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EFFICIENCY IN DEPLOYED CAMPS: THE IMPACT OF CLIMATE ON DEPLOYED FORCE INFRASTRUCTURE LIFE CYCLE COSTS

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ABSTRACT

Access to secure and reliable energy sources are paramount to support the conduct of deployed operations. Although energy consumption has been steadily increasing on operations for decades, the magnitude of inefficiencies within deployed camps is noteworthy. Poorly insulated tented structures are employed for extended durations and a remarkable amount of energy is dedicated to heating or cooling these inefficient structures. The problem is further compounded by the influence of extreme hot and cold climates on overall energy consumption. Remarkably, climate is not an explicit consideration in the type of Deployed Force Infrastructure (DFI) selected to support an operation. This thesis explores the significance of climate on the energy efficiency of different types of DFI through the assessment of simulated deployed camps.

Natural Resources Canada assisted the Canadian Armed Forces in simulating a broad set of deployed camps in different climate regions. Four separate types of DFI, including two types of tents and two types of semi-permanents structures, were modelled in four distinct climate regions. The simulation study identified that heating and cooling are the greatest electrical demands within deployed camps by a large factor. Thus, a strong correlation was observed between exterior temperature and energy consumption. Deployed camps in cold climates were found to consume between one and a half to four times more fuel than an identical camp in a hot climate. Additional insulation was observed to greatly reduce heating costs in cold climates but was less significant than the impact of cooling equipment efficiency in hot climates. Improperly sized electrical generating equipment was observed to be more significant factor in determining fuel consumption than the type of DFI employed in all climates. The results of the study provided the foundational data used to create operational scenarios allowing the costs of different DFI to be assessed with time in different climates.

Operational scenarios were created for Goose Bay, Newfoundland and Labrador, Riga, Latvia, Manila, Philippines, and Kano, Niger. The costs to procure, transport and operate the DFI were estimated over a ten-year period for each location. The results of this study identified that higher standards of DFI become more economical than tents within one to two years in cold climates. Conversely, tents remained more economical than semi-permanent structures longer in hot climates since the overall costs related to heating and cooling were significantly less than in cold climates. Fuel and transport costs were observed to significantly alter the cost benefit of different DFI in each climate region. Transport costs were generally not a significant unless large amounts of movement by air were required. Where air movement was required, tented structures were favourable since tents can be moved more economically. The higher fuel costs associated with non-permissive operating environment reduced the buy-back period for higher standards of DFI and greatly increased the relative savings associated with employing a higher standard. In sum, the results of the assessments indicate that climate significantly affects energy consumption within deployed camps and greatly alters the cost benefit analysis when comparing different DFI.

Simulation proved to be an effective tool in assessing the energy efficiency of DFI in various climates. As this study highlights, the relative importance of climate is a key consideration in DFI procurements and selection of DFI standards for operations. Properly selecting DFI to operate efficiently within a given climate region was demonstrated to greatly reduce energy consumption creating greater resilience and energy security for the operation.

CHAPTER 1: INTRODUCTION

Access to secure and reliable energy sources are paramount to support the conduct of deployed operations. Although energy consumption has been steadily increasing on operations for decades, the magnitude of inefficiencies within deployed camps is noteworthy. Poorly insulated tented structures are employed for extended durations and a remarkable amount of energy is dedicated to heating or cooling these inefficient structures. The problem is further compounded by the influence of extreme hot and cold climates on overall energy consumption. Remarkably, climate is not an explicit consideration in the type of Deployed Force Infrastructure (DFI) selected to support an operation.

Considering these factors, what is the relevance of climate on Deployed Force Infrastructure (DFI) decisions? This essay will explore the importance of climate and type of DFI on the life cycle costs of DFI on operations. The study is presented in five sections. First, background information pertaining to DFI will be covered to highlight relevant literature, policy and doctrine. Second, current CAF DFI related practices will be discussed to identify the significance of climate in planning DFI support to CAF Operations as well as the observed effectiveness of CAF DFI in different climates. Third, an overview of a large DFI simulation study conducted by Natural Resources Canada will be presented to demonstrate the relative performance of different DFI in varied climate regions. Next, the results from the NRCan Simulation Study will be used to develop operational scenarios that will allow the relative cost of employing different DFI under various conditions to be assessed. The thesis will end with concluding remarks and recommendations pertaining to DFI planning, doctrine and life cycle management.

The Natural Resources Canada CANMETEnergy (NRCan) simulation study of deployed camps will provide the nucleus of data utilized in this study.[1] The study employed the FORCESIM simulation application that is capable of modelling Canadian Armed Forces (CAF) DFI, heating and cooling equipment as well as electrical generation equipment in any climate region. Numerous scenarios of various sized camps composed of different DFI were simulated in four separate climate regions. Variations of electrical generating equipment were assessed within in each scenario. As a result, the NRCan study provided results from sixty-four unique scenarios. Analysis of the data set helped to determine the relevance of factors such as the impact of climate, electrical generation equipment and camp size on energy efficiency in deployed camps. Further extrapolation of the data set into operational scenarios allowed the relative significance of operating costs associated with energy consumption to be compared with procurement and transportation costs.

The following points will be demonstrated in this thesis. First, the results of the NRCan simulation study will confirm that climate significantly affects energy efficiency in deployed camps. Similarly, the difference in energy efficiency will be shown to be directly related to the exterior temperature and type of DFI employed. Thus, higher efficiency DFI will be proven to be a more cost-effective alternative in most operating environments. Finally, the selection of electrical generation and heating or cooling equipment will be demonstrated to be a significant contributor to inefficiencies in deployed camps. Although the study will illustrate the relative importance of climate and type of DFI, the results are not intended to constitute a rigorous costing assessment.

[1] Stéphanie Breton et al., "Report of a Simulation-Based Study of the Power and Energy Requirements for Deployed Camps" (Natural Resources Canada, July 10, 2019), pp. 137.

CHAPTER 2: DEPLOYED FORCE INFRASTRUCTURE BACKGROUND

PROBLEM FRAMING

The Department of National Defence views access to adequate, reliable and affordable energy sufficient to meet mission essential requirements as a strategic capability that is vital to enable readiness and operations.[2] Nonetheless, the Canadian Army theorizes that the future operating environment will be characterized by conflict over energy supplies.[3] Global supply chains provide opportunities for adversaries to influence or control energy supply, often from outside the area of operations. Thus, energy can serve not only as an enabler but a weapon of war.[4] The notions of energy and security are thus intertwined from the strategic to tactical levels. Security of energy resources can be improved by increasing protection to energy supply chains or by reducing the overall demand through more efficient equipment or less wasteful operating practices.

Although energy is available in a variety of forms, diesel and petroleum products serve as the life blood of modern militaries. Energy consumption on operations has increased at a rapid rate since WWII. The gallons of fuel burned per soldier each day doubled between the first and second Gulf Wars.[5] Electrical generators now consume more fuel during combat operations than tactical vehicles or aircraft.[6] Furthermore, the majority of the electricity generated is used to

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[2] Canada and Department of National Defence, *Defence Energy and Environment Strategy: Harnessing Energy Efficiency and Sustainability : Defence and the Road to the Future.* (Ottawa: National Defence, 2017), p.8.

[3] Canada, Department of National Defence, and Canadian Army Land Warfare Centre, *Canada's Future Army, Volume 1: Methodology, Perspectives and Approaches.*, 2015, p.4.

[4] Constantine Samaras, William J. Nuttall, and Morgan Bazilian, "Energy and the Military: Convergence of Security, Economic, and Environmental Decision-Making," *Energy Strategy Reviews* 26 (November 2019): p.1.

[5] General Charles Wald (USAF Ret), "Energy Security - Americas Best Defense. A Study of Increasing Dependence on Fossil Fuels in Wartime and Its Contribution to Ever Higher Casualty Rates" (Deloitte, 2009), p.3.

[6] David B Moore, "Lean, Mean, and Green: An Expeditionary Imperative," *United States Marine Corps Command and Staff College Marine Corps University*, April 29, 2010, p.1.

cool or heat inefficient structures such as tents.[7] The demand continues to increase despite the costs in terms of money, materiel and lives. Although force protection measures can account for as much as 90% of the Fully Burdened Cost of Fuel (FBCE), a casualty occurred once in every twenty four US fuel resupply convoys in Afghanistan.[8] Current energy practices on operations trend towards supporting greater forms of comfort that further increase energy demands, particularly in military camps.

The multiplier effect of the logistical chain, combined with the non-permissive operating environment and large distances between the domestic and deployed theatre, contribute greatly to high fuel costs on operations.[9] Costs are incurred to move both materiel as well as massive amounts of fuel required to support deployed camps. The opportunity cost of the fuel demand are resources that could be expended elsewhere towards additional combat capabilities or development projects. In a broader perspective, the true costs to operate Deployed Force Infrastructure (DFI) are not reflected in life cycle costing conducted during operational level planning. Thus, efficient DFI are rarely employed despite the fact the higher initial capital costs would likely be rapidly recovered through reductions in energy consumption.

Climatic conditions significantly impact energy consumption on operations, particularly in extreme hot or cold environments. The cost to cool inefficient tented shelters in extreme hot climates accounts for as much as 75% of the overall electrical load of a deployed camp.[10] Since climate control require greater energy in cold climates, larger costs would be incurred in cold

[7] *Ibid,* p.2.
[8] David S. Eady, Steven B. Siegel, R. Steven Bell, and Scott H. Dicke, “Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys,” *Army Environmental Policy Institute*, September 2009, p. i.
[9] Eva Regnier et al., “The Fuel Multiplier in Multi-Stage Supply Chains,” *The Journal of Defense Modeling and Simulation* 12, no. 1 (January 1, 2015): 5–17, https://doi.org/10.1177/1548512913515362.
[10] Moore, “Lean, Mean, and Green: An Expeditionary Imperative." p.16.

climates than hot climates.[11] Remarkably, most militaries employ the same type of DFI in all climatic regions despite the extreme differences in climate. The infrastructure and equipment often perform adequately at best in moderate climates and poorly in the extremes. Thus, relatively inexpensive infrastructure employed on operations likely costs significantly more to operate than procure.

The relative performance of different DFI in different climate regions is poorly understood, as is the relative significant of the permissiveness of the operating environment on the life cycle costs of DFI. Since the costs associated with these factors are known to be sizeable, additional study is warranted to identify potential savings that could be achieved through an improved understanding of DFI in different environments.

LITERATURE REVIEW

The efficiency of deployed camps has always been an active research area in the military sector. The current literature tends to focus on individual components or factors that impact energy consumption in the camp. In particular, adaptations to electrical generation systems, shelters, camp operating methodology and user behaviour have been demonstrated to generate sizeable cost savings. Albeit, the studies are generally limited in scope supported by trials and modelling over relatively short durations such as the investigations of various types of "huts" by the US Army Corps of Engineers Engineering Research Development Centre.[12] A recent doctoral dissertation on Computing Tools for Designing Self-Sufficient Military Base Camps serves as a rare example of a thorough holistic assessment of camp operating costs,[13] although

[11] Michael Sivak, "Air Conditioning versus Heating: Climate Control Is More Energy Demanding in Minneapolis than in Miami," *Environmental Research Letters* 8, no. 1 (March 2013): 014050, p 3.

[12] Megan A Kreiger, "ERDC/CERL TR-15-19 'The Structural Insulated Panel "SIP Hut": Preliminary Evaluation of Energy Efficiency and Indoor Air Quality,'" , pp. 128.

