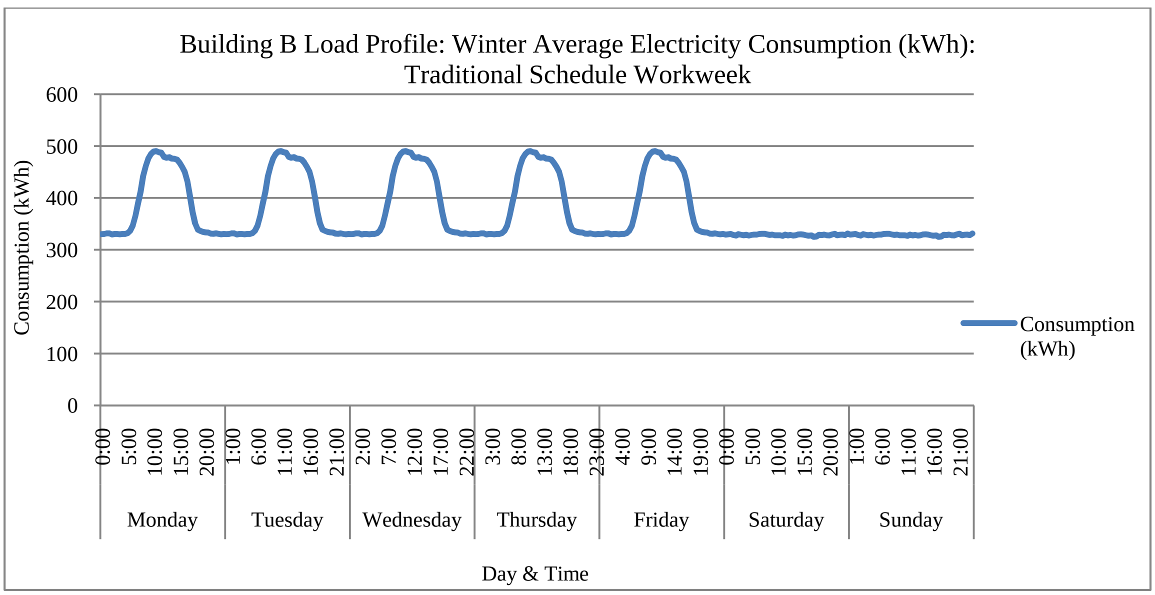


Figure 5. Building B Load Profile: Winter Average Electricity Consumption: Traditional Schedule Workweek

Converting to a 4-day workweek transforms Friday to a non-duty day, reducing the amount of electricity consumed on Fridays to Saturday and Sunday levels. The CWS requires employees to work two additional hours Monday through Thursday, increasing the load profile for these duty-days. Figure 6 depicts the Building B load profiles for an average duty-day under traditional and compressed work schedules in the winter season.

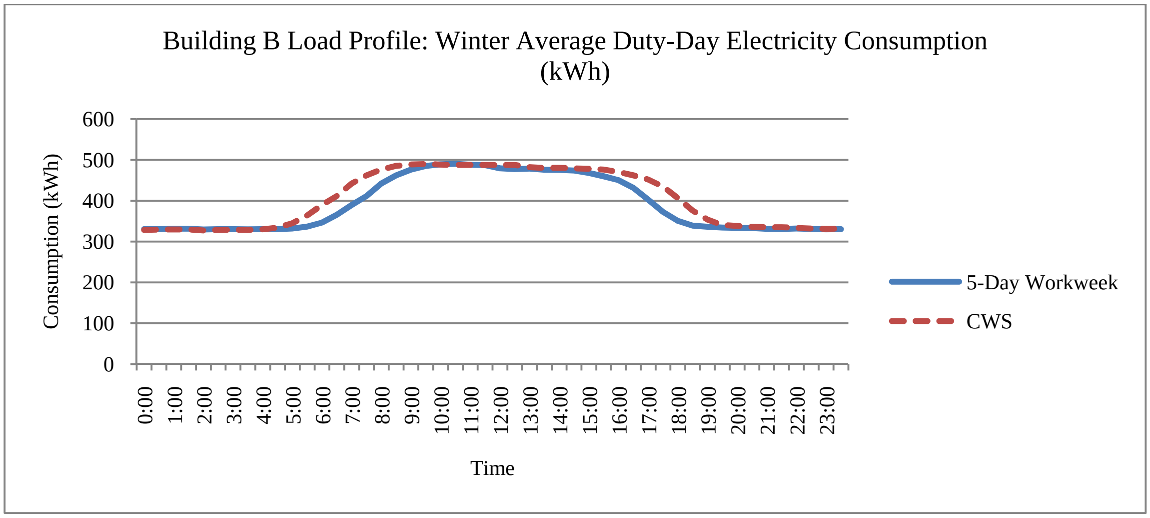


Figure 6. Building B Load Profile: Winter Average Duty-Day Electricity Consumption

The duration of the peak demand period varies with the selected work schedule. Traditional 5-day work schedules requiring employees to occupy a facility for a common 8-hour shift result in the lowest daily electricity consumption on business days. Compressed work schedules requiring building occupation for a 10-hour shift increases daily electricity consumption. Likewise, flexible work schedules intensify electricity consumption compared to traditional work schedules by increasing the duration of building occupation, thus requiring additional energy to support office personnel.

Building A operates under a flexible work schedule best described as a gliding schedule, requiring employees to work 8-hours per day, Monday through Friday. Individual arrival and departure times vary between 0600 and 1800. Building B operates under a traditional 5-day work schedule with employees arriving at 0700 and leaving at 1600. These differences in scheduling were considered when converting the electricity consumption data to reflect the CWS. Figure 7 depicts the Building A load profiles for an average duty-day under traditional and compressed work schedules in the winter season; the effect of holding the transition periods consistent with that of the 5-day schedule is illustrated.

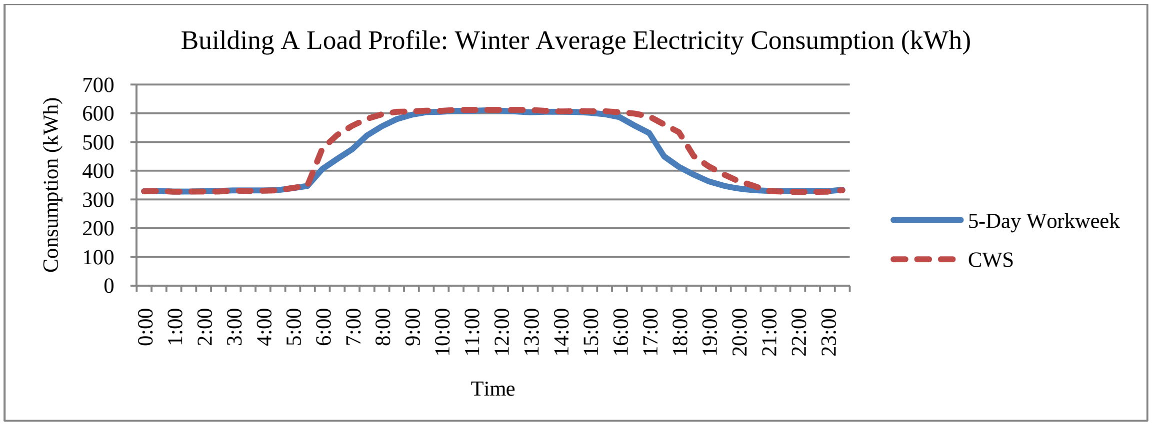


Figure 7. Building A Load Profile: Winter Average Duty-Day Electricity Consumption

Electricity consumption under compressed work schedules was calculated by extending the peak demand periods on duty-days. The load profile curve was shifted outward by two data points (1 hour) on either side of 1130 hours, a point in the observed peak demand period. For Building A, the beginning and ending of the transition period remain consistent with that of a 5-day work schedule when adjusting to the CWS. It was assumed that employees would not begin work before 0600 or end work after 1800 at the onset of 10-hour days. For Building B, the beginning and ending of the transition period was adjusted to reflect earlier arrival and departure times. Table 4 depicts the conversion method used to adjust duty-day electricity consumption under 5-day schedules to that of the CWS. The compressed work schedule adjustments were repeated for each duty-day based on the 5-day schedule metered data, represented by the baseline figures below.

Table 4. Converting 5-Day Workweek Schedules to a Compressed Work Schedule

Time	Building A Consumption (kWh)		Building B Consumption (kWh)		Conversion Explanation
	Flexible Schedule (Baseline)	CWS Adjusted	Traditional Schedule (Baseline)	CWS Adjusted	
0:00	250	250	250	250	Consumption (kWh) Equal to Baseline Data
0:30	250	250	250	250	
1:00	250	250	250	250	
1:30	250	250	250	250	
2:00	250	250	250	250	
2:30	250	250	250	250	
3:00	250	250	250	250	
3:30	250	250	250	250	
4:00	250	250	250	250	
4:30	250	250	250	250	
5:00	250	250	250	350	Consumption (kWh) Equal to Baseline Data Two Time Periods Ahead
5:30	250	250	250	425	
6:00	350	475	350	475	
6:30	425	500	425	500	
7:00	475	525	475	525	
7:30	500	550	500	550	
8:00	525	575	525	575	
8:30	550	585	550	585	
9:00	575	600	575	600	
9:30	585	600	585	600	
10:00	600	600	600	600	
10:30	600	625	600	625	Consumption (kWh) Equal to Demand at 1130
11:00	600	625	600	625	
11:30	625	625	625	625	
12:00	600	625	600	625	
12:30	600	625	600	625	
13:00	600	600	600	600	Consumption (kWh) Equal to Baseline Data Two Time Periods Behind
13:30	600	600	600	600	
14:00	600	600	600	600	
14:30	600	600	600	600	
15:00	600	600	600	600	
15:30	600	600	600	600	
16:00	600	600	600	600	
16:30	600	600	600	600	
17:00	600	600	600	600	
17:30	575	600	575	600	
18:00	550	600	550	600	
18:30	500	575	500	575	
19:00	450	550	450	550	
19:30	400	500	400	500	
20:00	350	450	350	450	
20:30	300	400	300	400	
21:00	250	250	250	350	
21:30	250	250	250	300	
22:00	250	250	250	250	Consumption (kWh) Equal to Baseline Data
22:30	250	250	250	250	
23:00	250	250	250	250	
23:30	250	250	250	250	

Step 3: Simulate Energy Consumption with the Monte Carlo Method

Upon completion of Step 2, the data set consisted of electricity consumption information for 5-day workweek duty-days, 4-day workweek duty-days, and non-duty days (these figures are the same under all schedules) for buildings A and B. The figures served as the domain for the Monte Carlo simulation inputs. Segmenting the data into the 3-month increments detailed in Table 3 allowed for the analysis of seasonal differences.

As discussed in the literature review, the metered consumption figures and CWS adjusted values represent point-estimates of future values. The summation of these figures is equivalent to one trial of electricity consumption for a given time period. The observed data is affected by random fluctuations caused by chance events such as changes in weather conditions and occupation of the facilities. These events determine the utilization of the devices that contribute to energy use. Monte Carlo simulation allows for repeat trials of electricity use within the domain of the point-estimates. The result is a probabilistic model accounting for the random fluctuations in consumption.

Each half-hour of electricity use was explained with a triangular probability distribution. The seasonal populations were described in terms of maximum, minimum and modal values (Brighton Webs Ltd, 2009); these parameters determined the skew of each triangular probability distribution. Appendix B presents the triangular distributions used in the Monte Carlo simulations. Each facility has 48 distributions per season for 5-day duty-days, CWS duty-days, and non-duty days; the total number of distributions is 1,152. The average half-hour consumption figures for each season served as the mode or most likely outcome. Table 5 provides three sample triangular distributions.

Table 5. Sample Triangular Distributions

Building B Example	Distribution Values (kWh)		Distribution Chart
Summer CWS Workday Time: 0300	Minimum Most Likely Maximum	342 444 498	
Summer CWS Workday Time: 1130	Minimum Most Likely Maximum	593 638 728	
Summer CWS Workday Time: 1600	Minimum Most Likely Maximum	548 634 692	

The electricity consumption simulations were conducted in Microsoft Excel. The random number function was applied to each set of triangular probability distributions for 10 thousand iterations. For each iteration, values were generated within the triangular distributions by applying the following formula: =if(p<=(mode-min)/(max-min), min+sqrt(p*(mode-min)*(max-min)), max-sqrt((1-p)*(max-mode)*(max-min))). The repeated random selection of a value within each distribution added uncertainty to the consumption models, thus providing a probabilistic range of possible daily energy use outcomes.

The number of calculations being performed made it necessary to direct the simulation to produce total daily consumption figures. The alternative method is to produce half-hour outputs, the summation of which would determine the total. This practice did not change the values of the outputs but did make it necessary to run additional Monte Carlo simulations to determine the peak demand values discussed later in Part III.

Histograms were generated in Microsoft Excel to display cumulative probability distributions for daily energy consumption with 5-day workweek schedules, 4-day workweek schedules, and non-duty days for each season. Figure 8 displays one such histogram. The cumulative confidence levels depicted in the histograms were consolidated into tables to aid with the comparisons. Table 6 displays the confidence level output corresponding to Figure 8. For Building A, daily electricity consumption under the flexible schedule was 21,834 kWh or less in 80 percent of the winter simulations. The 80 percent confidence level was used to compare simulation outputs.

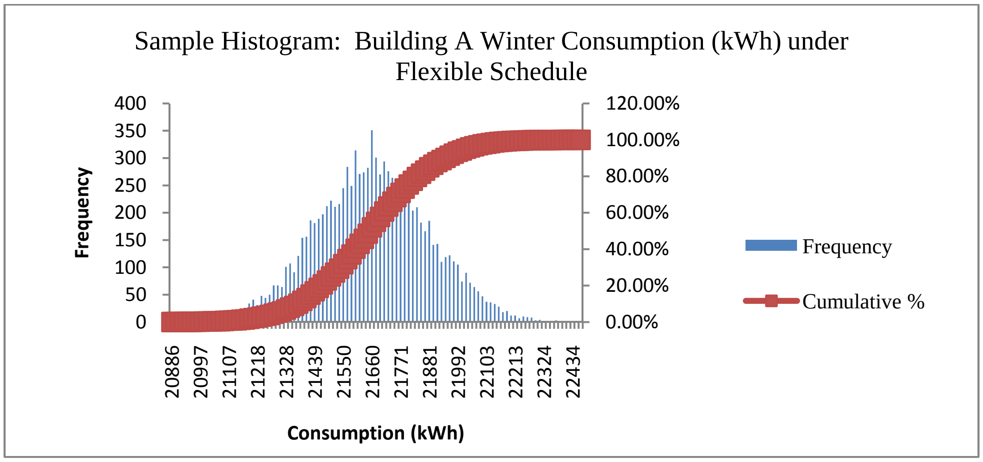


Figure 8. Sample Histogram: Building A Winter Consumption under Flexible Schedule

Table 6. Associated Confidence Levels

Confidence Level	Consumption (kWh)
10%	21,376
20%	21,471
30%	21,534
40%	21,597
50%	21,644
60%	21,708
70%	21,771
80%	21,834
90%	21,945
99%	22,166

Step 4: Conduct Calendar Analysis to Determine the Number of Duty and Non-Duty Days under 5-Day and Compressed Work Schedules

In order to convert the daily electricity consumption outputs to seasonal totals, it was necessary to define the number of duty and non-duty days under 5-day workweeks and compressed work schedules. Table 7 displays the number of duty and non-duty days under various schedules by season. Further detail regarding calendar adjustments is provided in Appendix C.

Table 7. The Number of Duty and Non-Duty Days under Various Schedules

Summer		Fall		Winter		Spring	
# of Days	92	# of Days	91	# of Days	90	# of Days	92
5Day Work	64	5Day Work	61	5Day Work	61	5Day Work	64
5Day Non-Duty	28	5Day Non-Duty	30	5Day Non-Duty	29	5Day Non-Duty	28
CWS Work	52	CWS Work	48	CWS Work	48	CWS Work	51
CWS Non-Duty	40	CWS Non-Duty	43	CWS Non-Duty	42	CWS Non-Duty	41

Step 5: Compare Electricity Consumption under 5-Day and Compressed Work Schedules

The electricity consumption analysis was completed by applying the Step 3 outputs to the number of duty and non-duty days computed in Step 4. The resulting figures represented seasonal consumption totals for 5-day and compressed work schedules. The electricity consumption totals were then compared at common confidence levels to determine the effectiveness of compressed work schedules in improving energy efficiency.

Part II: Environmental Impact

The second part considered the environmental impact of Department of Defense office facilities. As discussed in Chapter I, power plants produce electricity by burning fossil fuels, a process that discharges harmful by-products into the atmosphere. Work schedules that decrease the amount of electricity consumed reduce the amount of emissions released into the environment.

Step 1: Identify Emissions Factors

In quantifying the impact of scheduling decisions on the environment, it is important to note that improvements in emission reductions were measured relative to the current levels. This study does not attempt to identify "acceptable" emissions levels. Instead, electricity consumption under various scheduling arrangements was compared and the measures that are comparatively less harmful to the environment were identified. The factors below were used to evaluate emissions under each scheduling alternative. On average, electricity consumption results in the following amount of pollutants:

1. 852 pounds of CO_2 per megawatt-hour of electricity produced.
   CO_2 contributes to the global warming of the environment.
   (Note that 1000 kilowatt-hours = 1 megawatt-hour, or 1000 kWh = 1 MWh)

2. 0.048 pounds of particulates per megawatt-hour of electricity produced.
   Particulates are small particles that can contribute to smog.

3. 0.024 pounds of oxides of sulfur per megawatt-hour of electricity produced.
   Oxides of sulfur contribute to acid rain pollution. (SEF, 2010)

Step 2: Calculate Emissions by Schedule Alternatives to Compare Environmental Impact

The environmental impact analysis was completed by applying the pollution factors in Step 1 to the electricity consumption data generated in Part I. Emissions totals for 5-day and compressed work schedules were compared to determine the alternative least detrimental to the environment.

Part III: Economic Impact

The third part evaluated 5-day and compressed work schedules from a cost perspective. Unlike many other initiatives designed to improve energy efficiency, transitioning to a compressed work schedule does not require any investment outlays. Therefore, any resulting cost savings are strictly positive gains.

Step 1: Identify Electricity Rates

As discussed in the literature review, energy-providers base the cost of electricity on use (consumption) and the rate of use (demand or peak demand). Table 8 displays the utility rates used to calculate electricity charges under the various scheduling arrangements. Computations were based on the average electricity rates for the 40-month period from October 2007 to January 2010 obtained from the Wright Patterson Air Force Base energy manager; peak demand rates remained constant.

Table 8. Electricity and Peak Demand Rates

Electricity Rate $/kWh	Peak Demand Rate $/kW
$0.02461	$13.00

Step 2: Determine Electricity Consumption and Demand Inputs

In order to calculate electricity charges under the various scheduling arrangements, it was necessary to define the electricity consumption and demand inputs. The outputs generated in Part I served as the consumption figures. Monte Carlo simulation was used to determine peak demand. The methodology was similar to the course of action taken in Part I, Step 3, with the exception that half-hour outputs from 1000 to 1400 hours were computed rather than a total figure. This time-period was the observed range in which peak demand occurred for each facility.

As discussed in the literature review, peak demand is calculated based on the highest level of electricity consumption (kW) in a 30-minute period for a given month; energy providers determine peak demand at the installation level rather than for a given facility. Therefore, it was necessary to assume the estimated peak demand value for each test facility occurred during the established installation peak demand period.

The outputs from the Monte Carlo simulation represented the range of possible peak demand figures for buildings A and B. The half-hour period with the greatest average peak demand for each season was selected to serve as the estimate for the 3-month period. Histograms were generated in Microsoft Excel to display cumulative probability distributions for seasonal peak demand. The cumulative confidence levels depicted in the histograms were consolidated into the table provided in Appendix D.

Step 3: Calculate Electricity Charges to Evaluate Economic Impact

The economic impact analysis was completed by applying the electricity rates detailed in Step 1 to the consumption and demand inputs. The cost totals for 5-day and compressed work schedules were compared to determine the most cost effective alternatives.

Part IV: Sensitivity Analysis

Sensitivity analysis answers the question, "What makes a difference in this decision?" (Clemen and Reilly, 2001:175) The study adopted a two-step approach to sensitivity analysis. First, the inputs used in the construction of the models for buildings A and B were varied. Second, the general conditions necessary for improved electricity efficiency under compressed work schedules were examined.

Step 1: Vary Inputs Critical to the Outcome of our Findings for Buildings A and B

In Step 1 of the sensitivity analysis, the inputs that affect the findings within the established construct of the load profiles for buildings A and B were varied. The sensitivity analysis focused on factors that influence electricity consumption and cost; emissions levels varied with changes in consumption. First, the electricity consumption totals generated in the Monte Carlo simulations were compared at the various confidence levels to determine if the confidence level selected changes the scheduling decision.

Second, the calendar adjustment figures were examined to determine if the mix of duty and non-duty days had an effect on energy efficiency. A range of possible duty and non-duty day combinations was developed by analyzing seven notional calendar years, each with 1 January occurring on a different day of the week. This analysis and the average number of duty and non-duty days in a given year under 5-day and compressed work schedule is provided in Appendix E. Seasonal electricity consumption under 5-day and compressed work schedules was compared across the established spectrum of duty and non-duty arrangements. Adjustments for holidays were completed in accordance with Table 9.

Table 9. Holiday Adjustments

Holiday	Observation	Duty-Day Effect: 5-Day Schedule	Duty-Day Effect : 4-Day Schedule
New Years Day	01 January	One Less if Jan 1 Mon-Fri	One Less if Jan 1 Mon-Thu
Martin Luther King Jr. Day	3rd Monday of January	One Less	One Less
Presidents Day	3rd Monday of February	One Less	One Less
Memorial Day	Last Monday of May	One Less	One Less
Labor Day	1st Monday of September	One Less	One Less
Columbus Day	2nd Monday of October	One Less	One Less
Veterans Day	11 November	One Less	One Less if Jan 1 Mon-Thu
Thanksgiving Day	4th Thursday in November	One Less	One Less
Christmas Day	25 December	One Less if Jan 1 Mon-Fri	One Less if Jan 1 Mon-Thu

Finally, the differences in electricity rates were accounted for by varying the consumption and demand charges used to calculate the cost portion of the research. WPAFB consumption rates from the 40-month observation period varied plus 9 percent and minus 10 percent. In this portion of the sensitivity analysis the seasonal rates were adjusted by plus and minus 50 percent. This range was selected to account for fluctuations in WPAFB rates and differences in rates at other installations.

Step 2: Assess the Effects of Varying the Load Profile

In Step 1, sensitivity analysis was conducted within the constructs of the simulated load profiles for buildings A and B. In Step 2, the load profile was altered by varying the consumption differences between duty and non-duty days. As discussed in Part I, efficiencies are gained by converting from a 5-day workweek to a CWS only if the consumption savings on the Friday non-duty day outweigh the increased electricity usage occurring Monday through Thursday.

The difference in electricity consumption between non-duty and duty hours directly influenced the work schedule decision. Table 10 displays electricity consumption on non-duty days as a percentage of electricity consumption on duty-days. Sensitivity analysis was conducted to establish energy usage ratios at various levels of daily consumption where the scheduling decision changed.

Table 10. Daily Non-Duty Day Electricity Consumption as a Percentage of Daily Duty-Day Consumption

	Building A		
	Daily Duty-Day Consumption (kWh)	Daily Non-Duty Day Consumption (kWh)	Daily Non-Duty Day Consumption as % of Duty-Day Consumption
Summer	22,110	17,167	78%
Fall	21,599	17,168	79%
Winter	21,834	17,040	78%
Spring	20,907	15,148	72%
	Building B		
	Daily Duty-Day Consumption (kWh)	Daily Non-Duty Day Consumption (kWh)	Daily Non-Duty Day Consumption as % of Duty-Day Consumption
Summer	24,578	22,153	90%
Fall	22,018	18,889	86%
Winter	18,582	15,782	85%
Spring	20,780	16,672	80%

Chapter Summary

In this chapter, the methodology to compare 5-day work schedules with compressed work schedules was described. An outline was provided detailing actions to examine scheduling alternatives by calculating electricity consumption, quantifying the environmental and economic impacts, and conducting sensitivity analysis. The results of the analysis are presented in Chapter IV.

Chapter IV. Results and Analysis

This chapter presents the results from the research. The effects of scheduling on electricity consumption, emissions levels, and energy costs for Department of Defense office facilities are detailed. The results of the electricity consumption comparison using Monte Carlo simulation are presented in Part I. The effect of schedule selection on the environmental impact of the test facilities is determined in Part II. The economic effects of various scheduling arrangements are quantified in Part III. Finally, the sensitivity analysis results are presented in Part IV, defining the changes to the inputs that vary the scheduling decision and the conditions most conducive to achieving energy efficiency through compressed work schedules.

Part I: Electricity Consumption Comparison

This research compared electricity consumption under 5-day and compressed work schedules. Based on the simulated load profiles of the test facilities, the study found that the implementation of compressed work schedules varies electricity consumption by less than one percent. The results of Part I were used to compute the environmental and economic impact of Department of Defense office facilities in Parts II and III.

Monte Carlo Simulation Results: Building A

Building A operates under a flexible schedule best described as a gliding schedule, requiring employees to work 8-hours per day, Monday through Friday. Individual arrival and departure times vary between 0600 and 1800. By converting to a compressed work schedule, Building A will realize a 0.40 percent reduction in electricity consumption. The energy savings totaled 29,276 kWh, equating to slightly more than one duty-day of electricity use. Table 11 displays the resulting seasonal electricity consumption totals. For Building A, compressed work schedules are more efficient for all seasons. The consumption differences between scheduling options proved to be statistically significant as detailed in Appendix F.

Table 11. Building A Electricity Consumption: Flexible and CWS Arrangements

		Seasonal Electricity Consumption (kWh)				
Season	Schedule	Duty Days	Non-Duty Days	Total	Difference (kWh)	% Difference
Summer	Flexible	1,415,000	480,670	1,895,700		
	CWS	1,206,800	686,680	**1,893,400**	2,300	0.12%
Fall	Flexible	1,317,500	515,040	1,832,500		
	CWS	1,086,700	738,220	**1,824,900**	7,600	0.41%
Winter	Flexible	1,331,800	494,160	1,826,000		
	CWS	1,094,400	715,680	**1,810,000**	16,000	0.88%
Spring	Flexible	1,338,000	424,140	1,762,100		
	CWS	1,137,600	621,060	**1,758,700**	3,400	0.19%
Annual Total	Flexible	5,402,300	1,914,020	7,316,300		
	CWS	4,525,500	2,761,650	**7,287,000**	29,300	0.40%

Note: The seasonal and annual totals reflecting the least amount of electricity consumption are highlighted.

The consumption totals listed in Table 11 are a function of the simulated daily figures and the number of work and non-duty days in a given season. Table 12 illustrates the increase in electricity consumption on duty-days when the load profile was adjusted to reflect a compressed work schedule. The difference in electricity consumption between duty and non-duty days was approximately 4,400 to 7,100 kWh. Table 12 also displays the number of duty and non-duty days under each schedule.

Table 12. Building A Daily Electricity Consumption and Duty-Day Mix

Season	Schedule	Daily Consumption (kWh) Duty Days	Daily Consumption (kWh) Non-Duty Days	Number of Duty Days	Number of Non-Duty Days	Seasonal Consumption (MWh)
Summer	Flexible	22,110	17,167	64	28	1,895.7
	CWS	23,208	17,167	52	40	1,893.4
Fall	Flexible	21,599	17,168	61	30	1,832.5
	CWS	22,640	17,168	48	43	1,824.9
Winter	Flexible	21,834	17,040	61	29	1,826.0
	CWS	22,800	17,040	48	42	1,810.0
Spring	Flexible	20,907	15,148	64	28	1,762.1
	CWS	22,307	15,148	51	41	1,758.7

A graphic depiction of the daily load profiles for 5-day workweeks, compressed work schedules, and non-duty days is provided in Figure 9. The area between the 5-day workweek and the non-duty day curves represents the energy savings achieved by converting to a CWS. The area between the CWS and 5-day workweek curves represents the increase in duty-day electricity consumption associated with compressed work schedules. The Building A load profiles for the remainder of the seasonal averages is presented in Appendix G.

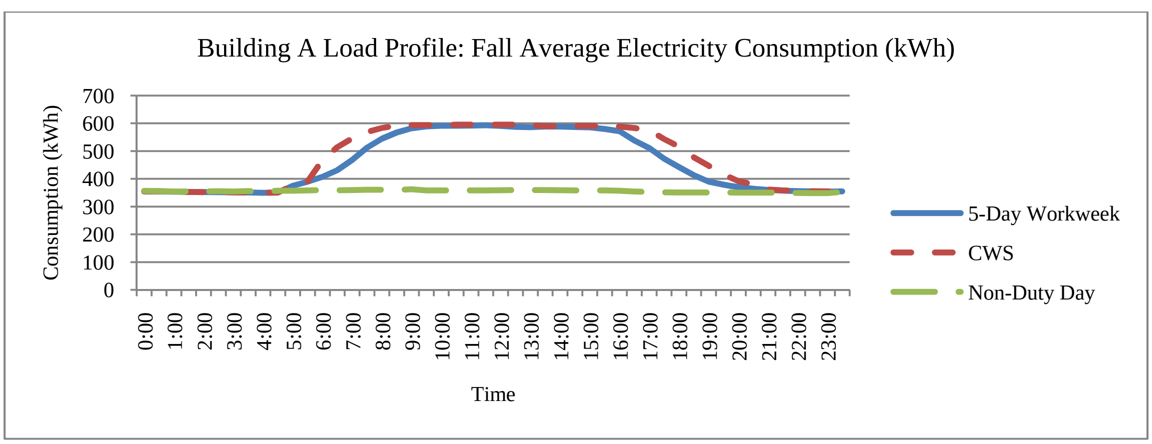


Figure 9. Building A Load Profile: Fall Average Electricity Consumption

As discussed in Chapter III, transition phases occur between the non-duty and peak demand periods when the buildings are at the highest levels of occupation. For Building A, the beginning and ending of the transition period were held consistent with that of a 5-day alternative work schedule when adjusting to the CWS. It is unlikely that individuals who decide to begin an 8-hour workday at 0600 under an alternative work schedule would elect to begin a 10-hour workday at 0400 under a compressed work schedule. Failure to employ this assumption would overstate the increased levels of duty-day electricity consumption under compressed work schedules. Figure 9 (above) illustrates the effect of holding the transition periods consistent with that of the 5-day schedule.

Seasonal differences in electricity consumption were addressed by segmenting energy analysis into 3-month periods. Utilization of the space conditioning devices that contribute to energy use varies by season; as discussed in the literature review, these devices account for approximately 28 percent of electricity consumption in commercial buildings. Transition periods between the cooling and heating of facilities occur in the fall and spring; the timing of the conversion depends on existing weather conditions. Energy managers adjust facility temperatures and humidity levels to support the comfort of building personnel (IEEE, 1991). Space conditioning also protects facility systems and equipment against such problems as freezing pipes, the accumulation of mold, and damage to computer equipment.

Peak demand periods remained relatively consistent between seasons. Winter electricity use was slightly lower than summer and fall levels due to a small decrease in non-duty consumption. Building A consumed the least amount of electricity in the spring months. Peak demand figures were consistent with that of other seasons; however, non-duty and transitional usage was lower. The facility energy manager attributed this difference to adjustments made to the systems due to the moderate temperatures of the spring. Decreased operation of air handlers during non-duty hours and the transition periods allowed for consumption savings while the building was maintained at appropriate comfort levels. This is a good example of active energy management resulting in energy savings. The seasonal load profiles for Building A duty-days are displayed in Figure 10; Figure 11 displays the non-duty day load profiles.