[13] Nathan Hassan Putnam, "Computer Tools for Designing Self-Sufficient Military Base Camps" (thesis, 2012), p. 52.

the study aims to optimize the US standardized 150-person camp system to a given scenario rather than assess operating costs between different climates and types of deployable infrastructure.

US and Canadian military research scientists have focused heavily on defining the true costs of fuel on operations. The Fully Burdened Cost of Energy (FBCE), a commonly accepted concept in the early 2010's, included the original cost of fuel as well as the cost of personnel and assets required to move, store and protect the fuel once received from the commercial supplier.[14] However, the challenges in defining input costs were found to reduce the consistency of the model leading to sizeable differences in FBCE for the same theatre. FBCE values for US forces in Afghanistan presented in the literature have ranged from $0.79/US Gal to $105/US Gal. Similarly, the Canadian Defence Scientist Ahmed Ghanmi estimated the costs to assure fuel delivery in support of CAF Operations in Afghanistan as ranging between 1.62 $/L[15] and 5.17 $/L.[16] Although the FBCE is no longer extensively employed, the literature recognizes the incredible growth in fuel consumption, wasteful practices and fuel dependency that has developed since WWII.[17] Accurate characterization of true fuel costs on operations remains an important topic discussed frequently in the literature.

The voluminous amounts of literature on transportation costs generally focus on civilian policy issues or attempts to quantify the decrease in global shipping costs that have occurred with time. Military literature is more limited and typically focus on methodologies to reduce transportation costs through various means, such as a study by a McGee et al on the assessment

[14] Paul C. Tisa, "Department of Defense Energy and Logistics: Implications of Historic and Future Cost, Risk, and Capability Analysis" (Ph.D., United States -- Pennsylvania, Carnegie Mellon University, 2016), pp. 317.

[15] The author is referring to Canadian dollars when a country is not denoted next to a $.

[16] Ahmed Ghanmi, "Fully Burdened Cost of Energy in Military Operations" (2012 First International Conference on Renewable Energies and Vehicular Technology, Defence Research and Development Canada - Centre for Operational Research and Analysis, 2012), pp. 10.

[17] Moore, "Lean, Mean, and Green: An Expeditionary Imperative." p. 52.

of transportation practices.[18] Regnier et al's introduction of the 'fuel multiplier' effect in multi-stage supply chains demonstrates that logistics activities themselves consume a significant amount of fuel.[19] Each additional logistical node increases the overall logistical requirements considerably. Studies linking transportation costs to local procurement options, particularly within different operational scenarios, are lacking from the literature.

Assessments of life cycle costing of military equipment in the literature tend to be limited to large combat platforms. The areas of DFI and accurate definition of operating costs on operations have garnered little attention. Although, the challenges with identifying realistic and accurate operating scenarios have been identified as impeding proper life cycle assessments.[20] Thus, the literature is limited in effectively linking camp operating costs to DFI life cycle decisions. The CAF Costing Manual provides no specific guidance on the life cycle costing of tents or the methodology to capture transportation and true fuel costs on operations. This is despite the fact multiple studies exist that demonstrate the operating costs of military equipment generally outweigh acquisition costs by a ratio of 3 to 1.[21]

DFI FACTORS IN CAF DEFENCE POLICY

CAF defence policy relevant to DFI will be presented to highlight the requirement for DFI on operations as well as the emphasis placed on energy efficiency within policy. Current Canadian defence policy envisions a CAF ready and capable to conduct expeditionary operations, engage in capacity building with partners and support allies where shared interests

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[18] Joshua B. McGee, Manuel D. Rossetti, and Scott J. Mason, "Quantifying the Effect of Transportation Practices in Military Supply Chains," *The Journal of Defense Modeling and Simulation* 2, no. 2 (April 1, 2005): 87–100.

[19] Regnier et al., "The Fuel Multiplier in Multi-Stage Supply Chains," pp. 13.

[20] Andrés Navarro-Galera, Rodrigo I. Ortúzar-Maturana, and Francisco Muñoz-Leiva, "The Application of Life Cycle Costing in Evaluating Military Investments: An Empirical Study at an International Scale," *Defence and Peace Economics* 22, no. 5 (October 2011): 509–43.

[21] *Ibid*, p. 510.

are at stake. To achieve this aim, *Strong Secure Engaged* (SSE) provides the CAF with the mandate to be prepared to support multiple operations concurrently. The majority of missions within the SSE concurrent mission set would likely require DFI. Thus, the CAF must possess the capability to concurrently manage multiple camps in different theatres ranging in size from 100 to 1500 personnel.[22] Although DFI and energy consumption on operations are not explicitly addressed within SSE, innovation of camps and alternative energy initiatives within the policy are relevant to the discussion in this study.

Climate change and energy efficiency addressed within SSE focus on two main themes: the security threats posed by climate change and the government's commitment to reduce greenhouse gas emissions. The climate change threats presented include the potential of climate issues to create regional insecurity and the challenges to Canadian sovereignty from an increasingly accessible Arctic. The CAFs response to climate change is thus correlated to improving readiness levels to respond to natural disasters as well as improving energy efficiency within DND. Greenhouse gas reductions are addresses through multiple initiatives to improve energy efficiency within a domestic setting. However, SSE initiative 102 to examine alternative energy options and their potential use for operations constitutes the only discussion on energy efficiency or greenhouse gas reduction on operations within the policy.

The Innovation for Defence Excellence and Security (IDEaS) Program initiated via SSE calls on innovators to propose and develop solutions in areas critical to future defence needs. The IDEaS "Pop up City" program is aimed at soliciting innovative solutions to provide reliable, efficient, integrated and scalable energy, water and waste management systems for Relocatable Temporary Camps (RTC). The competition will be assessed on the ability of the solutions to

[22] Canada and Department of National Defence, *Strong, Secure, Engaged - Canada's Defence Policy.*, 2017, p 82.

manage the energy, water and waste needs of a 150 to 1,500-person RTC operating in a temperate climate zone. The impact of different climates will not be considered in the competition. The competition is currently in the initial round of a four-round process.

DEFENCE ENERGY AND ENVIRONMENT STRATEGY

DND's policies on energy pertaining to DFI will be presented to highlight the aspects that impact deployed camps. The Defence Energy and Environment Strategy (DEES) represents an evolution in policy through the collective management of energy and environmental issues. The policy constitutes DND's response to the Federal Sustainable Development Strategy that was implemented as a result of the adoption of the UN 2030 Agenda on Sustainable Development. DEES reinforces Canada's commitment to the Paris Climate Accord through the target for DND to reduce greenhouse gas emissions to 40% below 2005 levels by 2030. As the largest consumer of energy in the Canadian Government, DND retains a central role in the Government's emissions reduction strategy.[23] DEES comprises four main objectives: reduce energy waste, move to cleaner energy production, reduced Defence environmental footprint and better managed energy and environmental performance.

Initiatives conducted to achieve DEES objectives are categorized into four categories: energy efficiency, sustainable operations, green procurement, and sustainable real property. Due to the unpredictability of CAF operations, federal emission reduction targets do not include emissions from military activities and operations. As a result, the majority of DEES initiatives focus on domestic infrastructure, vehicles and training areas, although reductions of energy consumption and emissions within operational activities are encouraged. Overarching all initiatives is the mandate to procure military equipment that is "as energy efficient as is

[23] Canada and Department of National Defence, *Defence Energy and Environment Strategy,* 2017, p.5.

practical" in order to reduce operating costs and minimize environmental impacts.[24] As a result, expenditure estimates must now emphasize energy performance as well as environmental considerations through all life cycle phases.

DFI related initiatives presented in DEES reside within the energy efficiency category. The target to reduce petroleum-generated electrical energy consumption by 50% at deployed camps by 2030 constitutes the most stringent requirement. Additional measures include the promotion of energy conservation through awareness and training, the use of cleaner fuels for the military fleet, designing more efficient soldier equipment, and the provision of more efficient power solutions for operations. Improving awareness aims to ensure energy savings opportunities and best practices are considered in all decisions at all leadership levels. The investigation of the use of alternative fuel blends aims to maintain interoperability with allies and increase energy security and resiliency on operations. Efficient solider equipment will incorporate smaller light weight energy generating capabilities for dismounted soldiers. Field heaters and generators are to be replaced with modern fuel-efficient systems to improve efficiency on operations. Each of these activities will serve to reduce energy consumption within deployed camps.

CAF DEPLOYED FORCE INFRASTRUCTURE DOCTRINE

Canadian Forces Joint Publication (CFJP) 3-12.2 Force Beddown governs DFI on operations. The publication superseded B-GL-361-012/FP-001 Accommodations, Installations and Engineering Services previously drafted by the Canadian Army in 2015. CFJP 3-12.2 is currently being revised with the aim to modernize and align the doctrine with NATO ATP-3.12.1.4 Deployed Force Infrastructure. Due to the hierarchy of doctrine, this thesis will focus

[24] *Ibid*, p. 21.

on the standards and principles presented in CFJP 3-12.2. The infrastructure standards, climate and transport considerations presented in the doctrine will be highlighted to frame current DFI practices relevant to this study.

Each of the two doctrines subscribe to the common principle that infrastructure standards at any given location are expected to be improved with time. The current CFJP utilizes tactical, initial, temporary and permanent standards whereas the revised CFJP and NATO Doctrine employ a numbered Tier system. Current CAF doctrine prescribes a sequential series of infrastructure improvements planned to occur within specific timeframes. CJFP 3-12.2 infrastructure standards are presented below.[25]

Tactical Standard (arrival in theatre until Initial Standard established) - DFI established within the means and resources of a unit.

1. Initial Standard (less than six months depending on facility) - austere facilities that may require replacement or upgrade during the course of operations.
2. Temporary standard (six to 24 months) - minimal facilities for sustained operations. Can be employed from the start of an operation when it is judged to be more cost or operationally effective than a shorter duration standard.
3. Permanent (more than two years) - purpose built, robust infrastructure that could include the occupation of existing buildings upgraded to suit required needs.

The revised CFJP, when released, is intended to mirror the NATO Tier system. The Tier system prescribes longer timeframes within each infrastructure standard, allows for overlap of timeframes between Tiers and permits different Tiers to be employed within separate components of the same camp. For example, a Tier 3 electrical system could be implemented

[25] Canadian Joint Operational Command, "CFJP 3-12.2 Force Beddown 1st Edition" (Minister of National Defence, 2015), p. 1-2.

within an overall Tier 1 camp and kept in place for over 10 years. The NATO Tier system is as follows.[26]

1. Tier 1 (several weeks to months) - support is what the initial personnel deploying on operations can carry within the Unit.
2. Tier 2 (one to two months to two years) - austere working and living space.
3. Tier 3 (over six months to more than 10 years) - semi-permanent accommodation for the sustainment phase of an operation. A cost-benefit analysis should be completed to validate the increase in standard over the planned duration of the mission.
4. Tier 4 - Permanent infrastructure and installations.

CFJP 3-12.2 identifies four climate zones: temperate, tropic, frigid and desert. An assortment of planning considerations ranging from drainage, orientation of tents to shield from wind or sun and foundation and road design are presented. The Canadian doctrine does not provide guidance in terms of climate considerations on the selection of DFI or the standard employed. However, the Tier process is intended to be supported by cost-benefit analysis that provides solutions with reduced operation and maintenance costs that justify the capital expenditure. Climate considerations, particularly energy efficiency, would be reflected in the cost benefit analysis as the DFI progressed slowly from Tier 2 to 3.