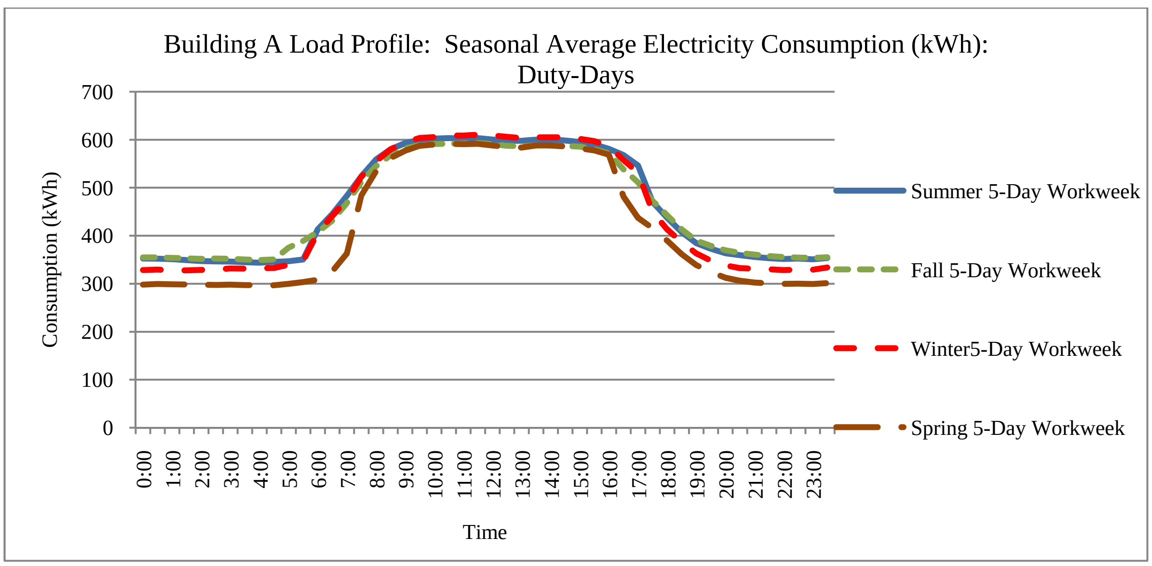


Figure 10. Building A Load Profile: Seasonal Average Electricity Consumption: Duty-Days

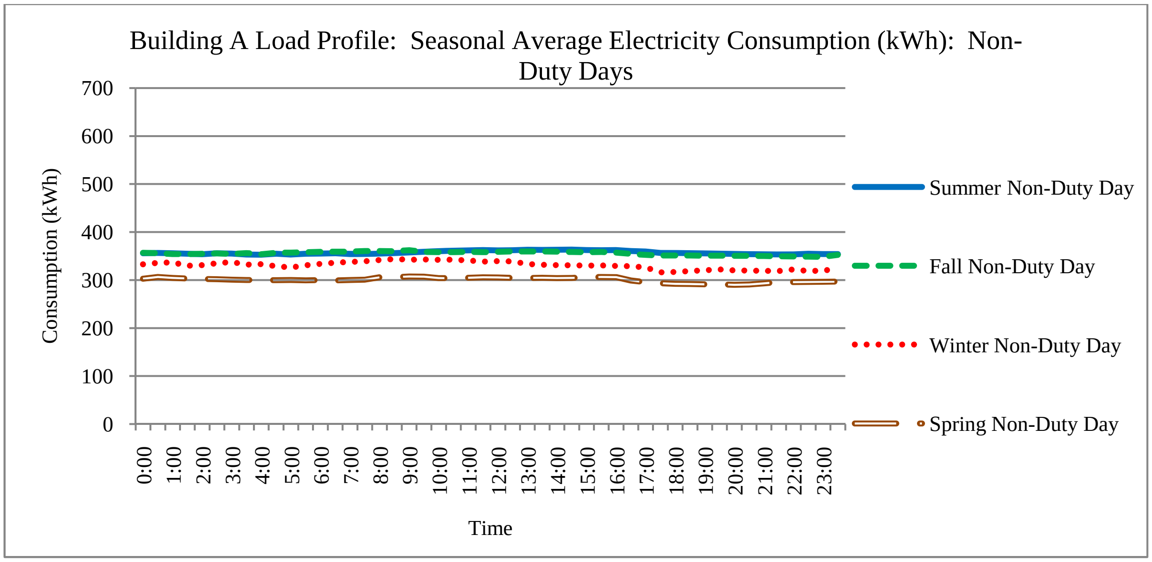


Figure 11. Building A Load Profile: Seasonal Average Electricity Consumption: Non-Duty Days

Monte Carlo Simulation Results- Building B

Building B operates under a traditional 5-day work schedule with employees arriving to work at 0700 and leaving at 1600. By converting to a compressed work schedule, Building B will realize a 0.30 percent increase in electricity consumption. The additional energy use totaled 22,386 kWh, equating to approximately one duty-day of electricity use. Table 13 displays the resulting seasonal electricity consumption totals. For Building B, the current traditional schedule was more efficient in the summer and fall seasons; compressed work schedules were more efficient in the winter and spring. The consumption differences between scheduling options proved to be statistically significant as detailed in Appendix F.

Table 13. Building B Electricity Consumption: Traditional, Compressed and Alternative Work Schedule Arrangements

		Seasonal Electricity Consumption (kWh)				
Season	Schedule	Duty Days	Non-Duty Days	Total	Difference	% Difference
Summer	Traditional	1,572,900	620,280	**2,193,200**		
	CWS	1,332,100	886,120	2,218,200	-25,000	-1.14%
	Flexible	1,639,500	620,280	2,259,800	-66,600	-3.04%
Fall	Traditional	1,343,000	566,670	**1,909,700**		
	CWS	1,108,900	812,220	1,921,200	-11,500	-0.60%
	Flexible	1,409,300	566,670	1,976,000	-66,300	-3.47%
Winter	Traditional	1,133,500	457,670	1,591,100		
	CWS	927,400	662,840	**1,590,300**	800	0.05%
	Flexible	1,178,600	457,670	1,636,300	-45,200	-2.84%
Spring	Traditional	1,329,900	466,810	1,796,700		
	CWS	1,100,000	683,550	**1,783,500**	13,200	0.73%
	Flexible	1,380,400	466,810	1,847,200	-50,500	-2.81%
Annual Total	Traditional	5,379,300	2,111,430	**7,490,700**		
	CWS	4,468,400	3,044,730	7,513,200	-22,500	-0.30%
	Flexible	5,607,800	2,111,430	7,719,300	-228,600	-3.05%

Note: The seasonal and annual totals reflecting the least amount of electricity consumption are highlighted.

In Table 13 (above), the effect should Building B convert to a flexible work schedule involving 5-day operations is displayed. Under this arrangement, the duty-day load profile would increase to that of CWS levels due to the extended operating hours of the facility. With flexible work schedules, Friday remains a duty-day; therefore, no energy savings offsets occur. The result for Building B was a 3.05 percent increase in electricity consumption.

Table 14 illustrates the daily electricity consumption under the traditional, compressed, and flexible work schedules. The difference in electricity consumption between duty and non-duty days was approximately 2,400 to 4,900 kWh. Table 14 also displays the number of duty and non-duty days under each schedule.

Table 14. Building B Daily Electricity Consumption and Duty-Day Mix

		Daily Consumption (kWh)				
Season	Schedule	Duty Days	Non-Duty Days	Number of Duty Days	Number of Non-Duty Days	Seasonal Consumption (MWh)
Summer	Traditional	24,578	22,153	64	28	2,193.2
	CWS	25,618	22,153	52	40	2,218.2
	Flexible	25,618	22,153	64	28	2,259.8
Fall	Traditional	22,018	18,889	61	30	1,909.7
	CWS	23,104	18,889	48	43	1,921.2
	Flexible	23,104	18,889	61	30	1,976.0
Winter	Traditional	18,582	15,782	61	29	1,591.1
	CWS	19,322	15,782	48	42	1,590.3
	Flexible	19,322	15,782	61	29	1,636.3
Spring	Traditional	20,780	16,672	64	28	1,796.7
	CWS	21,569	16,672	51	41	1,783.5
	Flexible	21,569	16,672	64	28	1,847.2

A graphic depiction of the daily load profiles for 5-day workweeks, compressed work schedules, and non-duty days is provided in Figure 12. The Building B load profiles for the remainder of the seasonal averages is contained in Appendix H. As discussed in Chapter III, when converting from the traditional schedule to the CWS, the facility operating hours were extended to reflect the earlier arrival and later departure of personnel. The outward shift of the transition period for Building B is evident on the graph.

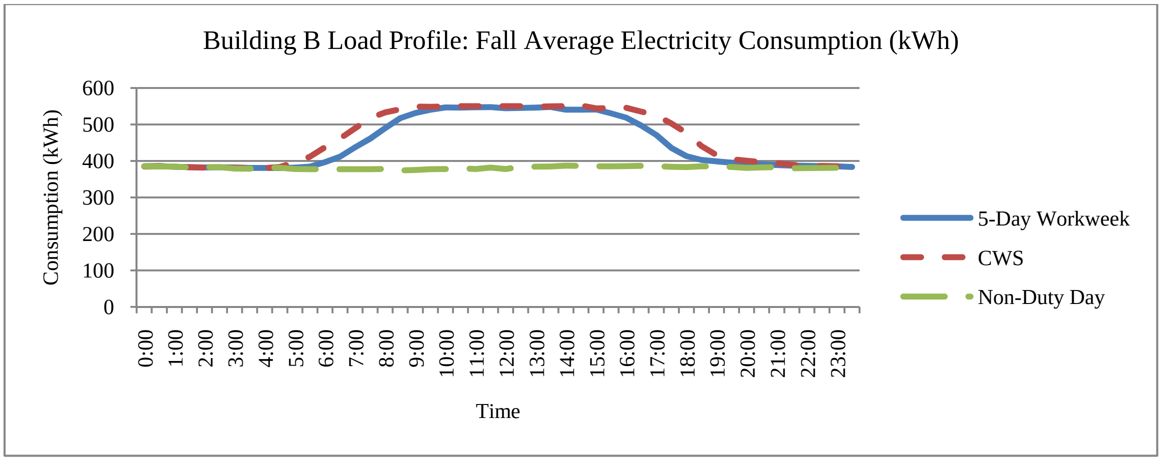


Figure 12. Building B Load Profile: Fall Average Electricity Consumption

Unlike Building A, Building B displays significant variability in seasonal electricity consumption. The traditional 5-day work schedule outperformed the CWS with the increased consumption in the summer and fall months. The lower levels of electricity consumption in the winter and spring months allowed for energy savings with the CWS. Winter and spring daily averages were almost identical. Figure 13 displays the seasonal load profiles for duty-days; Figure 14 illustrates the load profiles for non-duty days.

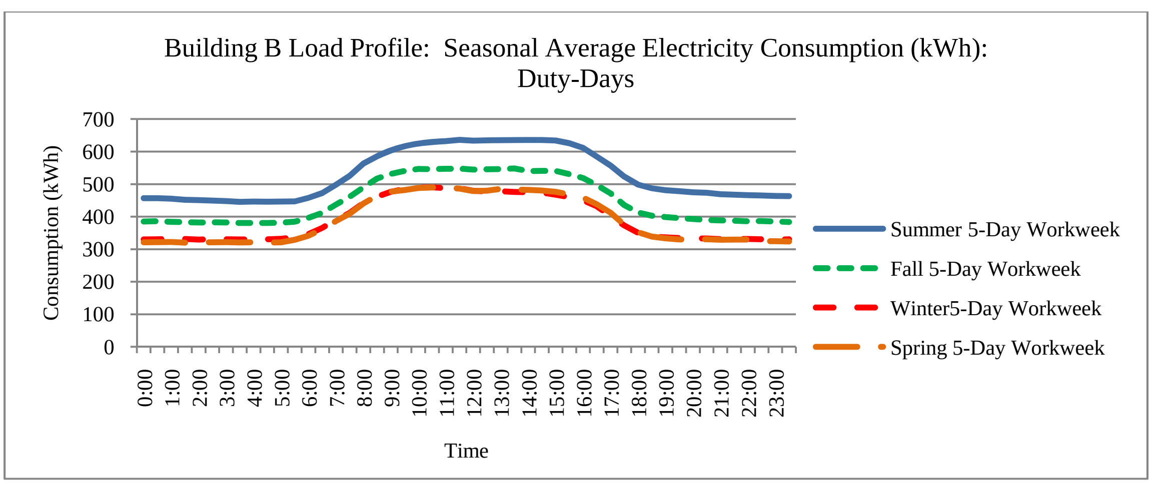


Figure 13. Building B Load Profile: Seasonal Average Electricity Consumption: Duty-Days

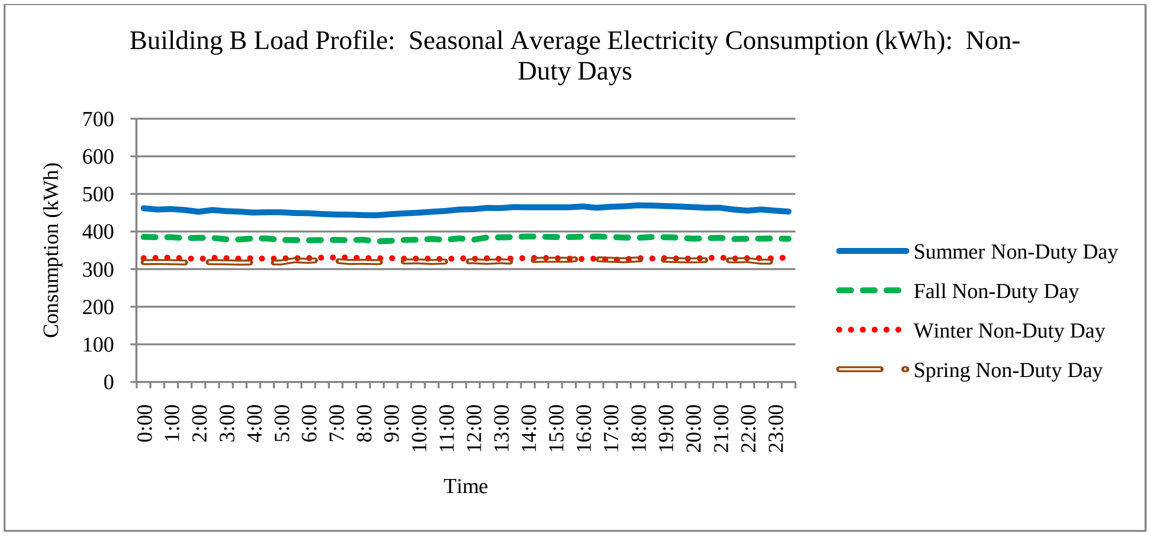


Figure 14. Building B Load Profile: Seasonal Average Electricity Consumption: Non-Duty Days

The fluctuations in seasonal electricity consumption resulted from increased reliance on the air conditioning system in warmer months. Building B contains three large air handlers responsible for 80 to 90 percent of the building's space conditioning needs; an additional smaller unit serves a portion of basement offices. The Air Force purchased these units the 1970s. In the warmer months, the facility chillers cool water to 46 degrees Fahrenheit; the water flows through coils in the air handlers. Thermostat settings in individual rooms dictate demand for cool air. A similar process occurs in the cooler winter and spring months with steam heat disbursed throughout the facility. The increased electricity consumption in warmer months is a result of the load generated by the chiller exceeding that of the heating system.

The air handlers currently operate non-stop, even during non-duty hours. Wright-Patterson Air Force Base is in the process of retrofitting the system to allow for automated control. It is likely that installation of the automated controls will result in moderate energy consumption reductions. Automation could reduce but not eliminate the operation of air handlers during non-duty hours. Air handlers and associated systems are sensitive to changes in operation; without careful management, complications can arise. The majority of the space conditioning load results from operation of the chiller. Shutting down the chiller during non-duty hours will temporarily reduce the load; however, the increased energy necessary to return the water to 46 degrees Fahrenheit will offset some, if not all, of the gains. Replacing the space conditioning systems with units that are more efficient requires large investment costs. The inefficiency of the current system was responsible for the relatively small difference in energy consumption between duty and non-duty hours.

Factors Contributing to the Electricity Consumption Results

The systems contained within buildings A and B and the mission requirements of the facilities contributed to the ratio of non-duty day electricity consumption to duty-day use. Building A consumed approximately 31 kWh of electricity per square foot; Building B consumed approximately 48 kWh of electricity per square foot. Civil Engineers reconstructed Building A in 1964 after a fire destroyed the facility three years earlier. Construction of Building B occurred in 1943; WPAFB converted the facility from labs to offices in the early 1970s. As with the facilities themselves, the space conditioning systems within the buildings are relatively old, which contributed to the amount of energy consumed.

Building A houses a 24-hour command post in the basement of the facility; this contributed to nighttime energy consumption. Management directed personnel in each facility to leave communications equipment on during non-duty hours with the exception of computer monitors. A portion of the lighting also remained in use when the buildings were vacant.