Guidance on scales of accommodations and consumption rates are also provided in CFJP 3-12.2 to support the sizing of facilities and engineering services on deployed camps. Recommended scales are provided for nearly all types of facilities including accommodations, kitchens, ablutions, canteens, recreation areas, gyms, administration and storage as well as support and maintenance areas. Consumption rates are provided for water and electrical use as

[26] NATO, "NATO Standard ATP- 3.12.1.4 Deployed Force Infrastructure Edition A Version 1" (NATO Standardizaton Office, August 2018), p 1.

well as rates for waste and wastewater generation. Since CAF DFI equipment have never possessed integral metering capabilities, the doctrinal planning values have been developed without the benefit of consumption data measured on operations. Thus, the accuracy of the planning rates on operations remains to be validated. Doctrinal planning rates relevant to this study are summarized in Table 2.1.

Category	Type of Facility	Rank	Scale
Facility Sizing	Accommodations	Officer	7.5m^2/person
		Sgt/WO	7.5m^2/person
		Junior NCM	6.0m^2/person
	Ablutions – Washbasins	All Ranks	12.5% of personnel[27]
	Ablutions – Showers		12.5% of personnel
	Ablutions –Water Closet		12.5% of personnel
	Ablutions - Urinals		10% of male personnel
Consumption Rate	Basic load	All Ranks	3.0 kW/person[28]

Table 2.1 – Relevant Doctrinal Scale of Accommodations and Consumption Rates.[29]

The NATO Allied and Environment Conditions and Test Publication Climatic Conditions defines standard climate categories correlated to specific regions of the world.[30] Maps of the climate categories are presented within Leaflet 2311/1 of the doctrine. The climate categories include temperature and humidity extremes serving as a reference point to compare climate between regions. The doctrine also provides guidance on the impact of temperature and humidity on military equipment during transportation, storage and handling. Relevant NATO climate conditions and characteristics are summarized in Table 2.2.

[27] Thus, a force of 500 personnel would require 500 x 12.5% = 63 washbasins, showers, toilets and urinals.

[28] Includes accommodations (heating, minimal air conditioning), ablutions, kitchen (includes freezer), water (includes hot water), sewage treatment. Does not include workshops or emergency power. Electrical planning rates are erroneously reported in units of kW/hr/person rather than kW/person.

[29] Canadian Joint Operational Command, "CFJP 3-12.2 Force Beddown 1st Edition.", p 3-2.

[30] NATO Standardization Agency, "AECTP-230 Climatic Conditions" (NATO, May 2009), pp. 147-143.

Climate Category	Description	Temp (°C)	Relative Humidity (%)
A1 Extreme Hot Dry	Areas which experience very high temperatures namely, hot dry deserts of North Africa, parts of the Middle East, northern India and south-western USA.	32 to 49	8 to 3
C1 Cold	Areas that experience moderately low temperatures such as central Europe, Japan and the central USA.	-21 to -32	Trending to Saturation

Table 2.2 – NATO AECTP 230 Edition 1 Climate Categories.

CAF DEPLOYED FORCE INFRASTRUCTURE CAPABILITIES

The CAF employs generic in-service systems as well as contracted DFI solutions tailored to specific operations. In-service DFI capabilities include the Tent Expandable Modular System (TEMS or Mod Tent), Headquarters Shelter System (HQSS) and the Relocatable Temporary Camp (RTC) suite of equipment. Each DFI system is intended to be employed within certain timeframes of an operation and managed at different levels within the CAF. Tactical systems, such as TEMS and HQSS, are employed by line Units and serve as the initial or Tier 1 standard of DFI. RTC serves as an operational level system constituting a temporary or Tier 2 standard of infrastructure. The CAF regularly employs DFI solutions other than tents on longer duration operations to improve quality of life standards. These include contracted ISO-based solutions or US style Hut systems that fulfil the semi-permanent or Tier 3 standards. Alternative solutions are available up to and including contracted construction or leased infrastructure serving as a permanent or Tier 4 standard. The components and purpose of each DFI system employed by the CAF will be highlighted herein as the equipment be discussed in detail within the results of the simulation study results.

TEMS is composed of a modular aluminium frame system covered by canvas. Each module is 2.5 x 5.4 m and is capable of being connected to other modules along the long axis of

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the tent. A variety of sub-systems, such as breezeways and carrefours, are available to allow for multiple configurations including crosses or H shapes. Thin cloth liners can be added within the system to provide a very small amount of additional insulation. TEMS is utilized for accommodations, command posts as well as office and storage space. The system is poorly suited for extreme cold and heat and is susceptible to damage in very high winds. A typical TEMS system is presented in Figure 2.1.

Figure 2.1 – CAF Tent Expandable Modular System.[31]

HQSS is intended to provide a deployable headquarters capability for the first nine months of a mission for all climate conditions including the Arctic. The system is composed of a modular aluminium frame system covered by canvas. However, components of the frame can be extended to raise the tent and the canvas is considerably more robust than TEMS. Shelters are available in different variants including operations (12.8 x 7.1 m), planning (6.3 x 7.1 m) and office (3.1 x 7.1 m) shelters. The Canadian Joint Operational Command (CJOC) intends to employ plans shelters as accommodations on operations. All variants can be connected to create

[31] "Canadian Army Steps in to Help with U.S. Asylum Seekers," *Mtltimes.Ca* (blog), August 10, 2017, https://mtltimes.ca/Montreal/montreal/canadian-army-steps-help-u-s-asylum-seekers/.

custom headquarter configurations or separated to create single use areas such as accommodations or medical facilities. A typical HQSS is presented in Figure 2.2.

Figure 2.2 – Headquarters Shelter System showing a Plans Shelter.[32]

RTC is composed of a variety of fabric structures, electrical generation, electrical distribution, ablutions, laundry facilities, waste management facilities and a variety of other niche and periphery equipment. The suite is intended, less a few capabilities, to fulfil DFI requirements within the 6 to 24-month period of an operation for nearly all climate conditions. A variety of Weatherhaven® shelters, ranging from 8 person accommodations to large administration or storage facilities, are available within the RTC suite. The Modular Tented System Lite (MTS Lite) and Series 4 (S4) tents are the most commonly employed accommodations shelters on CAF operations and are roughly 4.9 m x 9.8 m. The accommodations shelters are similar in structure although the MTS Lite does not have an integral flooring system. The MTS Lite and S4 tented accommodations structures are presented in Figure 2.3.

[32] Breton et al., "Report of a Simulation-Based Study of the Power and Energy", p 21.

S4 Accommodations Tent with Solar Shade

MTS Lite Accommodations Tent

Figure 2.3 – RTC MTS Lite and S4 Weatherhave® Accommodations Tents. Note the S4 has an integral flooring system as well as closer spaced support arches.[33]

Alternative DFI solutions typically incorporate variants of containerized systems or US style huts. The systems provide additional comfort, air and water tightness as well as significantly improved energy efficiency compared to fabric shelters.

Containerized Solutions. Installation costs are considerably higher and require longer timeframes for installation than tented structures. In addition, larger amounts of specialized engineering support are required during design while greater amounts of skilled labour and heavy equipment are required during construction. Two common container-based infrastructure solutions employed by the CAF include ISO Flatpacks and prefabricated containerized solutions.

ISO Flatpacks. The flatpacks are pre-fabricated structures that are transported unassembled in 'packs' of three to four shelters to minimize movement costs. Once on site, the components of the system are relatively easy to install and can be stacked up to three stories in height dependant on the manufacturers design.

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[33] "Weatherhaven - Products," accessed April 2, 2020, https://weatherhaven.com/Products.

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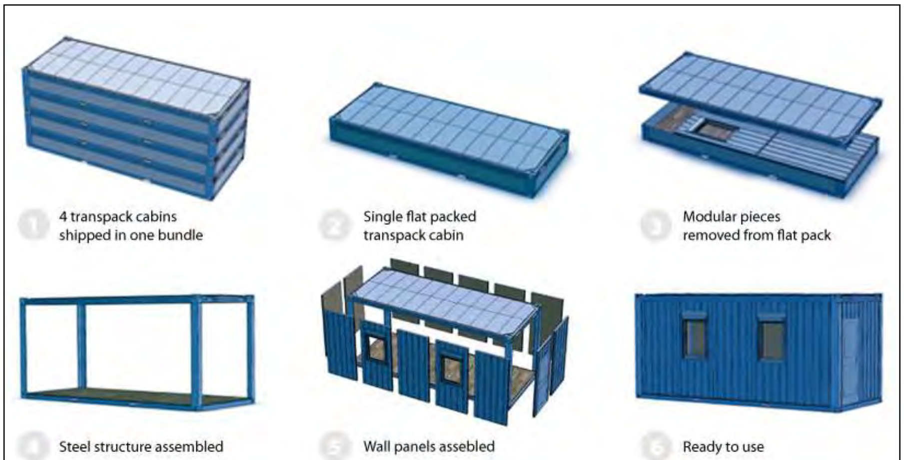
ISO Containerized systems. The systems are pre-fabricated off-site and are simply lifted into place once on site. The systems cost more to ship, require additional manufacture time but can be customized and greatly increase construction speeds on site.



ISO Flatpack

Pre-fabricated Containerized Infrastructure

Figure 2.4 – ISO Flatpack[34] and Containerized DFI Solutions.[35]

[34] "Pacific Modular - From Flat Pack and Telescopic Solutions to 5 Star Modular Hotel Designs, Pacific Modular Can Tailor Make the Perfect Solution for You.," accessed April 2, 2020, http://www.pacmodular.com/poducts_flat_pack.html.

[35] "Https://Www.Willscot.ca/Mobile-Offices/Office-Trailers," accessed April 2, 2020, https://ef349129d2344efda14e2e8340afcede.pages.ubembed.com/882ae900-2318-41d8-82ba-1e3696d1d5c0/a.html?closedAt=0.

US Military Style Huts. The US Military has produced a variety of 'Hut' designs including the South East Asia Hut (SEAHut) and South West Asia Hut (SWAHUT). Each hut design is 4.9 x 9.8 m and is tailored to the climate of the region where it will be deployed. For example, the SEAHut has openings covered by screen mesh at the top and bottom of the walls. The openings allow hot air and humidity common in the region to ventilate from the structure while preventing insects and animals from entering. Huts can be constructed using materials procured locally or shipped from North America. The Huts are assembled on site using specialized trades personnel or contractors. Construction timeframes are longer than tents but considerably shorter than containerized solutions. Photographs of typical Hut style infrastructure are presented in Figure 2.5.