The mix of outdated systems and operational requirements resulted in the load profiles generated by the test facilities. Energy managers strive to improve the efficiency of the facilities with the automation of system controls, incrementally reducing the amount of energy consumed. However, such updates are costly. For example, the estimated replacement cost of Building A is $36.2 million. Significant reductions in energy use under compressed work schedules require a greater difference between duty and non-duty day electricity consumption than currently observed in our test facilities. Additional facility information is provided in Appendix I.

Part II: Environmental Impact Comparison

The consumption results from Part I are used to compare the estimated emissions associated with the test facilities under various scheduling arrangements. Environmental analysis indicated that the implementation of compressed work schedules resulted in higher levels of facility emissions in Building B when switching from the traditional work schedule. However, for each test facility, compressed work schedules produced fewer pollutants than flexible schedules.

Environmental Impact Results

The amount of pollutants produced under each schedule was calculated by multiplying annual electricity consumption figures by the emission factors for carbon dioxides, particulates, and oxides of sulfur. For Building A, converting from the 5-day alternative work schedule to a CWS has a positive environmental effect. For Building B, the current traditional 5-day work schedule produced fewer emissions than that of a compressed work schedule; a flexible work schedule would increase pollution. Table 15 summarizes the environmental impact results.

Table 15. Estimated Annual Emissions from Buildings A & B

	Schedule	Consumption (MWh)	Emissions (lbs)	Difference from Status Quo	Nature of Emissions
Building A	Flexible	7,316.5	6,233,600		**Carbon Dioxides**
	CWS	7,292.7	6,213,300	20,300	Contributing to:
Building B	Traditional 5-Day	7,491.0	6,382,200		Global Warming
	CWS	7,536.5	6,421,000	(38,800)	Factor: 852 lbs/MWh
	Flexible	7,719.4	6,576,900	(194,700)	
Building A	Flexible	7,316.5	351		**Particulates**
	CWS	7,292.7	350	1	Contributing to:
Building B	Traditional 5-Day	7,491.0	360		Smog
	CWS	7,536.5	362	(2)	Factor: 0.048 lbs/MWh
	Flexible	7,719.4	371	(11)	
Building A	Flexible	7,316.5	176		**Oxides of Sulfur**
	CWS	7,292.7	175	1	Contributing to:
Building B	Traditional 5-Day	7,491.0	180		Acid Rain
	CWS	7,536.5	181	(1)	Factor: 0.024 lbs/MWh
	Flexible	7,719.4	185	(5)	

Part III: Economic Impact Comparison

The consumption results from Part I and peak demand figures generated in the Monte Carlo simulations are used to estimate the costs associated with the test facilities under various scheduling arrangements. The economic analysis indicated that the implementation of compressed work schedules result in remarkably small changes in facility energy spending relative to the total cost. As with the environmental analysis, compressed work schedules outperformed flexible schedules.

Economic Impact Results

Electricity costs under each schedule were calculated by multiplying consumption and demand rates by the outputs generated in our Monte Carlo simulations. The implementation of compressed work schedules resulted in a savings of $720 for Building A and an increase in energy expenditures of $553 for Building B. As discussed in Part I, the implementation of compressed work schedules varied electricity consumption by less than one percent. Compressed work schedules do not have the ability to decrease peak demand; therefore, monetary savings result only from reduced consumption costs. For Building A, the compressed work schedule reduces consumption by 0.40 percent and cost by 0.26 percent. For Building B, the compressed work schedule increases consumption by 0.30 percent and cost by 0.20 percent. Tables 16 and 17 summarize the economic results.

Table 16. Building A Electricity Cost: Flexible and CWS Arrangements

		Consumption Rate ($/kWh)	0.02461	Demand Rate ($/kW)	13.00			
Season	Schedule	Consumption (kWh)	Peak Demand (kW)	Consumption Cost ($)	Demand Cost ($)	Total Cost ($)	Savings ($)	% Savings
Summer	Flexible	1,895,700	616	46,653	24,024	70,677.00		
	CWS	1,893,400	616	46,597	24,024	**70,621.00**	56.00	0.08%
Fall	Flexible	1,832,500	612	45,098	23,868	68,966.00		
	CWS	1,824,900	612	44,911	23,868	**68,779.00**	187.00	0.27%
Winter	Flexible	1,826,000	628	44,938	24,492	69,430.00		
	CWS	1,810,000	628	44,544	24,492	**69,036.00**	394.00	0.57%
Spring	Flexible	1,762,100	622	43,365	24,258	67,623.00		
	CWS	1,758,700	622	43,282	24,258	**67,540.00**	83.00	0.12%
Annual Total	Flexible	7,316,300		180,054	96,642	276,696.00		
	CWS	7,287,000		179,333	96,642	**275,976.00**	720.00	0.26%

Note: The seasonal and annual totals reflecting the least amount of electricity cost are highlighted.

Table 17. Building B Electricity Cost: Traditional, Compressed and Flexible Work Schedule Arrangements

		Consumption Rate ($/kWh)	0.02461	Demand Rate ($/kW)	13.00			
Season	Schedule	Consumption (kWh)	Peak Demand (kW)	Consumption Cost ($)	Demand Cost ($)	Total Cost ($)	Savings ($)	% Savings
Summer	Traditional	2,193,200	690	53,975	26,910	**80,885.00**		
	CWS	2,218,200	690	54,590	26,910	81,500.00	-615.00	-0.76%
	Flexible	2,259,800	690	55,614	26,910	82,524.00	-1,639.00	-2.03%
Fall	Traditional	1,909,700	662	46,998	25,818	**72,816.00**		
	CWS	1,921,200	662	47,281	25,818	73,099.00	-283.00	-0.39%
	Flexible	1,976,000	662	48,629	25,818	74,447.00	-1,631.00	-2.24%
Winter	Traditional	1,591,100	514	39,157	20,046	59,203.00		
	CWS	1,590,300	514	39,137	20,046	**59,183.00**	20.00	0.03%
	Flexible	1,636,300	514	40,269	20,046	60,315.00	-1,112.00	-1.88%
Spring	Traditional	1,796,700	642	44,217	25,038	69,255.00		
	CWS	1,783,500	642	43,892	25,038	**68,930.00**	325.00	0.47%
	Flexible	1,847,200	642	45,460	25,038	70,498.00	-1,243.00	-1.79%
Annual Total	Traditional	7,490,700				**282,159.00**		
	CWS	7,513,200				282,712.00	-553.00	-0.20%
	Flexible	7,719,300				287,784.00	-5,625.00	-1.99%

Note: The seasonal and annual totals reflecting the least amount of electricity cost are highlighted. Negative numbers indicate the traditional schedule is more cost efficient.

The monetary differences between scheduling options was relatively small when compared to the total cost of facility energy. The magnitude of the cost to power DoD office facilities is displayed in the above tables. Improving energy efficiency has the potential to reap significant financial benefits; compressed work schedules are clearly not the sole solution to reducing energy expenditures. This research displayed the economic effects of facilities consuming large amounts of electricity on non-duty days. Facilities with a relatively large difference in duty-day and non-duty day electricity consumption achieve greater levels of cost savings when converting to a compressed work schedule.

In the next section, the conditions necessary for compressed work schedules to increase energy efficiency for Department of Defense office facilities are discussed.

Part IV: Sensitivity Analysis

In Parts I through III, the merits of compressed work schedules as a means to improve energy efficiency were evaluated. In Part IV, inputs and assumptions were varied to analyze the sensitivity of the results.

Sensitivity Analysis Results for Buildings A and B

The results generated for buildings A and B were sensitive to the selected confidence levels, calendar adjustments, and cost factors used in the calculations. Consumption totals were based on Monte Carlo simulation outputs; the simulations provided a probabilistic range of outcomes. The 80 percent confidence level was used throughout the research to compare electricity consumption.

Sensitivity analysis revealed variability in the scheduling decision when lower confidence levels are considered. Tables 18 and 19 display the differences in seasonal electricity consumption under 5-day and compressed work schedules at various confidence levels. Negative numbers indicate the compressed work schedule was more energy efficient; positive numbers indicate the 5-day schedule was more efficient. For Building A, the scheduling decision was variable at confidence levels below 40 percent in the spring season. For Building B, the scheduling decision changed at the 50 percent confidence level in the winter season.

Table 18. Sensitivity Analysis: Confidence Levels: Building A

Building A	Season Electricity Consumption (kWh): Negative Values indicate energy savings w/CWS. Positive Values indicate the 5-Day schedule is more efficient.			
Confidence Level	Summer	Fall	Winter	Spring
10%	-136	-4,358	-15,420	1,833
20%	-676	-5,591	-15,377	1,025
30%	-1,044	-5,055	-15,264	408
40%	-1,400	-6,044	-16,188	-273
50%	-1,168	-6,301	-15,368	-1,811
60%	-2,200	-7,290	-16,084	-2,169
70%	-1,852	-7,534	-17,008	-2,786
80%	-2,220	-7,635	-15,954	-3,467
90%	-2,708	-8,807	-16,839	-6,281
99%	-2,696	-9,869	-16,384	-8,414

Table 19. Sensitivity Analysis: Confidence Levels: Building B

Building B	Season Electricity Consumption (kWh): Negative Values indicate energy savings w/CWS. Positive Values indicate the 5-Day schedule is more efficient.			
Confidence Level	Summer	Fall	Winter	Spring
10%	31,100	20,473	1,333	-10,003
20%	29,456	18,266	576	-10,919
30%	28,536	16,981	590	-11,552
40%	28,476	15,362	765	-10,700
50%	27,820	15,547	-302	-12,791
60%	25,788	14,593	-559	-12,147
70%	25,900	13,009	-384	-12,468
80%	24,980	11,451	-880	-13,165
90%	24,168	10,621	-2,278	-12,649
99%	19,496	7,266	-2,672	-15,309

For each of the test facilities considered, the difference in electricity consumption under 5-day and compressed work schedules was less than one percent; this equated to a difference of one to two days of daily energy use. Therefore, the number of duty and non-duty days could potentially influence the decision. Seasonal electricity consumption was evaluated for each test facility within the range of possible duty and non-duty day combinations. This analysis found that the scheduling decision changed based on the mix of duty and non-duty days. The findings from the calendar sensitivity analysis is summarized Tables 20 and 21.

Table 20. Sensitivity Analysis: Calendar Adjustments: Building A

		5-Day Schedule			Compressed Work Schedule			
Building A		# Duty Days	# Non-Duty Days	Electricity Use (MWh)	# Duty Days	# Non-Duty Days	Electricity Use (MWh)	Summary
Winter								
Days:	90	60	30	1,821.2	47	43	1,804.3	Less energy is consumed with the CWS under each scenario.
Flexible Duty kWh:	21,834	**61**	**29**	**1,826.0**	**48**	**42**	**1,810.0**	
CWS Duty kWh	22,800	62	28	1,830.8	49	41	1,815.8	
Non-Duty kWh:	17,040							
Spring								
Days:	92	**64**	**28**	**1,762.1**	50	42	1,751.5	Variability exists at various duty-day combinations.
Flexible Duty kWh:	20,907	65	27	1,767.9	**51**	**41**	**1,758.7**	
CWS Duty kWh	22,307	66	26	1,773.7	52	40	1,765.8	
Non-Duty kWh:	15,148							
Summer								
Days	92	**64**	**28**	**1,895.7**	50	42	1,881.4	Variability exists at various duty-day combinations.
Flexible Duty kWh:	22,110	65	27	1,900.6	51	41	1,887.4	
CWS Duty kWh	23,208	66	26	1,905.6	**52**	**40**	**1,893.4**	
Non-Duty kWh:	17,167				53	39	1,899.5	
Fall								
Days	91	**61**	**30**	**1,832.5**	47	44	1,819.4	Variability exists at various duty-day combinations.
Flexible Duty kWh:	21,599	62	29	1,837.0	**48**	**43**	**1,824.9**	
CWS Duty kWh	22,640	63	28	1,841.4	49	42	1,830.4	
Non-Duty kWh:	17,168				50	41	1,835.8	

Note: The number of duty and non-duty days used to calculate the initial consumption totals is highlighted.

Table 21. Sensitivity Analysis: Calendar Adjustments: Building B

Building B		5-Day Schedule			Compressed Work Schedule			
		# Duty Days	# Non-Duty Days	Electricity Use (MWh)	# Duty Days	# Non-Duty Days	Electricity Use (MWh)	Summary
Winter								
Days	90	60	30	1,588.3	47	43	1,586.7	Variability exists at various duty-day combinations.
5-Day Duty kWh:	18,582	**61**	**29**	**1,591.1**	**48**	**42**	**1,590.3**	
CWS Duty kWh	19,322	62	28	1,593.9	49	41	1,593.8	
Non-Duty kWh:	15,782							
Spring								
Days	92	**64**	**28**	**1,796.7**	50	42	1,778.6	Less energy is consumed with the CWS under each scenario.
5-Day Duty kWh:	20,780	65	27	1,800.8	**51**	**41**	**1,783.5**	
CWS Duty kWh	21,569	66	26	1,804.9	52	40	1,788.4	
Non-Duty kWh:	16,672							
Summer								
Days	92	**64**	**28**	**2,193.2**	50	42	2,211.3	Less energy is consumed with the Traditional Work Schedule under each scenario.
5-Day Duty kWh:	24,578	65	27	2,195.7	51	41	2,214.7	
CWS Duty kWh	25,618	66	26	2,198.1	**52**	**40**	**2,218.2**	
Non-Duty kWh:	22,153				53	39	2,221.7	
Fall								
Days	91	**61**	**30**	**1,909.7**	47	44	1,917.0	Less energy is consumed with the Traditional Work Schedule under each scenario.
5-Day Duty kWh:	22,018	62	29	1,912.8	**48**	**43**	**1,921.2**	
CWS Duty kWh	23,104	63	28	1,916.0	49	42	1,925.4	
Non-Duty kWh:	18,889				50	41	1,929.6	

Note: The number of duty and non-duty days used to calculate the initial consumption totals is highlighted.

Varying the utility rates used in the economic impact analysis revealed that the selected rate does not change the scheduling decision. The scheduling decision resulting in lower levels of electricity consumption progressively outperformed the other scheduling options as consumption rates increased. Table 22 illustrates the effect of varying utility rates on cost savings; the calculations were based on Building A average consumption and peak demand data. The sensitivity analysis highlighted the previous assertion that compressed work schedules affect only the consumption portion of utility costs. As peak demand rates were increased, the cost savings decreased; as consumption rates were increased, the cost savings also increased.

Table 22. Compressed Work Schedule Cost Savings at Various Utility Rate Combinations

Consumption Rate ($s)		Peak Demand Rate ($s)												
		7.00	8.00	9.00	10.00	11.00	12.00	**13.00**	14.00	15.00	16.00	17.00	18.00	19.00
	0.0120	0.20%	0.19%	0.18%	0.18%	0.17%	0.16%	0.16%	0.15%	0.14%	0.14%	0.13%	0.13%	0.12%
	0.0138	0.22%	0.21%	0.20%	0.19%	0.18%	0.17%	0.17%	0.16%	0.15%	0.15%	0.14%	0.14%	0.14%
	0.0156	0.22%	0.21%	0.21%	0.20%	0.19%	0.18%	0.18%	0.17%	0.16%	0.16%	0.15%	0.15%	0.15%
	0.0174	0.23%	0.22%	0.21%	0.21%	0.20%	0.19%	0.19%	0.18%	0.17%	0.17%	0.16%	0.16%	0.15%
	0.0192	0.24%	0.23%	0.22%	0.21%	0.21%	0.20%	0.19%	0.19%	0.18%	0.18%	0.17%	0.17%	0.16%
	0.0210	0.24%	0.24%	0.23%	0.22%	0.21%	0.21%	0.20%	0.19%	0.19%	0.18%	0.18%	0.17%	0.17%
	0.0228	0.25%	0.24%	0.23%	0.23%	0.22%	0.21%	0.21%	0.20%	0.20%	0.19%	0.19%	0.18%	0.18%
	0.0246	0.25%	0.25%	0.24%	0.23%	0.22%	0.22%	**0.21%**	0.21%	0.20%	0.20%	0.19%	0.19%	0.18%
	0.0264	0.26%	0.25%	0.24%	0.24%	0.23%	0.22%	0.22%	0.21%	0.21%	0.20%	0.20%	0.19%	0.19%
	0.0282	0.26%	0.25%	0.25%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%	0.21%	0.20%	0.20%	0.19%
	0.0300	0.26%	0.26%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%	0.21%	0.20%	0.20%
	0.0318	0.27%	0.26%	0.25%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%	0.21%	0.20%
	0.0336	0.27%	0.26%	0.26%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.22%	0.21%	0.21%
	0.0354	0.27%	0.27%	0.26%	0.25%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%	0.21%
	0.0372	0.27%	0.27%	0.26%	0.26%	0.25%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%

Note: The number of duty and non-duty days used to calculate the initial consumption totals is highlighted.