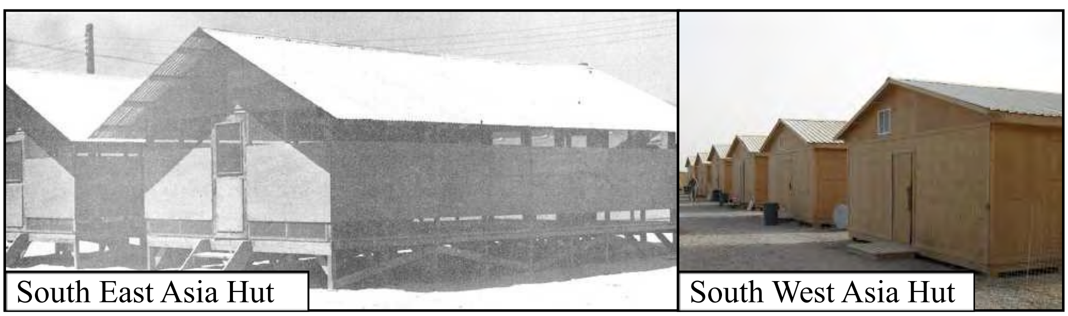


Figure 2.5 – US Mililtary Hut Style Structures.[36],[37]

The Mobile Expandable Container Configuration (MECC) Ablutions produced by Weatherhaven® serves as the most commonly employed ablution system within the CAF. The system constitutes a single 20 ft ISO shipping container that expands on site to provide 5 x showers, 5 x sinks, 5 x urinals and 5 x toilettes. The expandable side compartments are

[36] "Sea Hut," accessed April 2, 2020, http://constructionmanuals.tpub.com/14044/css/Sea-Hut-262.htm.
[37] Kreiger, "The Structural Insulated Panel "SIP Hut", p. 22.

composed of insulated fabric while the main compartment is formed by insulating the ISO Container. A typical MECC Ablution is presented in Figure 2.6.

Figure 2.6 – Interior and Exterior View of Mobile Expandable Container Configuration Ablutions.[38]

CAF FUEL SUPPLY ON OPERATIONS

The CAF's fuel supply methodology will be discussed to highlight practices and costs relevant to the operation of deployed camps. Fuel is typically contracted within the region of operations. Ground based resupply is generally employed between the supplier and the CAF reception point. The character of the operating environment has a significant impact on the cost and effort required to resupply fuel. Landlocked and non-permissive operating environments have the greatest impact on fuel delivery costs, timeframes and security of supply. Illustrative of this concept is the Fully Burdened Cost of Energy (FBCE) that includes all the costs associated with delivery of fuel to the point of use including force protection, transport, storage and purchase prices. The FBCE for CFS Alert was 800% the cost of the fuel alone. Similarly, the FBCE to various FOBs in Afghanistan ranged between 200 and 500%.[39] These FBCE

[38] "Weatherhaven - Products."
[39] Ghanmi, "Fully Burdened Cost of Energy in Military Operations", p. 413.

correspond to fuel costs of $8.85/L and $2.02/L to $3.49/L in terms of 2012 fuel prices. The fuel costs in Latvia, Kuwait and Goose Bay, Newfoundland were $1.96/L[40], $0.96/L[41] and $0.92/L[42] respectively as recently reported by in-situ CAF personnel. It is clear that the cost of fuel varies significantly regionally and dependent upon the permissiveness of the operating environment.

The quality of fuel varies regionally throughout the world. Certain regions, particularly Africa, supply considerably lower quality fuels than are available in North America or Europe. The poorer quality fuels result in lower operating efficiency and increased maintenance requirements of electrical generators. Fuel costs on operations are loosely tracked within the CAF logistical system. As such, it is not possible to identify costs specific to DFI less sporadic instances where deployed engineers or logisticians implemented manual tracking systems. Even with fuel cost data, the fully burdened cost of fuel in a CAF theater has not been assessed since Op ATHENA in Afghanistan.

CAF MOVEMENT IN SUPPORT OF OPERATIONS

Transportation costs and methodology will be discussed as these costs will impact the cost benefit analysis conducted in subsequent chapters. The CAF employs a variety of capabilities to support strategic movement of DFI equipment. Integral capabilities include air transport assets, such as the C-130 Hercules and C-17 Globemaster, as well as ground transport assets composed of a diverse fleet of trucks. The CAF regularly supplements integral resources with contracted sea, ground and air solutions to move lower priority items, specialized equipment or large inventories.

[40] Major John Dempsey, “Engineer Camp Costs,” February 8, 2020.
[41] Major Aarthi Prabhakaran, “FW: Deployed Force Infrastructure Costs,” November 8, 2019.
[42] Major Andrew Vandor, “RE:Deployed Force Infrastructure Cost,” November 15, 2019.

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Due to the economy of scale, operations that require the movement of large quantities of materiel are frequently supported via contracted movement by sea where feasible. The CAF maintains a Global Sustainment Sealift Contract (GSSC) that services Ukraine, Germany, Latvia, Kuwait, Ghana, Kenya and Senegal from 3 CSU in Montreal. The GSSC employs a unit cost per shipping container arrangement where the contracted movement costs to Europe are roughly half of the those to Africa or the Middle East.

Conversely, the CAF typically employs integral assets to conduct movement by air. The DND Cost Factor Manual establishes the operating cost of a C17 as $25,306 per hour.[43] Thus, the cost to move a full C17 containing approximately 3 sea containers worth of material to Germany would be approximately $46,000. The fifteen-fold additional cost to move by air versus sea substantially alters the life cycle cost comparison between DFI solution where sea lift is not feasible.

CAF LIFE CYCLE COSTING

Life Cycle Costing (LCC) assists in comparing costs between different alternative courses of action by assessing costs in the development, acquisition, operations, sustainment and disposal phases of a given capability.[44] LCC of the CAF capital program was recently changed from a cash and accrual basis to a purely accrual basis.[45] Operating costs were previously managed outside the capital program within annual cash allocations. Since acquisition projects were only responsible for the accrual portion of the capital budget, operating costs were less relevant to the approval processes since the costs were expected to be borne outside the project.

[43] Department of National Defence, "Cost Factors Manual - Volume II - Equipment and Facility Costs" (Government of Canada, 2015 2014), p. 3.
[44] Vrenti Ghergari, Lily Wang, and Abderrahmane Sokri, "Development of Cost Breakdown Structure for Defence Acquisition Projects" (DRDC – Centre for Operational Research and Analysis, May 2016), p. 3.
[45] Canada and Department of National Defence, *Strong, Secure, Engaged - Canada's Defence Policy*, p. 44.

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As a result, operating costs were typically underestimated by a large extent.[46] Funding for capital projects will now be managed on a purely accrual basis greatly simplifying the LCC process and increasing the relevance of accurately predicting operating costs.

CAF LCC must conform to the Treasury Board Guidelines on Cost Estimation for Capital Assets. The guidelines highlight the uncertainty of estimating future cost due to a variety of factors including the nature of the capital asset as well as the planned pattern of use of the capital asset over time. Costing in accordance with guidelines requires activities that result in a cost, the time when the cost will be incurred, and the relationship between the level of activity to the amount of resources that will be consumed to be defined.[47] In terms of DFI, the duration, location, climate and operating environment impact the planned use of the resource therefore affecting the LCC.

Although overarching Treasury Board policy exists, CAF specific direction on LCC remains fragmented since specific direction is not provided for all types of equipment in the CAF. Furthermore, the DEES mandate to consider energy efficiency and environmental impacts has yet to be captured in policy or doctrine. The DND Cost Factor Manual, the main reference pertaining to costing, provides information on the operational costs of various equipment and facilities. The costs presented include petroleum, oil, lubricants, spare parts, retrofit and overhaul as well as amortization costs. However, costing information specific to DFI are not presented. Consequently, the RTC project life cycle cost was estimated based on historical purchased and quotes from industry.[48] The estimate excluded important costs such as training, maintenance and storage resulting in frequent and sizeable unforecasted costs. Furthermore, the

[46] *Ibid.*.
[47] Treasury Board of Canada, "Archived - Guideline on Cost Estimation for Capital Asset Acquisitions," accessed February 4, 2020, https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=30094&section=html.
[48] Andre Picard, "RE: Life Cycle Management Costs," January 16, 2020.

support requirements within different operating environments and climates were not considered. A potential approach involves evaluating the performance of DFI in different scenarios, wartime versus peace or different climates, and averaging the results.[49] A scenario-based cost assessment that considered different climates has yet to be conducted for DFI within the CAF.

[49] Ghanmi, "Fully Burdened Cost of Energy in Military Operations", p. 406.

CHAPTER 3: DFI PRACTICES ON CAF OPERATIONS

This chapter will provide a general assessment of CAF DFI related practices on operations in order to highlight standard procedures as well as energy efficiency and climate considerations currently employed. A baseline appreciation of current practices is necessary to understand the similarities and deviations that exists with the camps modelled in the simulation study as well as to inform the operational scenarios presented in subsequent chapters. This section will open with a summary of DFI practices on three operations that possess sizeable amounts or unique types of DFI. Subsequently, an overview of the energy efficiency related activities associated with the Integrated Camp Utilities Technologies (I-CUT) will be presented to identify electrical consumption rates and wasteful practices observed on operations. Finally, an assessment of current activities will be presented to identify best practices and areas for improvement within DFI doctrine and employment methodology.

CAF DFI ON OPERATIONS

The CAF has employed DFI in multiple different regions and climates zones within the past five years. Although leased, contracted and allied or Host Nation (HN) DFI solutions were most commonly employed on smaller missions, blended solutions that included tented camps were regularly employed on larger operations. This study will focus on the DFI employed on Op IMPACT in Kuwait, Op REASSURANCE in Latvia and Op NABERIUS in Niger due to the large quantities or unique DFI employed. Furthermore, the significantly different climates the camps are situated in will allow insights to be made about the impact of climate on energy efficiency in camps. The camps and associated climates are also similar to those modelled in the NRCan simulation study and will thus allow useful comparisons to be drawn. Finally, the DFI on these operations were metered as part of the Integrated Camp Utilities Technologies (I-CUT).

The assessment of these camps will illustrate that the CAF consumes sizeable amounts of fuel operating DFI and that the consumption rates vary significantly by climate.

Many details presented in this section are taken from the author's personal experience while employed within the Joint Engineer in the Canadian Joint Operational Command. As a staff officer in the operations and equipment management teams, the author was intimately involved in coordinating DFI support to these operations between 2016 and 2019. The DFI practices from these operations are summarized below to facilitate an understanding of current DFI employment methodologies and energy efficiency performance.

Operation REASSURANCE eFP Battle Group (BG)

A multi-national BG was deployed in the summer of 2017 to Adazi, Latvia as part of NATO's enhanced forward presence in Eastern Europe.[50] Canada served as the Framework Nation responsible for command and management of the BG. Founded in a NATO C1 Intermediate climate[51], Latvia possesses a permissive operating environment that greatly facilitated the deployment, particularly the construction of DFI. A mix of HN, RTC and contracted solutions were utilized in support of the BG. A ship was contracted to move 90 sea containers of DFI related equipment to Latvia at an estimated cost of $252,000[52] and fuel was supplied via a contractor within the region.[53]

A theater opening element was deployed with a large engineer contingent. The lead engineer element oversaw separate teams engaged in project management or establishment of

[50] National Defence, "Operation REASSURANCE," education and awareness, aem, May 1, 2014, https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-reassurance.html.

[51] NATO Standardization Agency, "AECTP-230 Climatic Conditions.", p. 163.

[52] The cost was estimated as a proportion of the total cost to move all theater opening equipment.

[53] Lion Capt JP, "RE: Movement Cost Data," June 14, 2019.

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CAF DFI equipment.[54] DFI support was provided in three main areas: accommodations and ablutions areas to augment permanent Host Nation (HN) barracks, an operational area for CAF maintenance and support as well as operational areas for some Troop Contributing Nations (TCN). With over a year of planning time and the presence of HN infrastructure, Roto 0 personnel effectively occupied a semi-permanent standard DFI upon arrival.

Two large RTC camps were constructed to provide accommodations and ablutions for BG personnel. MTS Lites and MECC Ablutions were used to support both camps. The camps were subsequently combined at a single location in order to vacate terrain for future construction by the HN.[55] The combined camp was established on permanent tent pads and the HN constructed ablutions roughly two years after the initial deployment. Deployed CAF engineers subsequently converted the camp to operate on HN electricity.

The remainder of RTC equipment was combined with contracted large tented structures to establish the operational areas for both the CAF and other Troop Contributing Nations (TCN). The RTC components were established prior to the arrival of Roto 0 while the operational areas were in place within three to six months of the original deployment. Larger more complex permanent facilities, such as the task force headquarters and Role 2 medical facility, were initiated employing contractors for both the design and construction. Although the MIR was recently completed, the task force headquarters project is ongoing.

The CAF infrastructure is maintained by CAF engineers who also support regular training activities. Since an energy manager position is not included in the team, no formal energy management practices or procedures are employed within the DFI. Thus, energy

[54] The author was employed as an engineer planner at the Operational level during Theater Opening.
[55] The author was employed in the engineer operations and equipment management teams at the operational level once theater opening was completed.

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consumption or the magnitude of wasteful practices are not well understood.[56] As a result, no restrictions on energy use are in place. The doctrinal electrical consumption rate of 3kW/person was used to plan the accommodations areas. Electricity was initially provided by three separate CAF generator farms composed of multiple single speed generators ranging in size from 150 kW to 500 kW. The CAF generators were employed with a load bank and continue to be used in the operational area.

Operation IMPACT

Operation IMPACT began in 2014 as the Canadian Armed Forces (CAF) support to the Global Coalition to degrade and ultimately defeat Daesh in Iraq and Syria.[57] The operation has subsequently evolved into a Whole of Government approach to the region focused on assisting with building the militaries of Jordan, Lebanon and Iraq.[58] Leased infrastructure is utilized in more permissive environments with lower concentrations of personnel such as Jordan and Lebanon. Allied, HN and contracted semi-permanent facilities are typically employed in Iraq. The main operating base at Ali-al-Salem-Air-Base in Kuwait (AASAB) is comprised of HN infrastructure augmented by RTC for accommodations, ablutions, office and recreational space. This study will focus on the DFI in Kuwait as it is the only location that employs CAF owned DFI equipment. AASAB is located in a NATO A1 Extreme Hot climate region[59] and possesses a permissive operating environment.

[56] LGen M.N. Rouleau, "CJOC Integrated Camp Utilities Technologies (I-CUT) Programme Annual Report 2018" (CJOC, July 23, 2019), p. 2.

[57] National Defence, "Operation IMPACT," education and awareness, aem, August 19, 2014, https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-impact.html.

[58] *Ibid*.

[59] NATO Standardization Agency, "AECTP-230 Climatic Conditions.", p. 152.

The deployment of Op IMPACT occurred over two to three months in the fall of 2014.[60] A theatre opening team was deployed to construct an RTC based camp that leveraged existing infrastructure.[61] A semi-permanent standard was established early in Roto 0. DFI resources were moved via air due to the rapid timeframe of the deployment and fuel is contracted in theater. The amount of DFI equipment transported during theater opening could not be confirmed. A sea movement contract was subsequently established to support sustainment activities.[62] Portions of the camp were recently replaced as a result of the contracted construction of a containerized accommodations building.[63] The majority of the original MTS Lites remain in place serving as additional capacity for tactical visits, relief in place and potential surges in personnel.

The headquarters and accommodations of senior personnel are supported via HN infrastructure that was renovated during theatre opening. A variety of large tented structures and small containerized DFI have been incorporated within the CAF footprint since the original deployment. DFI maintenance is overseen by CAF engineers who complete the work with integral resources or oversee contracted support.[64] An energy manager has not been appointed and little formal energy management practices occur. As a result, controls or standards on energy, particularly air conditioning, and water use do not exist. The doctrinal consumption rate of 3kW/person for electricity was used to plan the accommodations portion of the camp. Contracted suppliers provide electricity to the camp via three larger generators farms composed of multiple 500 kW to 1000 kW generators.

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[60] Odding, "Original Report AASAB Electrical Issues August 2017," October 23, 2018.
[61] The author was involved in the initial planning of DFI support at the tactical level and subsequently at the operational level.
[62] Andrew Desrochers, "RE: Movement Costs," January 9, 2020.
[63] Captain Eric Dodd, "RE: Accommodations Building Kuwait," March 11, 2020.
[64] Aarthi Prabhakaran, "FW: Deployed Force Infrastructure Costs," November 8, 2019.

Operation NABERIUS

Operation NABERIUS is a training mission that was originally conducted by CANSOFCOM prior to transitioning to CJOC.[65] CAF personnel generally deploy twice a year to support two to three-month training programs for the Niger Defence Force. A small Theatre Coordination Element (TCE) remained on the main operating base of an Ally to coordinate support for the training teams when CJOC served as the force employer. Niger is located in a NATO A1 Extreme Hot climate[66] and possess a non-permissive operating environment. DFI resources were moved via air due to the land-locked location. A total of two sea containers of material were required to support the construction of two SWAHUT and tactical tents were flown as required. Fuel is supplied by Allies locally.

The tactical standard tents were employed to support the training teams who conduct shorter duration tasks. The coordination element was initially housed in similar tented structures relying on Allied infrastructure for ablutions. SWAHUT were subsequently constructed after several years, with the assistance of the US Naval Construction Battalion, to support the coordination element. CANSOFCOM has subsequently reassumed the mission and no longer require the SWAHUT. Energy management practices were not employed on the mission due to the small scale and readily available support from allies in theater. Electricity was provided via tactical generators provided by the CAF or loaned from Allies based on 3kW/person presented in doctrine.

[65] National Defence, "Operation NABERIUS," education and awareness, aem, October 20, 2017, https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-naberius.html.

[66] NATO Standardization Agency, "AECTP-230 Climatic Conditions.", p. 152.

Summary

The CAF generally utilizes a blend of infrastructure supplied via integral resources, Allies or contractors. Sea transport serves as the preferred method of transportation with integral air resources employed where sea lift is not feasible due to time constraints or land locked location. The CAF employs doctrinal consumption rates when designing deployed camps. Energy efficiency was not a key considerations deployment and operation of DFI on recent operations as priority was placed on the timeline to establish the camps. Initiatives to improve energy efficiency on deployed camps will be discussed in the next section to illustrate the level of energy management that presently occurs.

INTEGRATED CAMP UTILITIES TECHNOLOGY (I-CUT)

The CAF has led and participated in a variety of initiatives pertaining to energy efficiency within deployed camps since 2014. The Integrated Camp Utilities Technology (I-CUT) program serves as the primary CAF led initiative. NRCan provides support to I-CUT by metering electrical consumption within CAF's deployed camps as well as through the development of simulation tools. Although the metering data are limited in quantity and duration, the data are useful to understand real world energy consumptions. The I-CUT metering and simulation study will be highlighted to detail the methodology used to derive the data assessed in this study.

Overview

The CAF's energy efficiency initiatives pertaining to deployed camps were originally loosely coordinated within an interdepartmental team led by NRCan.[67] The metering activities

[67] LGen Bowes, "CJOC Implementation Plan Integrated Camp Utility Technologies (I-CUT)", p. 7.

initially focused on domestic training exercises and were nested within the Integrated Camp Energy Technologies (ICE-T) program that commenced in 2014.[68] In 2017, in response to the Defence Environment and Energy Strategy (DEES) Target 9 to reduce petroleum-generated electrical energy consumption by 50% within deployed camps by 2030, ICE-T initiatives were transferred and expanded upon within the Integrated Camp Utilities Technologies (I-CUT).[69] A deployed camp must meet the following conditions to fall within the DEES mandate: not be located in Canada; fall under the command of CJOC; not include a ship or commercial semi-permanent or permanent infrastructure; be occupied for at least six months; and utilize CAF pattern electrical generation and accommodations equipment. Since data measured on operations were not available at the inception of I-CUT, reductions were measured against the peak power demand of 3 kW/person presented in doctrine.[70] It is important to note that the doctrinal value constitutes a peak power load rather than the energy consumed and is thus more relevant to sizing electrical generating equipment than facilitating life cycle costs. I-CUT comprises the following three decisive points.

Energy Accounting. Accurate and quantifiable environmental performance metrics are highlighted in SSE as a necessity to properly gauge the effectiveness of initiatives aimed at "greening" the Defence Team.[71] CAF DFI does not possess an integral metering capability nor has energy consumption in deployed camps been measured and reported systematically.[72] Initial efforts within the I-CUT program were conducted in domestic training camps between 2012 and 2016. The efforts were aimed at developing a monitoring capability composed of metering

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[68] *Ibid,* p.1.
[69] Canada and Department of National Defence, *Defence Energy and Environment Strategy*, p. 14.
[70] Canadian Joint Operational Command, "CFJP 3-12.2 Force Beddown", p. 3-11.
[71] Canada and Department of National Defence, *Strong, Secure, Engaged - Canada's Defence Policy*, p. 76.
[72] LGen Bowes, "CJOC Implementation Plan ...", pp. 10.

equipment, planning and analysis tools, data management tools and training for monitoring specialists. Once the foundational capabilities were developed, efforts were focused on metering deployed camps. The Energy Accounting decisive point was considered achieved in 2019 once all camps within the DEES mandate were outfitted with a monitoring capability.[73]

Energy Awareness. Implementation of energy efficient technologies have been observed to create negligible savings, or even cost increases, when implemented without engaging the users.[74] Initiatives to promote awareness of the importance of energy efficiency were conducted concurrently with Energy Accounting projects commencing in 2018.[75] DFI planners and specialists were originally targeted through updates to doctrine, promulgation of I-CUT orders, working groups, and energy efficiency training initiatives. Awareness activities subsequently evolved to inform deployed users, staff and commanders in 2019.[76] The Energy Awareness decisive point remains ongoing.

Energy Action. Energy comprises targeted interventions that seeks to either modify user behaviours, implement more efficient technologies or employ a combination of the two. Examples include restricting heating or cooling in DFI or installing higher efficiency heating or cooling equipment. Energy Action activities have yet to commence since adequate baseline data to properly assess the effectiveness of targeted efficiency interventions continues to be collected. Targeted interventions are slated to begin in 2020.[77]

To facilitate the implementation of I-CUT, Natural Resources Canada CanmetENERGY in Varennes, Quebec (NRCan) has been engaged since 2012 to develop standardized equipment,

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[73] BGen Harding, "Update 002 - FY 19/20 Implementation Plan…", p. 1.
[74] Natural Resources Canada, "Who Creates Savings…", Presentation.
[75] LGen Bowes, "CJOC Implementation Plan…", p. 3.
[76] BGen Harding, "Update 002 - FY 19/20 Implementation Plan…", p. 2.
[77] *Ibid*, p.2.

data protocols, training packages, planning tools, reporting criteria and the FORCE-SIM simulation tool.[78] Engineering staff within CJOC and electrical technicians on operations work closely with NRCan to develop and refine all aspects of the program. The NRCan team also leads the NATO SPS G5525 project launched in the fall of 2018 that aims to develop energy monitoring and camp simulation tools for NATO. Due to the dual role of NRCan, the capabilities and practices developed within I-CUT thus conform to NATO standards. The benefits of standardized data and equipment greatly facilitate interoperability within NATO where energy efficiency initiatives often vary by Nation.[79]

I-CUT On Operations

The monitoring component of I-CUT commenced in 2014 with prototype metering equipment validated in a domestic setting.[80] The equipment was subsequently deployed on operations in 2017 with feedback from technicians used to inform multiple equipment modifications.[81] As a result, data collection on operations has been interrupted frequently to rectify issues or complete upgrades. Metering is currently conducted on two operations; Op IMPACT on Ali Al Salem Air Base (AASAB) in Kuwait and Op REASSURANCE on Camp Adazi in Latvia.[82] Metering was also conducted on Op NABERIUS in Niger but was recently stopped since the DFI was no longer utilized.[83] Monitoring observations from deployed camps will be discussed to highlight the scale of energy consumption associated with operating DFI on operations.