Sensitivity Analysis Results for Various Load Profiles

The sensitivity analysis thus far revealed the effect of confidence level selection, calendar adjustments, and cost factors on the scheduling decision. The sensitivity analysis was then continued outside of the constraints of the test facilities' simulated load profiles. In effect, a spectrum of the existing electricity consumption conditions necessary for compressed work schedules to increase energy efficiency for Department of Defense office facilities was provided.

Electricity consumption on non-duty days as a factor of duty-day use was evaluated. A factor of 1.0 indicates non-duty and duty day consumption are equal. Decreasing the factor signifies that an office facility consumed less energy when the building was not occupied. As the factor was decreased, compressed work schedules became more effective as the energy savings on non-duty days increased.

In the simulations, Building B generated a factor of 0.9 in the summer months by constantly operating air handlers, regardless of building occupation. With non-duty day electricity use at 90 percent of consumption on duty-days, there is little room for savings with a CWS. The results confirmed that Building B consumed more electricity in the summer months by adopting a compressed work schedule. In later seasons, Building B consumed less electricity on duty-days and the non-duty day factor approaches a value of 0.8. The relationship between duty and non-duty day electricity use in the winter and spring allowed Building B to realize energy savings by converting to a compressed work schedule. Table 23 displays the seasonal costs associated with the traditional 5-day and compressed work schedules for Building B.

Table 23. Seasonal Electricity Costs by Factor

	Season and Current Factor							
	Summer 0.90		Fall 0.86		Winter 0.85		Spring 0.80	
Factor	5-Day ($)	CWS ($)	5-Day ($)	CWS ($)	5-Day ($)	CWS ($)	5-Day ($)	CWS ($)
0.90	80,864	81,469	73,502	74,080	59,877	60,157	70,655	70,980
0.85	80,017	80,259	72,689	72,915	59,214	**59,196**	69,939	**69,932**
0.80	79,170	**79,050**	71,876	**71,750**	58,551	58,236	69,223	68,883
0.75	78,323	77,840	71,064	70,585	57,888	57,276	68,507	67,835
0.70	77,477	76,630	70,251	69,420	57,225	56,315	67,791	66,787
0.65	76,630	75,420	69,438	68,255	56,562	55,355	67,075	65,738
0.60	75,783	74,211	68,625	67,090	55,899	54,395	66,359	64,690
0.55	74,936	73,001	67,812	65,925	55,235	53,434	65,643	63,641
0.50	74,089	71,791	67,000	64,760	54,572	52,474	64,927	62,593

Note: The point at which the CWS becomes more efficient is highlighted.

It is critical for decision-makers to understand the relationship between duty and non-duty electricity consumption before making a scheduling decision. Energy managers strive to improve energy efficiency in part by reducing non-duty electricity consumption. Under favorable circumstances, compressed work schedules can effectively augment these efforts.

Data tables were used to establish the conditions necessary for energy savings with compressed work schedules. Duty-day electricity consumption was varied against non-duty consumption (computed as a factor of duty-day use) for 5-day and compressed work schedules. Electricity usage by schedule was compared to determine the points at which the relationship between duty and non-duty energy consumption allows for increased efficiency with compressed work schedules. Table 24 displays the maximum non-duty day electricity consumption figures under which compressed work schedules create energy savings given varied levels of duty-day usage. Factors of lesser values than the figures posted in Table 24 result in increased levels of energy savings under compressed work schedules. Figures 15 and 16 summarize the data table findings in surface area graphs. The energy savings text boxes define the schedule that produced energy savings. Comparative energy savings intensify toward the upper-left and lower-right corners of the graph.

Table 24. Energy Consumption Conditions under which Compressed Work Schedules Create Energy Savings

	Current 5-Day Schedule			
	Flexible		Traditional	
Current Duty-Day Consumption (kWh)	Maximum Factor Allowable for CWS Energy Savings	Maximum Non-Duty Day Consumption (kWh)	Maximum Factor Allowable for CWS Energy Savings	Maximum Non-Duty Day Consumption (kWh)
12,000		N/A		N/A
13,000	0.10	1,300		N/A
14,000	0.20	2,800	0.10	1,400
15,000	0.30	4,500	0.20	3,000
16,000	0.40	6,400	0.30	4,800
17,000	0.50	8,500	0.40	6,800
18,000	0.55	9,900	0.45	8,100
19,000	0.60	11,400	0.55	10,450
20,000	0.65	13,000	0.60	12,000
21,000	0.75	15,750	0.65	13,650
22,000	0.75	16,500	0.70	15,400
23,000	0.80	18,400	0.75	17,250
24,000	0.85	20,400	0.80	19,200
25,000	0.90	22,500	0.85	21,250
26,000	0.95	24,700	0.85	22,100
27,000	0.95	25,650	0.90	24,300
28,000	1.00	28,000	0.95	26,600
29,000	1.00	29,000	0.95	27,550
30,000	1.00	30,000	1.00	30,000

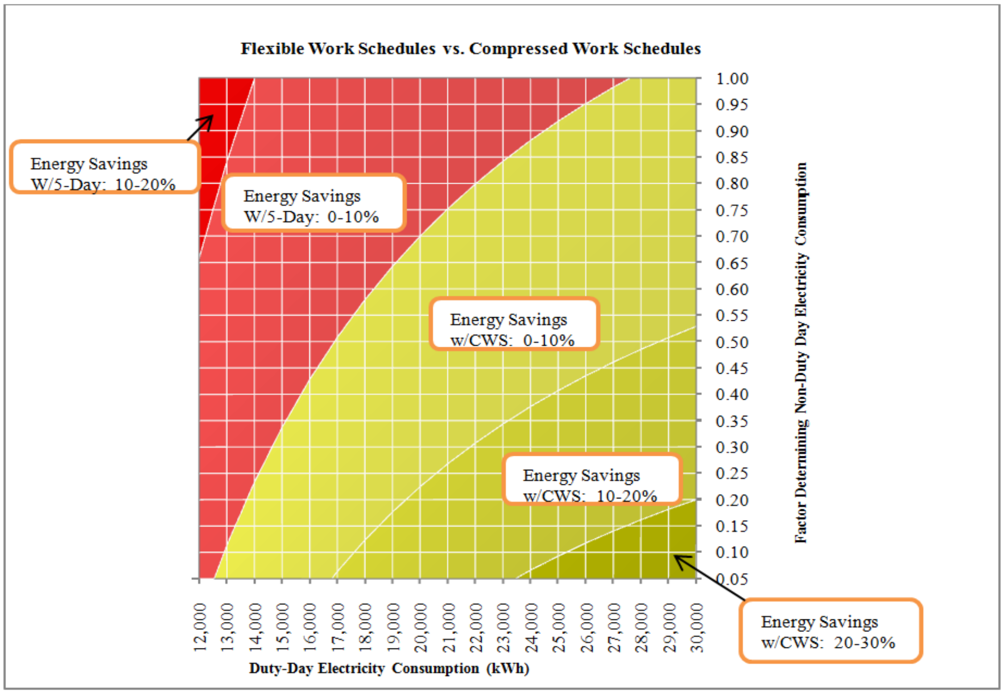


Figure 15. Surface Area Graph: Flexible Schedules vs. Compressed Work Schedules

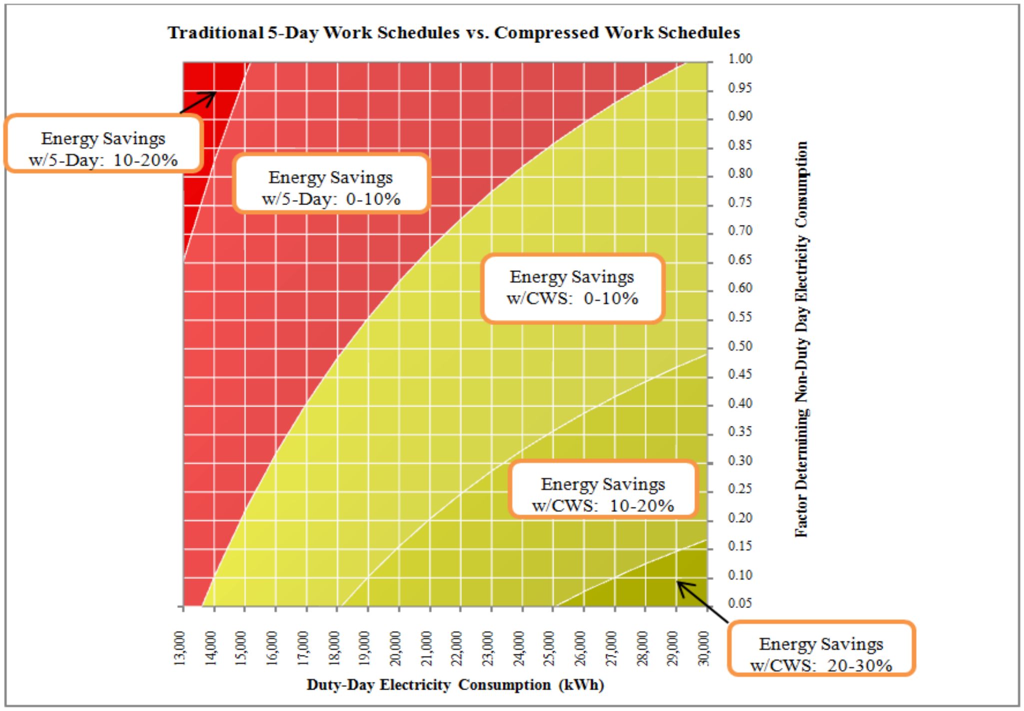


Figure 16. Surface Area Graph: Traditional 5-Day Work Schedules vs. Compressed Work Schedules

Chapter Summary

In this chapter, the results of the research were presented. The Monte Carlo method was used to produce a probabilistic range of electricity consumption and demand outputs; emissions and cost factors were applied to the simulation figures. The research determined the effects of scheduling on electricity consumption, emissions levels, and energy costs for Department of Defense office facilities. Finally, sensitivity analysis was conducted to provide installation commanders and energy managers details as to the conditions necessary for compressed work schedules to improve energy efficiency.

Chapter V. Conclusion and Recommendations

This chapter provides the conclusions and recommendations from the research. The chapter includes a summary of the research, answers to the research questions from Chapter I, and discussion of the benefits and limitations of the study. Finally, recommendations for future research are presented.

Research Summary

This study evaluated the ability of compressed work schedules to improve energy efficiency in Department of Defense office facilities. A basis for the research was established through discussion of legislation related to energy consumption, scheduling alternatives available to decision-makers, examples of compressed work schedule implementation, and previous research regarding alternative work schedule arrangements. The study analyzed the effect of scheduling decisions on test facilities by calculating the electricity consumption, emissions produced, and cost associated with various alternatives. Monte Carlo simulation was used to produce a probabilistic range of outcomes. Finally, sensitivity analysis was conducted to define the conditions most conducive to achieving energy efficiency through compressed work schedules.

Research Questions Answered

Can the Department of Defense reduce energy consumption in office facilities by adopting compressed work schedules?

Compressed work schedules are not a guaranteed means of reducing energy use in Department of Defense office facilities; however, CWS implementation can reduce electricity consumption under certain circumstances. For the test facilities considered, the implementation of compressed work schedules varied electricity consumption by less than one percent.

The relative performance of a compressed work schedule in a given facility is attributed to (a) the present work schedule and (b) the existing relationship between duty and non-duty electricity consumption. This study identified compressed work schedules as more efficient than flexible work schedules. Compressed work schedules have more potential to outperform traditional 5-day workweek schedules as the difference between duty and non-duty day electricity consumption increases. Therefore, efficient facilities benefit the most from compressed work schedules regardless of the scheduling status quo. Inefficient facilities must reduce non-duty electricity consumption before implementing a CWS.

Can the Department of Defense reduce the emissions attributed to electricity consumption by adopting compressed work schedules?

A direct relationship exists between the pollutants produced by a given facility and the amount of electricity consumed. For the test facilities, there was an overall increase in emissions when converting to compressed work schedules. The research found that compressed work schedules do less environmental harm than flexible work schedules. Installation commanders can reduce facility emissions through employee scheduling only when the existing relationship between duty and non-duty electricity consumption allows for increased energy efficiency.

Can the Department of Defense reduce energy expenditures attributed to office facilities by adopting compressed work schedules?

Compressed work schedules resulted in small changes in energy expenditures relative to the total cost to operate a facility. The cost to power DoD facilities is a function of energy consumption and peak demand; compressed work schedules have the ability to reduce the consumption portion of utility bills. Installation commanders can reduce facility electricity expenditures only when the existing relationship between duty and non-duty electricity consumption allows for increased energy efficiency.

The magnitude of the cost associated with operating DoD facilities is significant. Improving energy efficiency has the potential to reap significant financial benefits; compressed work schedules are clearly not the sole solution to reducing energy expenditures. However, when implemented in conjunction with other efficiency efforts, compressed work schedules can incrementally reduce energy spending.

What conditions are necessary to reduce energy consumption by adopting compressed work schedules?

Compressed work schedules improved energy efficiency when the energy savings resulting from a Friday non-duty day outweighed the increased consumption on the Monday through Thursday duty-days. The existing relationship between duty and non-duty day consumption determined the ability of a CWS to generate electricity savings. Compressed work schedules outperformed traditional and alternative 5-day work schedules as non-duty day use as a percentage of duty-day electricity consumption decreased.

Research Benefits

This research provides installation commanders and energy managers a template for evaluating compressed work schedules as a means to improve energy efficiency. As with the majority of energy efficiency initiatives, compressed work schedules are not appropriate in all instances. Previous CWS studies focus on employee perception of the scheduling arrangement. This research expands the CWS knowledge base by addressing the quantitative elements of scheduling decisions.

The study found that compressed work schedules are a limited means to meet energy consumption mandates, reduce the negative effects of DoD facilities on the environment, and combat increasing energy expenditures. The relationship between duty and non-duty electricity use determined if the CWS increased or decreased energy consumption. Therefore, decision-makers considering compressed work schedules should do so based on employee welfare and mission needs rather than energy efficiency.

It is important to note that while compressed work schedules did not dramatically decrease energy consumption and costs, the study revealed that significant increases were not present with alternative schedules either. This research opens the door for the creative scheduling of employees. Decision-makers should focus on the efficient use of the employees rather than the efficient use of the building. If, for example, a commander feels that utilizing a building for all 7-days of the workweek will improve productivity, the commander can take comfort in the fact that electricity use will not dramatically increase. Decision-makers should be encouraged by this study to find the scheduling option that works best for a given office. The limitations of the research are discussed in the following section.

Research Limitations

Significant research limitations resulted from the heterogeneous nature of Department of Defense facilities and the lack of available metered facility energy data. DoD office facilities vary greatly regarding characteristics that contribute to energy consumption such as building age, design, size, systems employed, overall efficiency, and function. These factors determine the manner in which facilities will respond to the CWS treatment. Therefore, it is difficult to generalize a study based on a limited number of facilities.

Furthermore, installations currently meter only a portion of office facilities for energy consumption. Advanced metering exists primarily for electricity; energy managers account for other sources of energy at the installation level. Therefore, access to the amount of detailed data necessary for an energy study with definitive widespread applicability was not available. In the next section, further research to expand the energy efficiency knowledge base beyond the established scope of this study is recommended.

Recommendations for Future Research

Future research should focus on applying this study's methodology to a larger number of DoD facilities or considering scheduling alternatives further outside of DoD norms. The National Energy Conservation Policy Act requires all federal buildings to implement individual facility electricity metering by 2012 and natural gas and steam metering by 2016. This measure will provide researches the data necessary to evaluate over 88 percent of the sources that contribute to DOD energy use. A study applying this study's methodology to the higher-level of detailed energy information will provide decision-makers a more comprehensive view of a compressed work schedule's ability to improve energy efficiency.

The scope of this research was limited to compressed work schedules. Other alternatives, such as telecommuting, exist as potential methods to reduce energy consumption with the management of personnel. Telecommuting can potentially reduce DoD energy consumption and cost figures by decreasing the amount of employees occupying office facilities. Telecommuting is likely to have greater environmental benefits than compressed work schedules by dramatically decreasing the number of vehicles on the roadways. Cultural acceptance of a significant change to the manner in which the DoD conducts business is likely to be met with resistance. However, research proving the merits of a given alternative will aid in the approval process.