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[78] LGen Bowes, "CJOC Implementation Plan..." p.7.

[79] NATO, "Smart Energy Team (SENT) Comprehensive Report: On Nations' Need for Energy in Military Activities, Focusing on a Comparison of the Effectiveness of National Approaches to Reduce Energy Consumption," May 6, 2015, p. 64.

[80] LGen S. Bowes, "CJOC Implementation Plan…" p.7.

[81] *Ibid*, p.2.

[82] Shawn Burdett, "RE: I-CUT Annual Report," March 11, 2020.

[83] *Ibid*.

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Op REASSURANCE. Metering is conducted in a 500-person tented camp that provides accommodations for personnel employed in the Enhanced Forward Presence BG (eFP BG). The characteristics of the camp presented herein are taken from the 1 Engineer Support Unit (1 ESU) metering installation report.[84] The camp is composed of roughly 47 MTS Lites and five MECC Ablutions. Internal electric heaters are used to provide heat and the camp is not air conditioned. Electricity is generated by two 500 kW CAF generators. A load bank is employed in the generator farm to ensure the generators operate at optimal speeds by introducing additional load when demand decreases. Due to the need to move the camp and upgrade aspects of the electrical system, reliable metering data only exists for the period between August and December 2018. The population of the camp during this period varied roughly between 375 and 525 personnel.[85] Key observations from the 1 ESU Annual Monitoring report for 2018/19 are presented below.[86]

1. Electrical power demand correlated inversely with temperature due to the electrical heat source utilized and lack of air conditioning. Lower temperatures created higher demand.
2. The daily peak electrical power demand, excluding the demand from the load bank, varied between 250 kW in the fall and 390 kW in the winter. The peak ambient temperatures correlated to these demands were approximately 19 °C and -5°C respectively.
3. A correlation between camp occupancy and electrical demand was not observed. Heaters likely run continuously regardless of occupancy or personnel are spread thinly amongst the tents.

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[84] Capt Nathan Williams, “Installation Report 1 ESU Energy Monitoring Op REASSURANCE, Latvia,” May 24, 2019, p. 6.
[85] Capt Williams, “Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19”, p. A-3/5.
[86] Capt Williams, "Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19", pp. 5.

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4. The draw for electrical heating was multiple times greater than any other demand (excluding the load bank which is not required for all electrical generator farms).

5. The load bank consumed roughly 225 kW of the peak power in the fall and 100 kW in the winter. Without a heating load, the generators were underworked causing the load bank to increase demand. The load bank wasted 88% of the energy produced in the fall and 33% in the winter.

Op IMPACT. Although Op IMPACT is supported with a diverse blend of infrastructure throughout the Middle East, metering is only conducted in the Life Support Area (LSA) on AASAB. The characteristics of the metered infrastructure presented herein are taken from the 1 ESU metering installation report.[87] The LSA is mainly composed of tented structures supporting accommodations, office space, recreation, medical and C2 facilities. The accommodations area contains 54 MTS Lites each fitted with two 18,000 BTU ductless split heat pump systems to provide heating and cooling. Electrical power is provided to the accommodations via two 500 kW generators without the use of a load bank. As a result of the rented generators, the camp does not fall within DEES reporting. Due to equipment upgrades, reliable metering data is only available for the fall of 2018 and winter of 2019. Thus, the full impact of air conditioning during peak cooling season was not captured. The population of the camp during this period varied approximately between 170 and 240 personnel.[88] Key observations from the 1 ESU Annual Monitoring Report for 2018/19 are presented below.[89]

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[87] Capt Nathan Williams, "Installation and Energy Monitoring Report - Op IMPACT 2018," November 28, 2018, p. 4.

[88] Capt Williams, "Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19", p. B-1/5

[89] Capt Williams, "Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19.", pp. 5.

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1. Power demand correlated directly with temperature due to the use of air conditioning and limited heating requirement. Higher temperatures created greater demand.
2. The daily peak power demand varied between roughly 450 kW in the fall and 250 kW in the winter. The peak ambient temperatures corresponding to these peak loads were approximately 30°C and 18°C respectively.
3. A correlation between camp occupancy and electrical demand was not observed. Air conditioners likely run continuously regardless of occupancy or personnel are spread thinly amongst the tents.
4. Peak daytime demands were 500% greater than night time loads. The electrical demand at night was relatively constant at approximately 75kW.
5. The generators typically operate within 20 to 30% of their peak capacity due to the lack of a load bank. As generators operate more efficiently at higher loads, decreasing the number of generators would allow generators to operate more efficiently and reduce rental costs.

Op NABERIUS. The characteristics of the infrastructure metered are drawn from the 1 ESU metering installation report.[90] The two SWAHUT used to support the Theatre Command Element (TCE) are metered on Op NABERIUS. The SWAHUT provide accommodations, office space, a Tactical Operations Centre (TOC) and kitchenette for up to 20 to 30 personnel. Two 18,000 BTU ductless splits heat pump are used to provide heating and cooling for each SWAHUT. Electricity is provided by allied generators and distribution systems that power the overall camp. Roughly three personnel reside in the SWAHUT continuously but occupancy

[90] Major Dan Arcouette, "RE: Op NABERIUS - Materials," October 10, 2018, pg 1.

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surges to roughly 30 personnel for two to three days in duration as training teams arrive in theatre before deploying forward.[91] Metering data is only available for the month of August 2019. Key observations from the installation and monitoring report for Op NABERIUS are presented below.[92]

1. Climate data was not collected to correlate to the electrical demand.
2. The peak power demand remained steady between 4 and 5 kW.
3. Peak daytime demands were 500% greater than night time loads. The electrical demand remained relatively constant at 1 kW at night.

<u>Discussion</u>

Although data measured across all seasons over multi-year periods has not been measured, a strong correlation between energy consumption in tented structures and temperature has been identified in both hot and cold climate zones. Electrical loads from heating and cooling constituted the largest demand in CAF tented structures by a substantial factor. This trend aligns with observations from other studies.[93] Sizeable variations in daily and monthly electrical demands were also observed in these climates. A lack of correlation between electrical demand and number of camp occupants is the result of poor energy management practices. Thus, the doctrinal planning value of 3kW/person provides a poor correlation for estimating electrical demands since it is based solely on camp population. As metering on operations continues to expand in scope and duration, refined planning values can be attained for different climates in order to refine doctrine.

[91] The Author worked in the engineer operations and equipment management teams at the operational level during the construction of the SWAHUT.
[92] Capt Nathan Williams, "Installation and Energy Monitoring Report - Op NABERIUS 18," October 5, 2018, pp. 5.
[93] Moore, "Lean, Mean, and Green: An Expeditionary Imperative.", p. 20.

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ASSESSMENT OF DFI PRACTICES

DFI practices on operations will be compared to DFI doctrine in order to assess the adherence to and relevance of doctrinal guidance. Then, an assessment of climate and energy related measures undertaken in deployed camps will be presented to identify best practices and areas for improvement. The section will conclude with an evaluation of DFI costing practices pertaining to DFI deployments that will be used to inform scenarios presented in subsequent chapters.

Adherence to Doctrine

The CAF frequently employs multiple standards or Tiers at the same time. Planners at the operational level seek to leverage existing HN or coalition infrastructure prior to constructing facilities for the CAF. As a result, both semi-permanent and permanent infrastructure are employed concurrently on Op IMPACT and Op REASSURANCE. Although the DFI on Op NABERIUS evolved to semi-permanent standard, the CAF leverages the semi-permanent and permanent facilities available on the larger alliance base. This practice provides greater economy of effort and aligns with the recently updated NATO DFI doctrine slated to be adopted in the near future by the CAF. Furthermore, semi-permanent and permanent structures are more energy efficient.

The CAF generally implemented semi-permanent standards of DFI faster than suggested by doctrine due to the planning time available or a desire from the chain of command. Although doctrine suggests that the semi-permanent standard is intended to support the 6 to 24-month period, a semi-permanent standard can be established at the outset of a mission provided the increase in standard is cost effective.[94] It is important to note that the establishment of a high

[94] Canadian Joint Operational Command, “CFJP 3-12.2 Force Beddown 1st Edition.", p. 1-2.

quality camp is more challenging under time constraints. Energy efficiency, transport costs and quality considerations require additional planning time to properly assess. Since nearly a year of planning time was available for Op REASSURANCE, semi-permanent accommodations camps were constructed in time for the arrival of Roto 0 personnel with minimal quality issues. However, the rapid deployment and desire to achieve a semi-permanent standard early during Op IMPACT resulted in quality issues with the electrical system and other DFI components.[95] The episodic employment utilized on Op NABERIUS allowed the tactical standard to be adequate to support the mission with minimal issues. The CAF conforms to doctrine but accepts reduced quality and energy efficiency where significant time constraints exist during theatre opening and HN infrastructure is unavailable.

CAF frequently sustains semi-permanent standards longer than the 24-months current doctrine suggests.[96] In particular, the MTS Lite is commonly deployed for extended periods. Although a semi-permanent containerized accommodations building was completed on AASAB in 2019, the MTS Lites have remained in place to support surges in personnel since 2014.[97] The tents have deteriorated significantly due to UV exposure and weakening of glued seams from the extreme temperatures.[98] Similarly, the MTS Lites on Op REASSURANCE have remained in place since 2017, albeit with minimal issue. The CAF is currently employing DFI practices similar to the NATO standards, where the semi-permanent standard ranges from 6 months to 10 years. CAF doctrine is currently being revised to include timeframes for the semi-permanent standard similar to those presented in NATO doctrine.[99] However, it is clear that energy

[95] Cohn Odding, “Original Report ASAB Electrical Issues August 2017,” October 23, 2018.
[96] Canadian Joint Operational Command, “CFJP 3-12.2 Force Beddown 1st Edition." p. 1-2.
[97] Captain Eric Dodd, “RE: Accommodations Building Kuwait,” March 11, 2020.
[98] Steve McCready, “RE: RTC Return,” March 6, 2018.
[99] NATO, “NATO Standard ATP-3.12.1.4 Deployed Force Infrastructure Edition A Version 1.", p. 1-1.

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consumption costs were not? considered in the decision to retain tented structures in theatre for extended periods in extreme climates.[100]

Climate and Energy Practices

Despite the significantly different climates, the same type of DFI was deployed on multiple operations. The MTS Lite was used in the extreme heat of Kuwait as well as the moderate cold of Latvia. This practice does not contradict CFJP 3.12.2 Force Beddown and NATO ATP 3.12.1.4 Deployed Force Infrastructure as guidance on climate considerations pertaining to DFI selection are not discussed within the doctrine. The practice resulted in significant electrical demand for heating and cooling as noted in the I-CUT results. The demand in the colder climate of Latvia was significantly greater that the hot climate of Kuwait. Furthermore, the tented structures experienced different failure mechanisms in extreme heat and cold. Although the employment of one type of DFI simplifies training requirements, equipment procurement and management as well as installation and maintenance, the practice results in highly inefficient camps that generate sizeable logistical support requirements.

The CAF adheres to doctrinal planning values for consumption rates in deployed camps. However, these rates remain to be validated in theatre and guidance has not been provided on the impact of climate on consumption rates. Intuitively, greater consumption of water would occur in the extreme heat. Similarly, sizing of electrical generators is based on the doctrinal value of 3kW/person in all climates despite significant differences in the heating and cooling equipment employed. CAF doctrine provides little guidance in terms of the impact of climate on deployed camps and thus climate is not an important consideration in DFI selection. The impacts associated with the lack of DFI doctrine pertaining to climate will be discussed below.

[100] The Author assisted with DFI assessments at the operational level for the operations discussed in this thesis.

CAF electrical generation equipment is composed of single speed generators and load banks. The equipment is highly efficient when operating at constant demand near the design capacity of the generator. However, the efficiency of the generators decreases rapidly as the demand decreases. In an oversimplification of the process, proper sizing of a generator involves assessing the "load profile", or how electrical demand varies with time, in a deployed camp. A generator is then selected that best meets both the peak demand as well as variability of demand in the system. The CAF sizes generators based almost exclusively on the peak load as load variability is addressed by employing the load bank. As a result, considerable amounts of energy are wasted in load banks or rented generators operate in highly inefficient ranges. This is despite the fact more efficient alternatives such as variable speed generators and load management equipment are currently available on the market. In sum, current practices indicate climate and efficiency are not key consideration in generator selection within current CAF doctrine.

Comfort standards have not been established for CAF deployed camps. As a result, the interior temperature of DFI are controlled at the individual user level. User behaviour has been identified as having the greatest impact on energy efficiency in buildings in Canada, even greater than technological solutions.[101] The fact that a correlation between camp occupancy and energy consumption was not observed indicates that energy is poorly managed within deployed camps. It is clear that the CAF unintentionally heats or cools empty tents as has been noted to occur on American deployed camps. [102] Since studies have identified that nearly 75% of the electricity deployed camps is used to heat or cool tented structures, the savings from limiting wasteful user behaviour could be significant.[103] At present, energy consumption and associated user

[101] Natural Resources Canada, "Who Creates Savings...", Presentation.
[102] Moore, "Lean, Mean, and Green: An Expeditionary Imperative.", p. 2.
[103] *Ibid*, p. 16.

behaviours are not controlled on operations. In summary, current DFI doctrine is unreliable for planning and costing estimates owing the excessively generic nature of the doctrine.

DFI Costing practices

The CAF costing manual does not define a methodology for costing DFI. As a result, the RTC project was costed in a relatively informal process that aimed to adhere to best practices[104]. Large inventories of equipment were purchased based on the assumption that a single suite of DFI would be utilized to support every mission. Current DFI practices on operations demonstrates that the majority of the CAFs DFI requirements are met with HN, Allied or contracted infrastructure. As a result, sizeable portions of the RTC suite have never deployed but incur significant storage and maintenance costs.[105] In-service costs were focused on rates of replacement or design life and did not consider climate, transport or deployment scenarios. Thus, the impact of energy efficiency in extreme climates, fuel transport to support the camps in non-permissive environments or the cost of transport to remote locations was not considered in the life cycle analysis. The results of the I-CUT monitoring indicate that the costs to operate deployed camps are sizeable. These costs will impact life cycle comparisons between DFI.

Summary

The CAF relies heavily on DFI to support operations. Current DFI doctrine does not adequately reflect the importance of climate and DFI type on energy efficiency. Inefficient tented structures are thus employed for long durations in both extreme heat and cold. Poor sizing of electrical generation equipment on operations contributes further to sizeable inefficiencies. Although the CAF employs little energy management practices on operations, to its credit, it has

[104] Andre Picard, "RE: Life Cycle Management Costs," January 16, 2020.
[105] James Legresley, "FW: RTC Equipment Reduction," October 22, 2019.

recently? engaged in an energy monitoring program that will inform future DFI procurements, doctrine and management. To better assess the significance of climate and DFI type, the results of the NRCan DFI simulation study will be used to developed operational scenarios. The results and scenarios are presented in the next chapter.

CHAPTER 4: SIMULATION OF DFI

This chapter will provide an overview of the simulation capabilities and tools NRCan has provided the CAF. First, the capabilities and functionality of the FORCESIM simulation application will be presented to facilitate a basic understanding. Second, the NRCan simulation study will be discussed in detail by covering both the methodology of the study and the results. Finally, the results of the simulation study will be assessed and contrasted against current CAF DFI practices to identify key observations and trends. The simulation study results will subsequently serve as the foundational data employed to develop the operational scenarios presented in the next chapter.

ENERGY SIMULATION OF DEPLOYED CAMPS

As part of the I-CUT program, NRCan has developed simulation tools to support planning of camps at the operational level as well as to assess the effectiveness of energy saving initiatives prior to implementation. Simulation studies of deployed camps are useful to inform DFI decision-making processes by augmenting the limited energy consumption data that exists from operations. The recent NRCan study discussed in this thesis represents the most comprehensive simulation study of energy consumption in deployed camps undertaken by the CAF. The NRCan tools were developed based on standard practices employed within the energy simulation field and are composed of state-of-the-art tools.

FORCESIM 3.0

The FORCESIM energy simulation tool was developed by NRCan to allow engineer planners to estimate energy requirements in deployed camps. The program was developed based on commercially available energy simulation tools and is currently licenced to the CAF from

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NRCan.[106] The program is validated annually against data measured within deployed camps in order to improve the accuracy of the simulations. Since NRCan monitors energy consumption on deployed camps through both I-CUT and the NATO SPS G5525 projects, the FORCESIM programme has been validated with data measured on both CAF and Allied deployed camps. The program has been updated several times and is currently available in Version 3.1 which was used to complete the simulation study.

The program employs the TRNSYS 17 platform to simulate thermal and electrical energy systems.[107] A graphical user interface (TRNSED) hides the simulation engine and limits inputs to commonly known shelters and camp parameters in order to simplify the use of the program. The FORCESIM interface functions similarly to how an engineer planner would design a camp. A user of the simulation program selects a specific location or climate, shelter types, heating and cooling equipment, electrical generation equipment, occupancy and user load profiles. The camp is depicted graphically in the program as it is constructed. The majority of the CAFs inventory of shelters, electrical generation and HVAC equipment are available within the program. Data metered on operations has been used to refine parameters within the program allowing FORCESIM to accurately predict energy consumption within 5 to 8% of metered values.[108] A camp simulated within FORCESIM is presented in Figure 4.1.

[106] "FORCE-SIM v3.0 Software End-User License Agreement" (Natural Resources Canada, May 30, 2019).

[107] TRNSYS is a commercially available simulation program developed at the University of Wisconsin. The program is used primarily in the fields of renewable energy engineering and building simulation. Typical meteorological year data is employed in the program to determine the long-term cost savings between different energy systems.

[108] Eric McDonald - Natural Resources Canada CanmetENERGY, Varennes, QC "RE: Simulation Report," February 10, 2020.

Figure 4.1 – Typical Camp Constructed in FORCESIM 3.0.

FORCESIM utilizes Typical Meteorological Year 2 (TMY2)[109] data that are a collation of weather data selected to include a range of weather phenomena relative to a specific location.[110] TMY2 data are frequently used in engineering assessments, building simulations and efficiency assessments for solar energy systems but are poorly suited to design against extreme climate conditions. An electrical demand profile can be selected to simulate given operational tempos within the camp. For greater realism, the engineer planner may also select from a variety of profiles measured on operations or create a unique profile. Once a scenario is inputted, FORCESIM uses the climate data to influence the energy systems that are composed of user load profiles, deployable shelters, electrical generation equipment and HVAC equipment. Power

[109] TMY2 files are comprised of hourly solar radiation, illuminance and meteorological elements. The data is based on typical meteorological months between 1961 and 1990, which is then concatenated to form a typical meteorological year. The data was compiled by the National Renewable Energy Laboratory in the US Department of Energy.

[110] "Typical Meteorological Year," in *Wikipedia*, February 12, 2020, https://en.wikipedia.org/w/index.php?title=Typical_meteorological_year&oldid=940419233.

demands calculated within the program are subsequently converted into fuel consumed by either electrical generation or heating equipment.

NRCAN SIMULATION OF DEPLOYED CAMPS

FORCESIM 3.0 was used in 2019 to predict the power and energy requirements in deployed camps in different climates. The simulation study included multiple different sized camps composed of different shelters that were modelled in a variety of climates. Since TMY2 constitutes only twelve months of data, the simulation results were collated into a notional year. As such, each simulation scenario produced a variety of energy consumption rates for each month of the year. To compare scenarios with multi-year timeframes, the engineer planner simply adds additional notional annual datasets for each full calendar year. Each partial year is estimated by adding the monthly totals for the applicable period of the year. The methodology conforms to standard simulation practices, simplifies the calculations, allows simulation time to be greatly reduced, and provides a data set that can be used to assess a far greater number of scenarios. The operational scenarios presented in the next chapter were developed in this manner. A typical data set from the simulation study is presented in Table 4.1.

	Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Electricity (MWh)	24.4	21.7	22.7	20.2	19.2	17.4	16.2	16.3	18.0	20.4	21.4	24.1	241.9
Peak kW/ person	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 4.1 – Representative results from FORCESIM 3.0 for Goose Bay HQSS 500-person camp.[111]

[111] Breton et al., "Report of a Simulation-Based Study of the Power and Energy Requirements…", p. 19.

The study comprised sixty-four separate scenarios. The simulation included 100, 500, 1000 and 1500-person sized camps based on the extremes presented in the SSE concurrent mission sets.[112] Each size of camp was constructed four separate times using a single type of shelter each time. The shelters simulated included MTS Lite, HQSS, SWAHUT and ISO Flatpacks. Thus, sixteen separate camps were constructed to be analysed within FORCESIM as presented in Figure 4.2.