Conclusion

As the largest energy consumer in the United States, the Department of Defense must consider all fiscally responsible means to improve energy efficiency. Budgetary and environmental concerns are a catalyst for numerous initiatives designed to reduce energy consumption. Congressional mandates outline the rate at which agencies must reduce facility energy use. Federal agencies and organizations have considered compressed work schedules as a means to reduce energy consumption; the body of research on CWS implementation focuses on employee perception of the work arrangement rather than quantitative analysis of the effect on energy use.

This study achieved the research objectives by determining the effects of compressed work schedules on electricity consumption, emissions levels, and energy costs for Department of Defense office facilities. The research found the relationship between duty and non-duty day use to be a significant factor in determining if compressed work schedules improve energy efficiency. The research provides installation commanders and energy managers a quantitative method by which to evaluate the energy-saving merits of a compressed work schedule for a given office facility.

Because compressed work schedules do not dramatically alter electricity consumption, decision-makers must be encouraged to seek the scheduling arrangement that maximizes the efficiency of the employees. Improving the productivity of the individuals who occupy a facility will likely outweigh any increases to energy consumption and costs. Decision-makers must weigh the merits of alternative work schedules with employee welfare and mission requirements as the primary considerations rather than energy efficiency. Should the relationship between duty and non-duty day electricity consumption allow for improved energy efficiency, the case for a compressed work schedule is that much stronger.

Appendix A

In this section, the 5-4/9 CWS option was examined. Duty-day electricity consumption under the 5-4/9 CWS was estimated as the mid-point between energy use under the flexible and 4-10 schedules. Seasonal consumption was computed with the following formula:

> 5-4/9 Seasonal Consumption = (4-10 # of duty days * 5-4/9 daily consumption) + ((5-4/9 # of duty days – 4-10 # of duty days) * flexible daily consumption) + (5-4/9 # of non-duty days * 5-4/9 non-duty daily consumption).

For the summer season, a numeric example is as follows:

> 5-4/9 Summer Consumption = (52*22659) + ((58-52)*22110) + (34*17167).

This method accounted for increased electricity consumption with 9-hour workdays Monday through Thursday and an 8-hour Friday workday on alternating weeks.

Season	Schedule	Daily Consumption (kWh) Duty Days	Daily Consumption (kWh) Non-Duty Days	Number of Duty Days	Number of Non-Duty Days	Seasonal Consumption (kWh)	CWS Savings
Summer	Flexible	22,110	17,167	64	28	1,895,700	
	5-4/9	22,659	17,167	58	34	1,894,600	0.06%
	4-10	23,208	17,167	52	40	1,893,400	0.12%
Fall	Flexible	21,599	17,168	61	30	1,832,500	
	5-4/9	22,120	17,168	54	37	1,826,500	0.33%
	4-10	22,640	17,168	48	43	1,824,900	0.41%
Winter	Flexible	21,834	17,040	61	29	1,826,000	
	5-4/9	22,317	17,040	55	35	1,820,400	0.31%
	4-10	22,800	17,040	48	42	1,810,000	0.88%
Spring	Flexible	20,907	15,148	64	28	1,762,100	
	5-4/9	21,607	15,148	57	35	1,757,500	0.26%
	4-10	22,307	15,148	51	41	1,758,700	0.19%

For Building A, the 5-4/9 CWS had the same effect on electricity consumption as the 4-10 CWS. However, in three of the four seasons, the savings generated with the 5-4/9 CWS were not as great as the savings with the 4-10 CWS. Therefore, decision-makers should be aware the 5-4/9 CWS option is available, but should not expect the same level of energy savings as with the 4-10 CWS.

It is important to note that the analysis was completed based on an estimated 5-4/9 duty-day electricity consumption value. Adjustment of the metered electricity consumption data, similar to the approach taken in Chapter III, would provide a more accurate estimate of energy use under the 5-4/9 schedule. 5-4/9 CWS option provides decision-makers a possible compromise between flexible and 4-10 compressed work schedules.

Appendix B

	Triangular Distributions: Building A: Flexible Schedule Duty-Days											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	283	352	434	292	355	431	278	329	435	261	298	427
0:30	287	352	436	292	355	428	279	329	434	263	300	428
1:00	284	351	431	293	354	419	280	328	432	263	299	430
1:30	285	349	421	292	353	410	278	328	434	262	298	428
2:00	285	347	417	292	352	408	278	329	432	263	298	425
2:30	286	347	413	292	353	407	277	330	431	260	298	425
3:00	287	346	412	292	352	406	277	332	429	263	298	431
3:30	282	345	412	292	350	405	276	332	432	263	297	425
4:00	285	344	404	291	349	404	275	332	431	263	297	426
4:30	287	345	409	293	350	405	275	333	429	263	297	423
5:00	290	347	412	301	375	406	276	339	434	267	300	435
5:30	290	350	421	303	389	439	279	347	441	272	303	436
6:00	387	413	441	351	408	442	283	406	442	276	308	440
6:30	410	445	465	382	431	460	312	441	468	294	326	464
7:00	445	483	501	407	468	491	348	475	501	324	363	491
7:30	479	524	542	445	513	540	463	523	545	404	484	530
8:00	509	559	576	470	545	571	496	555	575	432	534	567
8:30	528	580	598	486	567	590	527	580	612	492	562	611
9:00	542	593	610	495	582	609	534	595	627	492	577	616
9:30	549	600	619	497	589	614	545	604	634	514	588	618
10:00	551	602	626	499	591	620	525	605	635	512	590	628
10:30	553	603	623	498	592	620	505	609	643	516	592	631
11:00	554	603	621	503	592	621	500	609	638	515	591	637
11:30	554	603	623	502	593	626	542	610	638	510	591	635
12:00	550	600	620	501	591	626	534	609	637	503	588	633
12:30	546	598	616	497	587	618	531	606	638	502	585	631
13:00	543	598	618	499	586	614	530	604	637	498	584	632
13:30	554	600	620	495	588	615	522	605	634	500	588	634
14:00	550	600	621	493	588	622	513	605	633	498	588	635
14:30	546	598	620	494	587	621	499	605	639	495	586	623
15:00	543	595	614	489	586	615	473	602	633	485	582	623
15:30	529	590	612	485	580	606	447	597	631	470	578	623
16:00	511	581	603	467	572	596	437	587	623	455	569	605
16:30	505	568	593	372	539	582	432	558	606	380	482	592
17:00	490	546	566	330	511	560	421	531	582	342	437	572
17:30	414	470	522	304	473	532	347	450	555	326	415	553
18:00	377	437	495	294	442	513	322	413	531	304	390	524
18:30	338	408	471	296	413	478	306	387	510	290	362	492
19:00	321	385	450	290	390	466	295	363	495	284	339	472
19:30	301	373	444	290	379	446	289	348	472	285	325	461
20:00	299	363	431	290	370	439	293	338	467	280	312	452
20:30	295	359	427	291	364	434	289	332	454	275	306	439
21:00	291	356	425	290	361	431	285	331	447	273	303	438
21:30	290	353	424	289	358	424	280	330	451	274	301	428
22:00	290	352	417	289	356	422	280	329	439	274	300	425
22:30	291	352	416	292	355	418	280	329	438	276	300	429
23:00	290	351	416	291	354	420	279	329	435	276	299	425
23:30	289	354	430	290	355	424	281	334	435	280	301	428

	Triangular Distributions: Building A: CWS Workdays											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	283	353	434	292	355	431	278	328	430	261	299	427
0:30	287	353	436	292	355	428	279	329	432	263	300	428
1:00	284	351	431	293	354	419	280	327	432	263	300	430
1:30	285	349	421	292	353	410	278	328	434	262	299	428
2:00	285	347	417	292	352	408	278	328	431	263	299	425
2:30	286	347	413	292	353	407	277	328	431	260	299	425
3:00	289	346	412	292	352	406	277	330	429	263	299	431
3:30	282	345	412	292	351	405	276	330	432	263	298	425
4:00	285	344	404	291	350	404	275	331	431	263	298	426
4:30	287	345	409	293	351	405	275	332	429	263	298	423
5:00	290	347	412	301	376	406	276	340	434	267	301	435
5:30	292	351	421	303	390	439	284	349	441	272	305	436
6:00	468	486	501	407	468	491	351	477	501	333	363	491
6:30	509	526	542	461	514	540	493	524	545	404	485	530
7:00	540	561	576	500	546	571	519	556	575	432	536	567
7:30	565	582	598	518	569	589	542	581	612	520	565	611
8:00	581	596	610	538	583	603	551	596	627	492	580	616
8:30	585	603	619	548	592	614	559	605	634	558	590	618
9:00	589	605	626	554	594	620	525	606	635	558	592	628
9:30	587	606	623	520	594	620	505	609	643	559	594	631
10:00	586	606	621	520	594	621	500	609	638	550	593	637
10:30	588	607	623	521	595	626	563	612	638	557	594	635
11:00	588	607	623	521	595	626	563	612	638	557	594	635
11:30	588	607	623	521	595	626	563	612	638	557	594	635
12:00	588	607	623	521	595	626	563	612	638	557	594	635
12:30	588	607	623	521	595	626	563	612	638	557	594	635
13:00	585	604	620	518	593	626	554	611	637	553	591	633
13:30	583	602	616	515	590	618	540	609	638	555	588	631
14:00	584	602	618	515	589	614	530	606	637	552	587	632
14:30	582	604	620	517	591	615	522	607	634	559	591	634
15:00	579	603	621	518	591	614	513	607	633	558	591	635
15:30	572	602	620	518	589	613	499	607	639	556	590	623
16:00	569	599	614	519	588	613	473	604	633	555	586	623
16:30	562	595	612	516	583	606	447	599	631	551	582	623
17:00	545	587	603	521	576	596	437	589	623	542	574	605
17:30	521	574	593	438	544	582	432	561	606	462	487	592
18:00	496	552	566	394	516	560	422	534	582	420	443	572
18:30	431	474	522	350	478	532	347	451	555	399	420	553
19:00	396	441	495	325	447	513	322	416	531	373	396	524
19:30	351	410	471	316	416	478	306	388	510	320	366	492
20:00	326	387	450	312	392	466	295	364	495	284	342	472
20:30	304	374	444	304	380	446	289	348	472	303	328	461
21:00	291	356	425	301	362	431	285	329	447	283	304	438
21:30	290	353	424	299	359	424	280	328	451	280	302	428
22:00	290	352	417	296	357	422	280	326	439	281	302	425
22:30	291	352	416	293	356	418	280	327	438	280	302	429
23:00	290	351	416	291	355	420	279	327	435	277	301	425
23:30	289	354	430	294	357	424	281	332	435	280	301	428

	Triangular Distributions: Building A: Non-Duty Days											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	292	356	409	291	357	418	281	333	432	272	303	322
0:30	291	357	410	292	356	411	286	336	434	273	306	435
1:00	286	356	409	292	354	408	286	337	434	272	305	428
1:30	285	355	408	290	354	405	282	330	426	272	303	425
2:00	282	354	405	291	355	408	284	331	425	273	302	424
2:30	286	356	410	290	356	411	281	335	424	273	302	422
3:00	284	355	411	292	355	409	284	338	426	273	301	419
3:30	283	353	405	291	356	407	282	332	421	271	300	418
4:00	283	353	406	291	354	408	283	333	420	270	300	417
4:30	285	355	408	291	357	409	282	329	419	266	300	418
5:00	286	353	405	289	357	410	281	326	423	267	300	416
5:30	299	355	407	296	358	410	280	331	424	264	299	417
6:00	300	355	409	298	359	409	279	334	424	268	300	415
6:30	302	356	404	296	359	410	281	336	428	266	299	416
7:00	301	354	402	299	359	419	279	338	439	267	300	422
7:30	299	354	409	300	361	432	281	339	452	268	301	418
8:00	298	355	410	297	361	427	288	342	456	269	306	415
8:30	298	356	408	299	360	432	287	344	456	268	306	416
9:00	298	357	408	297	362	437	287	343	465	270	307	415
9:30	299	358	411	297	358	415	286	343	463	272	307	418
10:00	302	360	417	297	358	415	289	342	466	267	304	323
10:30	301	361	418	296	358	418	289	343	463	272	304	323
11:00	302	362	421	297	359	420	289	341	463	278	305	331
11:30	301	363	423	301	358	421	290	338	459	279	306	326
12:00	301	362	415	294	359	417	288	339	455	279	305	323
12:30	302	362	414	295	360	418	287	339	455	272	304	322
13:00	298	363	417	293	360	425	287	334	450	272	304	322
13:30	305	363	417	293	360	423	288	332	455	270	305	325
14:00	307	363	418	299	359	421	288	331	449	268	304	322
14:30	306	363	420	299	358	422	287	331	446	271	305	325
15:00	302	362	418	297	358	417	288	330	446	272	306	332
15:30	306	362	415	298	358	415	289	331	447	276	306	329
16:00	307	363	415	298	357	415	288	330	444	268	306	328
16:30	305	361	417	297	355	416	287	329	441	267	299	325
17:00	303	359	416	287	352	414	285	326	435	260	296	322
17:30	291	357	414	294	351	410	286	316	425	261	293	319
18:00	284	357	411	291	351	407	288	317	428	260	292	319
18:30	288	356	423	292	351	407	288	319	424	260	292	319
19:00	288	355	418	295	351	409	287	320	424	260	291	319
19:30	291	355	418	293	351	406	285	322	424	262	291	323
20:00	288	354	424	291	350	406	284	320	428	261	290	321
20:30	288	354	422	291	351	406	282	320	426	260	291	318
21:00	292	354	418	290	350	410	283	319	424	260	293	369
21:30	288	353	407	291	350	411	279	319	426	263	296	396
22:00	287	354	406	290	349	411	279	322	427	262	296	393
22:30	289	355	408	290	349	411	279	319	428	263	296	390
23:00	288	354	408	289	349	410	278	320	427	263	297	395
23:30	284	354	408	292	353	407	280	324	430	262	297	391

	Triangular Distributions: Building B: Traditional 5-Day Schedule Duty-Days											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	344	457	504	307	385	512	306	330	358	289	321	466
0:30	348	457	514	310	386	507	308	330	353	290	322	461
1:00	348	455	508	310	384	500	306	332	376	289	322	461
1:30	349	452	502	310	383	497	305	332	363	289	320	455
2:00	347	451	506	306	382	495	298	330	367	290	322	463
2:30	344	450	500	309	383	487	307	330	359	289	321	455
3:00	342	448	503	312	382	487	297	330	365	288	322	455
3:30	341	446	499	306	381	487	300	330	372	289	321	452
4:00	341	447	512	307	381	484	301	330	364	290	321	459
4:30	343	446	503	308	381	483	304	330	371	288	320	453
5:00	344	447	511	313	382	486	303	332	371	290	321	465
5:30	346	447	511	309	384	487	304	337	375	297	329	460
6:00	360	458	519	322	397	501	320	346	375	312	342	483
6:30	375	473	530	336	412	509	324	365	398	321	361	492
7:00	399	498	543	350	437	540	344	389	420	354	386	518
7:30	429	526	577	365	461	566	376	412	448	372	409	536
8:00	455	563	622	320	490	610	387	442	483	406	441	574
8:30	474	586	637	384	517	630	406	462	497	423	464	619
9:00	482	603	664	371	532	646	411	476	507	431	477	624
9:30	487	616	670	370	541	658	420	485	519	437	482	637
10:00	496	625	702	370	547	677	412	489	523	441	488	656
10:30	492	629	710	379	546	680	433	490	528	444	490	673
11:00	499	632	710	365	547	689	443	488	520	447	488	671
11:30	489	636	728	368	548	699	445	487	522	438	486	670
12:00	490	634	721	360	545	701	416	479	513	433	479	629
12:30	502	635	702	369	546	703	421	477	510	430	480	650
13:00	502	635	696	365	546	709	407	479	532	440	485	653
13:30	495	636	705	365	548	710	387	476	512	402	483	705
14:00	493	636	704	370	540	696	385	476	531	439	482	712
14:30	494	636	702	339	541	692	381	474	515	432	480	640
15:00	548	634	692	345	541	691	367	468	514	420	476	647
15:30	516	626	691	338	530	679	340	460	494	409	468	666
16:00	499	611	678	327	519	685	331	450	501	399	458	654
16:30	468	584	649	319	497	658	323	432	485	368	438	626
17:00	429	557	617	320	471	624	319	403	454	345	412	591
17:30	401	523	592	322	436	580	297	373	427	324	375	538
18:00	377	499	554	311	413	543	269	351	390	314	352	519
18:30	371	487	536	317	403	538	283	339	368	300	339	498
19:00	360	482	537	312	399	542	280	336	377	296	333	501
19:30	361	478	520	297	395	540	278	334	374	293	330	496
20:00	358	475	524	307	393	526	277	333	372	295	330	494
20:30	360	473	515	305	390	515	269	333	371	294	330	490
21:00	356	469	520	305	388	517	276	331	370	296	329	480
21:30	355	468	523	308	388	523	279	331	366	298	329	479
22:00	350	466	513	309	386	515	269	332	368	297	329	477
22:30	353	465	515	309	386	516	278	331	368	287	325	473
23:00	347	464	507	306	385	514	274	330	375	287	325	469
23:30	343	463	515	306	383	506	277	330	367	291	324	474

	Triangular Distributions: Building B: CWS Duty-Days											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	344	453	499	307	385	512	306	328	351	292	322	466
0:30	348	453	500	310	386	507	308	329	353	294	322	461
1:00	348	452	500	310	383	500	306	330	345	289	323	461
1:30	349	448	496	310	383	497	305	329	353	291	321	455
2:00	347	447	498	306	382	495	298	327	352	290	323	463
2:30	344	446	492	309	382	487	307	328	354	289	322	455
3:00	342	444	498	312	381	487	297	329	358	288	322	455
3:30	341	442	491	312	380	487	300	328	362	289	322	452
4:00	344	442	492	314	381	478	303	330	361	290	321	465
4:30	346	442	489	309	384	487	304	334	362	297	329	460
5:00	360	454	515	322	396	501	320	345	375	312	342	483
5:30	375	468	514	338	412	506	324	364	398	331	362	492
6:00	399	494	543	374	437	540	344	390	420	354	388	518
6:30	429	522	577	393	461	566	376	412	448	375	411	536
7:00	455	562	622	320	490	610	403	442	483	409	443	574
7:30	488	585	637	438	518	630	414	462	497	423	466	619
8:00	519	604	664	439	533	646	421	476	507	431	479	624
8:30	514	617	670	453	542	657	427	485	519	437	484	637
9:00	533	626	702	451	549	677	443	489	523	441	490	656
9:30	543	631	710	455	549	680	433	490	519	444	492	673
10:00	544	634	710	454	550	689	443	488	520	447	492	671
10:30	593	638	728	453	550	699	445	488	522	438	490	670
11:00	593	638	728	453	550	699	445	488	522	438	490	670
11:30	593	638	728	453	550	699	445	488	522	438	490	670
12:00	593	638	728	453	550	699	445	488	522	438	490	670
12:30	593	638	728	453	550	699	445	488	522	438	490	670
13:00	582	636	721	450	549	701	424	482	513	433	483	629
13:30	589	636	702	452	550	703	421	480	510	430	484	650
14:00	588	636	696	438	550	709	407	481	532	449	491	653
14:30	580	637	705	453	553	710	407	479	512	402	487	705
15:00	572	638	704	408	544	696	394	478	531	442	487	712
15:30	579	639	702	378	546	692	386	476	515	447	484	640
16:00	548	634	692	426	546	691	367	470	498	436	481	647
16:30	516	628	691	414	535	679	340	462	494	436	473	666
17:00	499	615	678	402	525	685	331	452	501	433	464	654
17:30	468	588	649	350	503	658	323	435	485	404	444	626
18:00	429	560	617	321	477	624	324	406	454	385	419	591
18:30	401	525	592	328	441	580	329	376	427	347	380	538
19:00	377	498	554	321	416	543	320	354	390	317	355	519
19:30	371	486	536	317	405	538	309	340	368	300	341	498
20:00	360	480	535	312	400	542	315	338	377	296	335	501
20:30	361	476	520	297	396	540	310	336	374	293	332	496
21:00	358	473	524	311	394	526	310	335	372	295	331	494
21:30	360	472	515	305	390	515	308	335	371	294	331	490
22:00	350	464	513	311	386	515	307	333	368	297	330	477
22:30	353	463	510	313	386	516	305	332	368	293	326	473
23:00	347	462	507	313	385	514	305	331	375	287	325	469
23:30	343	461	515	307	383	506	304	332	367	291	324	474

	Triangular Distributions: Building B: Non-Duty Days											
	Summer			Spring			Fall			Winter		
Time	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
0:00	410	462	508	304	386	478	265	329	357	292	319	377
0:30	419	458	492	309	385	486	278	330	361	296	319	378
1:00	410	460	505	299	385	484	277	331	366	292	318	376
1:30	411	457	496	304	382	469	280	329	355	292	318	376
2:00	417	453	489	305	383	476	274	327	356	289	319	378
2:30	410	457	500	308	383	468	277	330	355	296	319	373
3:00	404	454	507	305	379	466	268	329	359	292	318	373
3:30	411	453	493	298	379	473	276	328	355	290	317	373
4:00	399	451	494	303	382	480	274	329	357	293	318	375
4:30	404	451	503	305	382	473	265	328	357	291	317	371
5:00	410	451	492	306	378	459	278	329	354	294	318	372
5:30	406	449	492	303	377	463	270	329	356	302	323	380
6:00	408	449	490	308	377	468	295	329	356	296	322	370
6:30	397	447	490	303	377	466	297	330	355	300	324	383
7:00	395	445	493	306	378	457	302	331	359	296	322	369
7:30	401	445	490	305	377	469	302	331	357	291	319	370
8:00	399	444	498	303	378	463	305	329	357	294	320	371
8:30	402	443	486	300	374	460	297	329	361	290	319	370
9:00	410	446	498	303	375	469	302	329	369	295	320	369
9:30	410	448	496	297	378	472	287	328	363	291	320	376
10:00	411	450	507	305	378	459	299	328	364	293	321	379
10:30	416	453	495	310	380	462	288	328	360	293	319	375
11:00	418	455	503	305	378	457	295	327	360	296	320	379
11:30	419	458	517	304	382	479	299	329	367	299	320	374
12:00	423	459	511	299	378	458	290	328	372	297	321	372
12:30	424	463	522	306	384	489	304	329	370	295	320	371
13:00	423	462	510	306	385	507	296	327	364	297	321	377
13:30	421	465	522	301	385	478	296	328	367	295	319	369
14:00	421	464	517	307	387	509	306	329	377	296	324	471
14:30	423	465	520	310	386	498	305	330	397	296	325	475
15:00	423	464	510	299	385	501	304	329	369	294	325	486
15:30	428	464	518	306	385	490	311	328	361	293	325	488
16:00	423	467	522	300	386	498	302	327	361	291	328	512
16:30	418	463	515	308	387	501	296	328	364	288	326	508
17:00	429	466	526	308	386	495	298	325	360	288	325	516
17:30	416	467	523	308	384	495	284	326	352	285	324	485
18:00	422	469	527	307	383	495	300	329	358	286	326	511
18:30	419	469	532	309	385	506	305	328	359	290	324	489
19:00	421	468	528	309	385	498	290	329	354	290	325	493
19:30	418	467	524	307	384	490	301	328	351	295	324	480
20:00	416	465	514	310	381	498	300	328	355	295	323	484
20:30	421	463	517	308	382	491	294	330	357	295	324	481
21:00	411	463	516	307	383	493	302	331	360	298	324	477
21:30	405	458	516	310	380	493	300	328	356	295	323	442
22:00	405	456	501	306	381	491	304	329	362	298	324	445
22:30	405	458	503	300	381	492	288	329	352	294	320	417
23:00	410	455	500	307	381	489	298	328	352	294	320	436
23:30	404	453	493	312	381	478	298	331	354	295	318	418

Appendix C

In this section, a visual comparison of calendars under 5-day, 4-10 CWS, and 5-4-9 CWS arrangements is provided. The duty and non-duty days are highlighted as follows: Red signifies a holiday, providing a non-duty day under all scheduling arrangements. Yellow signifies a non-duty day. Green signifies a duty-day under a 5-4-9 CWS and a non-duty day under a 4-10 CWS.

Summer 2008

June						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

July						
Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

August						
Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

5-Day Schedule

Total Days	92
Duty Days	64
Non-Duty Days	28

June						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

July						
Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

August						
Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

4-10 CWS

Total Days	92
Duty Days	52
Non-Duty Days	40

5-4-9 CWS

Duty Days	58
Non-Duty Days	34

Fall 2008

September						
Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

October						
Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

November						
Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

5-Day Schedule

Total Days	91
Duty Days	61
Non-Duty Days	30

September						
Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

October						
Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

November						
Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

4-10 CWS

Total Days	91
Duty Days	48
Non-Duty Days	43

5-4-9 CWS

Duty Days	54
Non-Duty Days	37

Winter 2008/2009

December						
Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

January						
Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

February						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

5-Day Schedule

Total Days	90
Duty Days	61
Non-Duty Days	29

December						
Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

January						
Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

February						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

4-10 CWS

Total Days	90
Duty Days	48
Non-Duty Days	42

5-4-9 CWS

Duty Days	55
Non-Duty Days	35

Spring 2009

March						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

April						
Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

May						
Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

5-Day Schedule

Total Days	92
Duty Days	64
Non-Duty Days	28

March						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

April						
Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

May						
Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

4-10 CWS

Total Days	92
Duty Days	51
Non-Duty Days	41

5-4-9 CWS

Duty Days	57
Non-Duty Days	35

Appendix D

In this section, the peak demand figures (kW) from the Monte Carlo simulations are provided.

	Building A Peak Demand (kW)				Building B Peak Demand (kW)			
Confidence Level	Summer	Fall	Winter	Spring	Summer	Fall	Spring	Winter
10%	603	591	609	598	648	592	492	570
20%	606	596	614	603	657	609	497	587
30%	608	599	616	606	665	619	500	595
40%	610	601	619	610	670	628	504	606
50%	611	604	621	613	674	634	505	614
60%	613	606	623	616	680	645	509	623
70%	614	609	626	618	684	653	510	631
80%	616	612	628	622	690	662	514	642
90%	618	614	631	625	698	674	518	657
99%	622	622	637	632	715	697	526	693

Appendix E

In this section, the calculations used in the calendar sensitivity analysis are provided. The columns below display the mix of duty and non-duty days under 5 and 4-day work schedules for seven years. The years differ by the day of the week 1 January occurs. The seasonal calculations were adjusted to include December in the winter for which it precedes January. Therefore, columns are not calendar years; for example, the Thursday column represents December 2008- November 2009. No adjustments were made for leap years.

		Duty and Non-Duty Day Mix when January 1 occurs on the following weekday													
		Su		Mo		Tu		We		Th		Fr		Sa	
Number of Duty-Days in Workweek:		5	4	5	4	5	4	5	4	5	4	5	4	5	4
Winter	Duty	62	48	60	47	60	47	61	47	61	48	60	49	62	49
	Non-Duty	28	42	30	43	30	43	29	43	29	42	30	41	28	41
Spring	Duty	65	51	65	50	65	52	65	51	64	51	66	52	65	50
	Non-Duty	27	41	27	42	27	40	27	41	28	41	26	40	27	42
Summer	Duty	65	52	65	50	64	50	64	51	66	53	66	52	65	52
	Non-Duty	27	40	27	42	28	42	28	41	26	39	26	40	27	40
Fall	Duty	61	47	61	49	61	48	63	49	62	48	61	50	61	49
	Non-Duty	30	44	30	42	30	43	28	42	29	43	30	41	30	42
Total	Duty	253	198	251	196	250	197	253	198	253	200	253	203	253	200
	Non-Duty	112	167	114	169	115	168	112	167	112	165	112	162	112	165

Average	5-Day	4-Day
Duty	252	199
Non-Duty	113	166

Appendix F

In this section, the tests for statistical significance are presented. For each test facility, the 5-day and CWS duty-day electricity consumption means were compared by season to determine if the differences were statistically significant. In each instance, the z-statistic indicated the difference in the sampling distributions were statistically significant.

Anova: Single Factor: Building A: Summer

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	219854414	21985	22983
4-Day	10000	231001528	23100	17569
			-1115	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6212907526	1	6212907526	306410.0713	0	3.841923647
Within Groups	405488384.2	19998	20276.44685			
Total	6618395911	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	21985	23100
Known Variance	22983	17569
Observations	10000	10000
Hypothesized Mean Difference	1115	
z	-1107.2	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building A: Fall

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	214364575	21436	38743
4-Day	10000	224986703	22499	28318
			-1062	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5641480162	1	5641480162	168249.8278	0	3.841923647
Within Groups	670540479.9	19998	33530.37703			
Total	6312020642	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	21436	22499
Known Variance	38743	28318
Observations	10000	10000
Hypothesized Mean Difference	1062	
z	-820.3	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building A: Winter

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	216524304	21652	48856
4-Day	10000	226232279	22623	42740
			-971	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4712238930	1	4712238930	102892.0045	0	3.841923647
Within Groups	915866637.2	19998	45797.91165			
Total	5628105567	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	21652	22623
Known Variance	48856	42740
Observations	10000	10000
Hypothesized Mean Difference	971	
z	-641.6	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building A: Spring

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	207169223	20717	55865
4-Day	10000	221458774	22146	38463
			-1429	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10209563389	1	10209563389	216468.9194	0	3.841923647
Within Groups	943187822.3	19998	47164.10753			
Total	11152751211	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	20717	22146
Known Variance	55865	38463
Observations	10000	10000
Hypothesized Mean Difference	1429	
z	-930.5	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building B: Summer

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	243690104	24369	63851
4-Day	10000	254329542	25433	48767
			-1064	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.66E+09	1	5.66E+09	100515.06	0	3.8419236
Within Groups	1.126E+09	19998	56308.795			
Total	6.786E+09	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	24369	25433
Known Variance	63850	48766
Observations	10000	10000
Hypothesized Mean Difference	1064	
z	-634.1	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building B: Fall

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	217036078	21704	136557
4-Day	10000	228370883	22837	106835
			-1133	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.424E+09	1	6.424E+09	52786.426	0	3.8419236
Within Groups	2.434E+09	19998	121695.87			
Total	8.858E+09	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	21704	22837
Known Variance	136557	106835
Observations	10000	10000
Hypothesized Mean Difference	1133	
z	-459.4	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building B: Winter

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5-Day	10000	184668229	18467	20324
4-Day	10000	192142498	19214	15927
			-747	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.793E+09	1	2.793E+09	154105.84	0	3.8419236
Within Groups	362472377	19998	18125.431			
Total	3.156E+09	19999				

z-Test: Two Sample for Means

	5-Day	*4-Day*
Mean	18467	19214
Known Variance	20324	15927
Observations	10000	10000
Hypothesized Mean Difference	747	
z	-784.9	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Anova: Single Factor: Building B: Spring

SUMMARY

Groups	Count	Sum	Average	Variance
5-Day	10000	205258374	20526	90253
4-Day	10000	213239103	21324	89578
			-798	

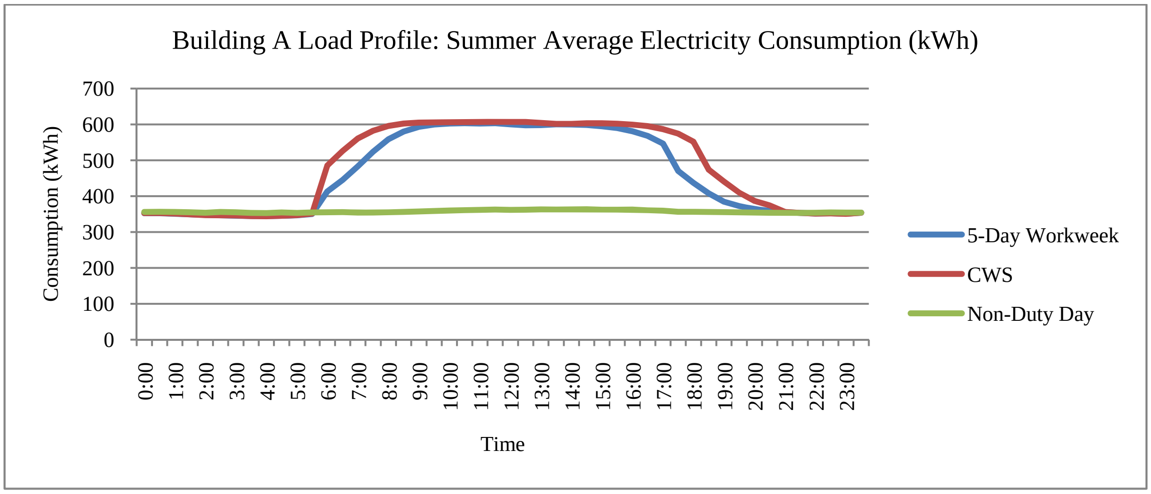
ANOVA

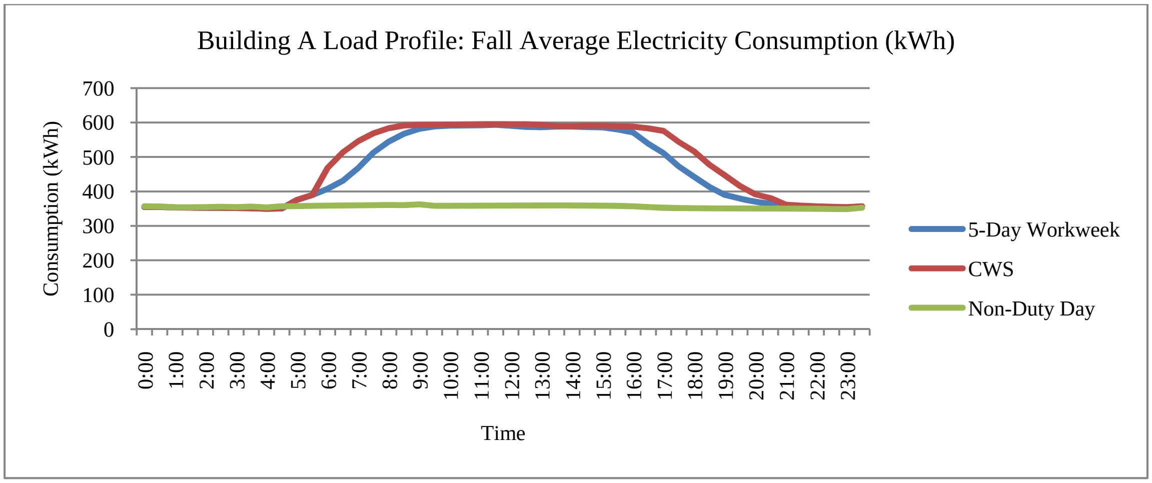
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.185E+09	1	3.185E+09	35417.775	0	3.8419236
Within Groups	1.798E+09	19998	89915.353			
Total	4.983E+09	19999				

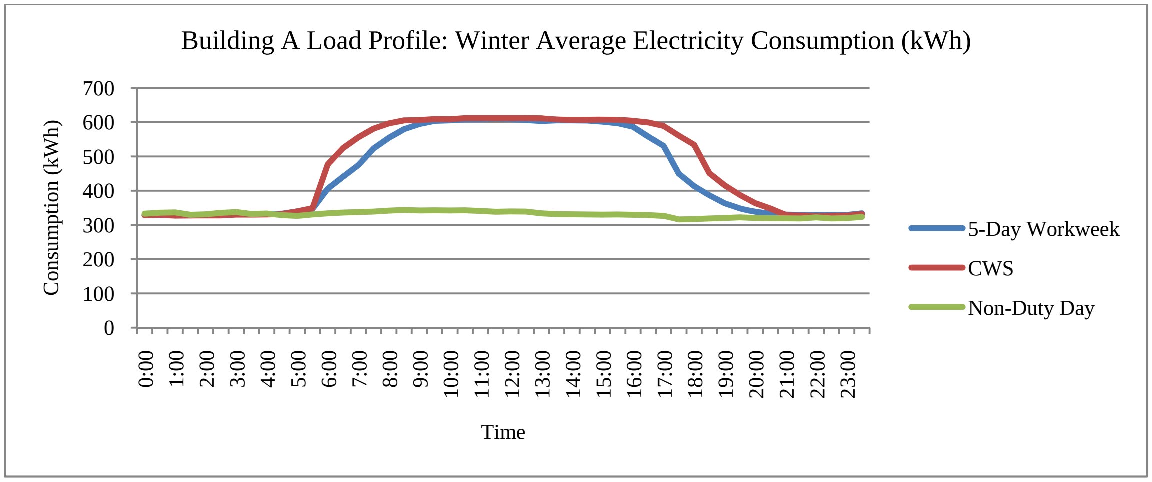
z-Test: Two Sample for Means

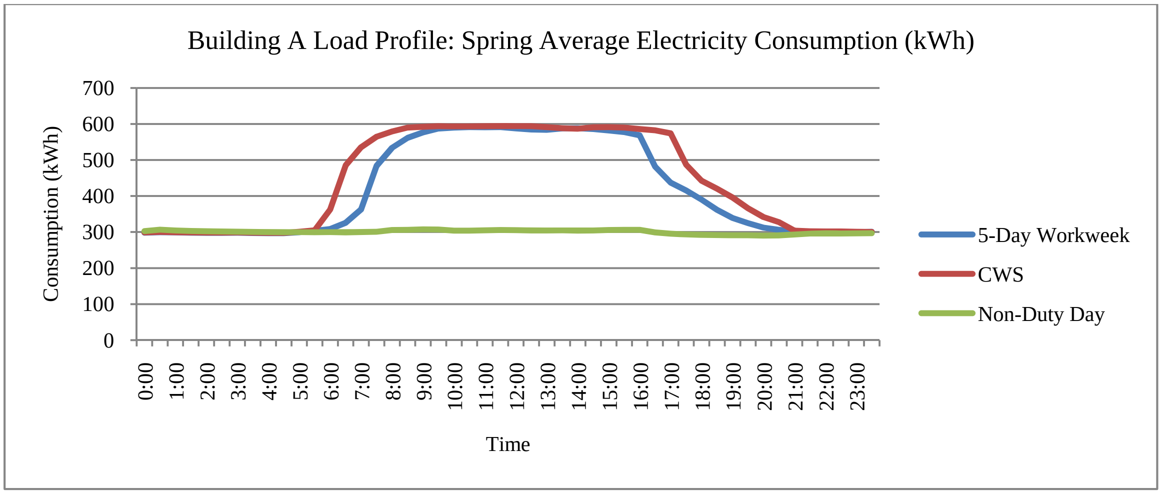
	5-Day	4-Day
Mean	20526	21324
Known Variance	90253	89578
Observations	10000	10000
Hypothesized Mean Difference	798	
z	-376.4	
P(Z<=z) one-tail	0	
z Critical one-tail	1.6449	
P(Z<=z) two-tail	0	
z Critical two-tail	1.9600	

Appendix G

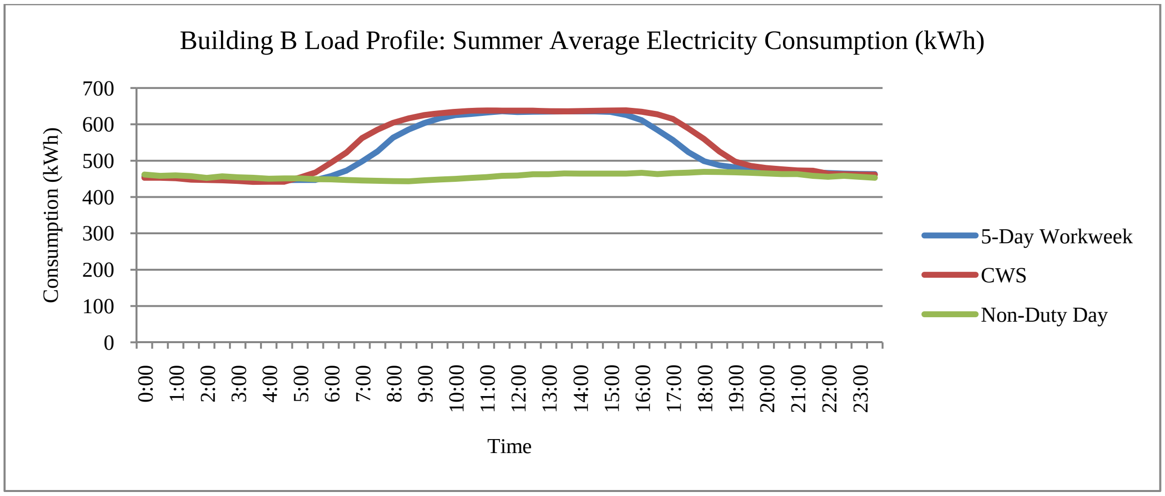

Building A Load Profile: Summer Average Electricity Consumption (kWh)
Consumption (kWh)
700
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day

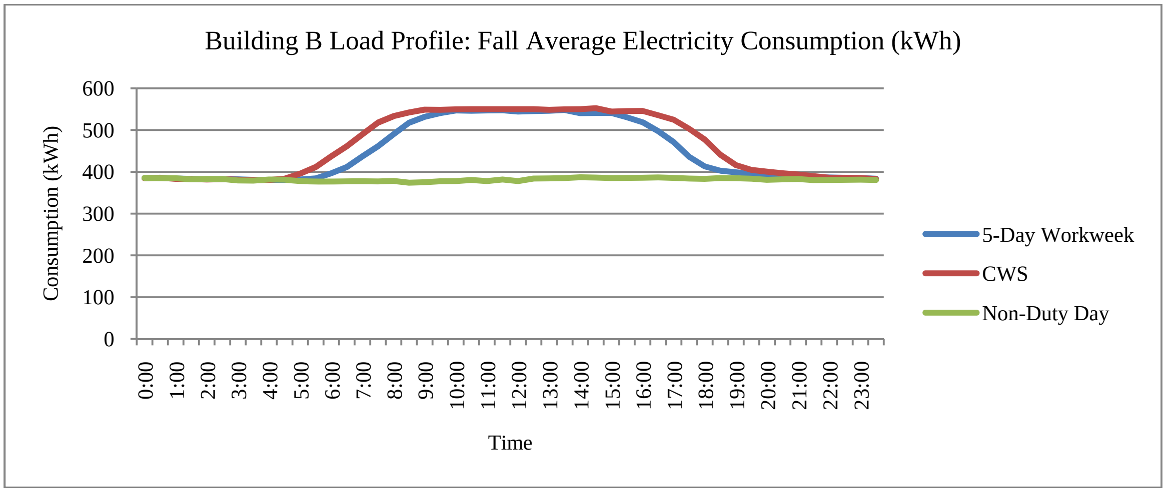

Building A Load Profile: Fall Average Electricity Consumption (kWh)
Consumption (kWh)
700
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day

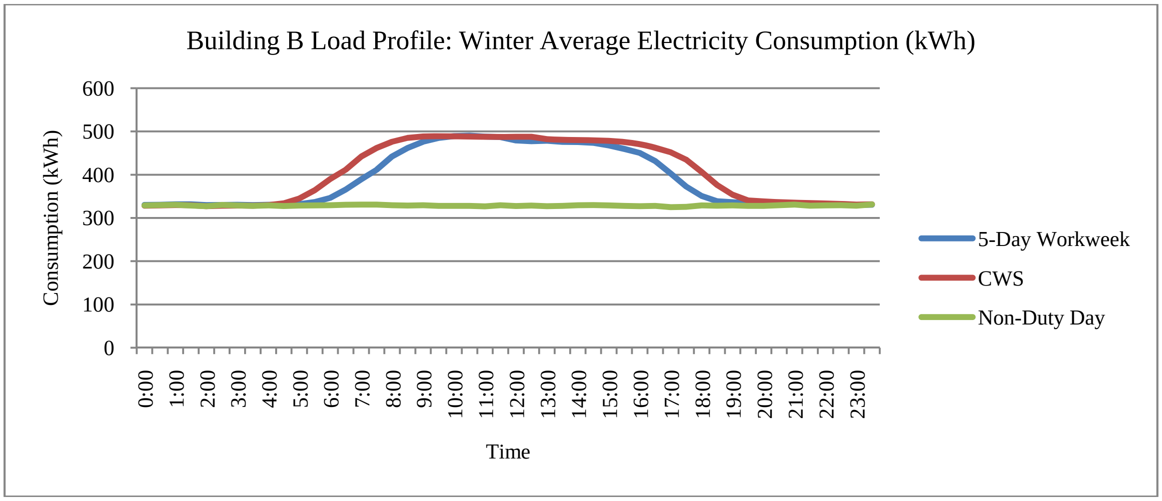

Building A Load Profile: Winter Average Electricity Consumption (kWh)
Consumption (kWh)
700
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day

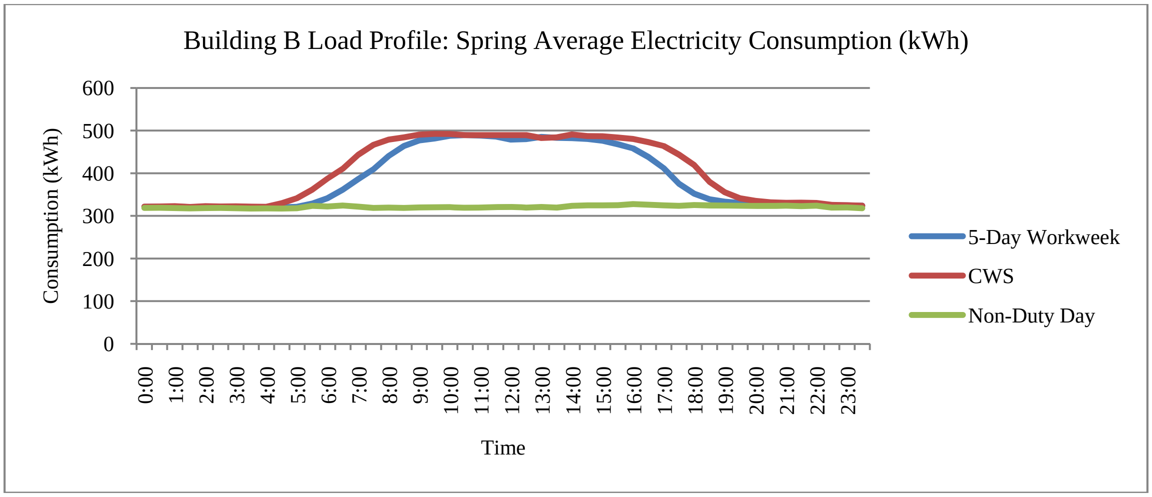

Building A Load Profile: Spring Average Electricity Consumption (kWh)
Consumption (kWh)
700
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day

Appendix H


Building B Load Profile: Summer Average Electricity Consumption (kWh)
Consumption (kWh)
700
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day


Building B Load Profile: Fall Average Electricity Consumption (kWh)
Consumption (kWh)
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day


Building B Load Profile: Winter Average Electricity Consumption (kWh)
Consumption (kWh)
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day


Building B Load Profile: Spring Average Electricity Consumption (kWh)
Consumption (kWh)
600
500
400
300
200
100
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
5-Day Workweek
CWS
Non-Duty Day

Appendix I

Building	A	B
Square Footage	235,445	155,010
# Floors	3 + 1 Sub-Floor	2 + 1 Sub-Floor
Layout	Office Space & Cubicles	Office Space & Cubicles
Approximate # Occupants	900	385
Hours of Operations	0600-1800, skiff 24/7	0700-1600
# Air Handlers	7	4
Air Handlers Turn-on/off	0500/1800	None
	3 Air handlers 24/7	
Heat	Steam	Steam

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14. ABSTRACT

As the largest energy consumer in the United States, the Department of Defense must consider all fiscally responsible means to improve energy efficiency. Budgetary and environmental concerns are a catalyst for numerous initiatives designed to reduce energy consumption. Congressional mandates outline the rate at which agencies must reduce facility energy use.
In this study, Monte Carlo simulation was used to compare electricity consumption, cost, and emissions produced under 5-day workweeks and compressed work schedules. The research provides energy managers a template for evaluating compressed work schedules as a means to improve energy efficiency.
The study found the relationship between the amount of electricity consumed on duty and non-duty days determines the effectiveness of compressed work schedules in improving energy efficiency. Electricity use in the test facilities on non-duty days was 72 to 90 percent of duty-day consumption. The resulting difference in electricity consumption, cost, and emissions was less than one percent when implementing compressed work schedules.
Compressed work schedules can incrementally improve energy efficiency for facilities with lower levels of electricity consumption on non-duty days. Therefore, energy managers will achieve greater gains in energy efficiency by improving the facilities themselves rather than focusing on the use of the buildings.

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