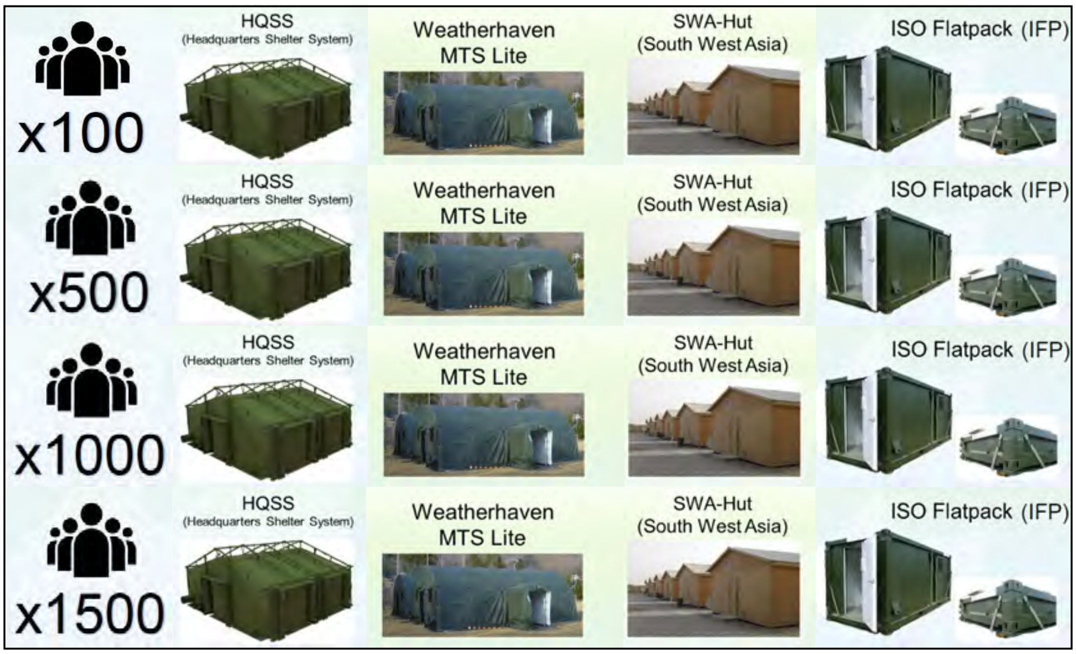

Figure 4.2 – Summary of Camp Configurations Simulated in the NRCan Study.

The scope of the study was limited to the accommodations and ablutions areas of the camps since these areas have been metered on operations and subsequently validated in FORCESIM. An occupancy rate of 8 personnel per tent or SWAHUT and 4 personnel per ISO Flatpack was utilized to size the camps. Thus, twice as many ISO Flatpack were required for a given camp size. Although the occupancy rate slightly deviates from current CAF doctrine,

[112] Canada and Department of National Defence, *Strong, Secure, Engaged - Canada's Defence Policy*, pg 82.

similar standards have been utilized frequently on operations.[113] Ablutions were provided at a rate of 1 shower/1 sink/1 toilette per 12.5% of the camp population. The ablution standard conforms to doctrine as well as current practices on operations.

Each of the sixteen camp scenarios was simulated within four separate climate regions. The climate regions selected were significantly different in order to ensure a broad range of conditions were modelled. Arctic conditions were not included in the study as CAF operating equipment and procedures in the Arctic deviate significantly from deployed camps in other climates. A representative location for each climate region was selected to allow correlations to be made to a known geographical location. Each location was selected based on a balance of the quality of TMY2 climate data available and the desire to select a location where the CAF recently conducted operations. These measures were intended to improve the quality of the simulation while allowing readers to correlate the climate characteristics simulated with experience or knowledge.

The climate locations selected include: Riga, Latvia (Riga) which directly correlates to Op REASSURANCE eFP BG; Manila, Philippines (Manila) which roughly correlates to a large amount of the Indo Pacific region and was in close proximity to the area of operations for the DART response to Super Typhoon Haiyan in 2014; and Kano, Nigeria (Kano) that roughly correlates to Op NABERIUS in Niger. Since the CAF possesses little recent operational experience in cold climates, Goose Bay, Newfoundland and Labrador (Goose Bay) was selected as climate, fuel and transport data could easily be obtained for the location. It is important to note that the location of Goose Bay at 53 degrees Northing lies two degrees outside of the Artic. Thus, a total of sixty-four total scenarios were simulated as depicted in Figure 4.3.

[113] Major Matt Arndt, "Costing - Adazi," February 13, 2017.

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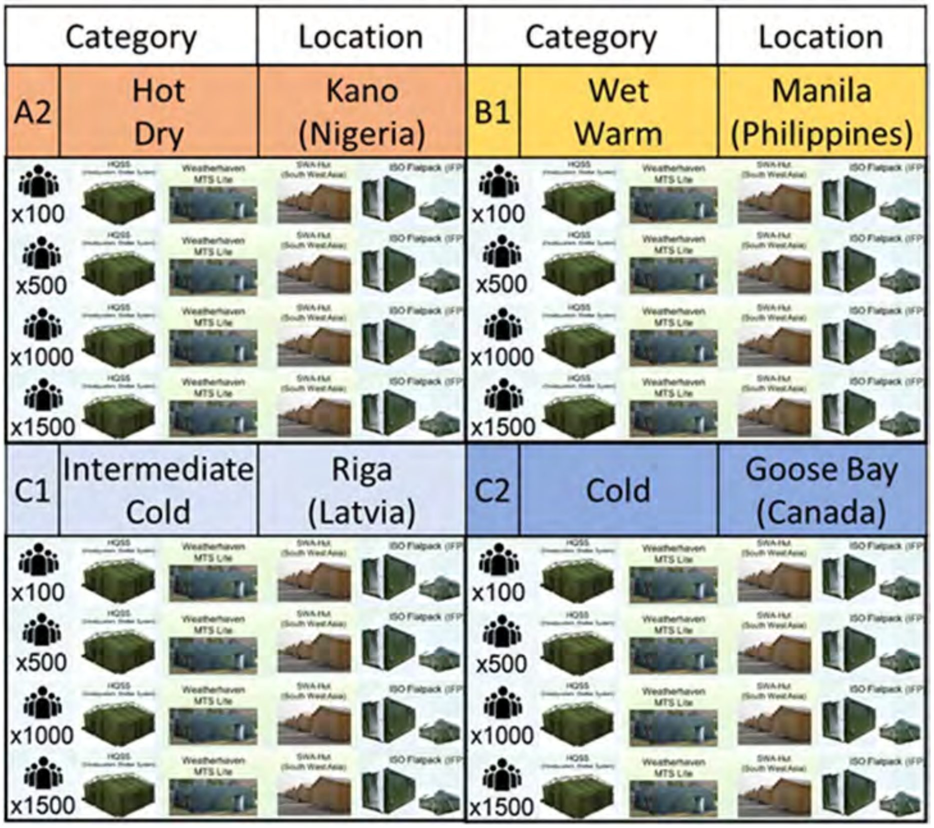

Figure 4.3 – Summary of Climate and Camp Configurations Simulated in the NRCan Study.

Standardized heating and cooling parameters were selected in order to facilitate comparison between DFI. Heating and cooling temperature set points of 21°C and 23°C were employed respectively in accordance with the National Energy Code of Canada standards for buildings.[114] The two 5 kW electric heating systems integral to the MTS Lite were selected as the standard heater for all scenarios. However, initial simulations in Riga and Goose Bay demonstrated that the heaters were not capable of sustaining the temperature set point within the MTS Lite, HQSS and MECC Ablutions. As a result, 100 kBTUh diesel heaters with a 1/6 horsepower blower were used to heat these structures in the cold climates. Heating canvass

[114] Natural Research Council Canada, *National Energy Code of Canada for Buildings 2017* (Government of Canada, 2017).

structures with diesel heaters is common practice on CAF deployments. Cooling for the MTS Lite, HQSS and MECC Ablution was simulated using the HQSS 5 ton packaged air conditioning unit. The SWAHUT and ISO Flatpack were cooled using a 3 ton and 1.5 ton ductless mini-split system respectively. The Seasonal Energy Efficiency Ratio (SEER)[115] and Energy Efficiency Ratio (EER)[116] of the systems were 13 and 11 for the tented structures and 16 and 14.6 for the hardened structures. Thus, minor differences in heating and cooling equipment existed between the DFI.

Electrical generation was simulated using multiples of either 60 kW or 300 kW electrical generators dependent upon the electrical demand. A load bank was included for all single speed generators. FORCESIM provided estimates of peak electrical demand as well as energy consumed over time. These practices and equipment conform to standards currently employed during training and operations.

Since the study focused on camps that generally house long-term occupants who work during the day and return to the accommodations in the evening, the electrical demand of the camp users was based on the National Energy Code of Canada for Buildings (NECB) standard "G" schedule. The timeframe for occupancy of structures, lighting usage, convenience electrical load and domestic hot water use demands provided within the "G" schedule are similar to those of a residential apartment building in Canada.[117] All lighting loads were based on LED as engineers typically upgrade to LED bulbs immediately on all deployments.

[115] The SEER rating of a unit is the cooling output during a typical cooling-season divided by the total electric energy input during the same period. The higher the unit's SEER rating, the more energy efficient it is. https://en.wikipedia.org/wiki/Seasonal_energy_efficiency_ratio.

[116] An air conditioner's efficiency is measured by the energy efficiency ratio (EER). The EER is the ratio of the cooling capacity (in British thermal units [Btu] per hour) to the power input (in watts). The higher the EER rating, the more efficient the air conditioner. https://www.energy.gov/energysaver/room-air-conditioners.

[117] Natural Research Council Canada, *National Energy Code of Canada for Buildings 2017*, p. 27.

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Sensitivity analysis on key variables noted on operations were conducted as part of the simulation study. These included varying the composition of the electrical generation equipment within each scenario as well as varying both the internal and external temperatures for given scenarios. Internal temperature variations were simulated to assess the impact of excessive cooling or heating. Exterior temperature variations were simulated to assess the impact of changes in weather from year to year. The impact of single speed versus variable speed generators was assessed by simulating all sixty-four scenarios with both types of generators. Fuel consumption was subsequently calculated based on efficiency curves for the generator employed to provide a more meaningful metric.[118] The results of the simulation study will be discussed in detail in the next section.

SIMULATION STUDY RESULTS

The results presented in this chapter were drawn from the NRCan Simulation Study Report.[119] Significant deviations in performance were noted between different DFI in the same climate and the same DFI in different climates. As should be anticipated, insulated hardened structures were significantly more energy efficient than tented structures. The results for a notional year will be presented first to illustrate the relative performance of each type of DFI in each climate. Subsequently, the impact of key variables such as interior and exterior temperature as well as electrical generating equipment will be assessed to highlight the significance of the variable on energy consumption in the deployed camp.

[118] Breton et al., "Report of a Simulation-Based Study of the Power and Energy Requirements…", p. 27.
[119] *Ibid*, pp. 139.

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Notional Year Results

Assessments will be presented in terms of the volume of fuel consumed over the entire notional year to simplify comparisons and eliminate the variance associated with fuel prices. Although both single speed and variable speed generators were simulated, the notional year data presented will be based on the variable speed results to minimize the effect of the generator system on fuel consumption. Different relative performance and fuel consumption rates were noted between the hot and cold climates. As such, the results from cold climates (Goose Bay and Riga) will be presented separate from hot climates (Manila and Kano). The large number of variables involved in the simulations caused the relative performance of the DFI to vary between each camp size in the same climate. Thus, the presentation of the results will focus on identifying the general trends in the relative performance of each type of DFI in each climate. The notional year data will be presented in normalized graphs to facilitate additional comparison between DFI and camps size.

Cold Climate

Energy consumption was strongly correlated to heating demands in the cold climates. The relative performance of each DFI was nearly identical between Riga and Goose Bay. The well insulated ISO Flatpack demonstrated a considerably higher level of energy efficiency than the alternative DFI. Although the SWAHUT possesses roughly 25% less insulation than the ISO Flatpack, over 50% more fuel was required to heat the SWAHUT. The tented structures proved highly inefficient requiring almost twice as much fuel the ISO Flatpack. The ratios of fuel consumed for each DFI option to the fuel consumed for the ISO Flatpack in Goose Bay and Riga are presented in Figure 4.4.

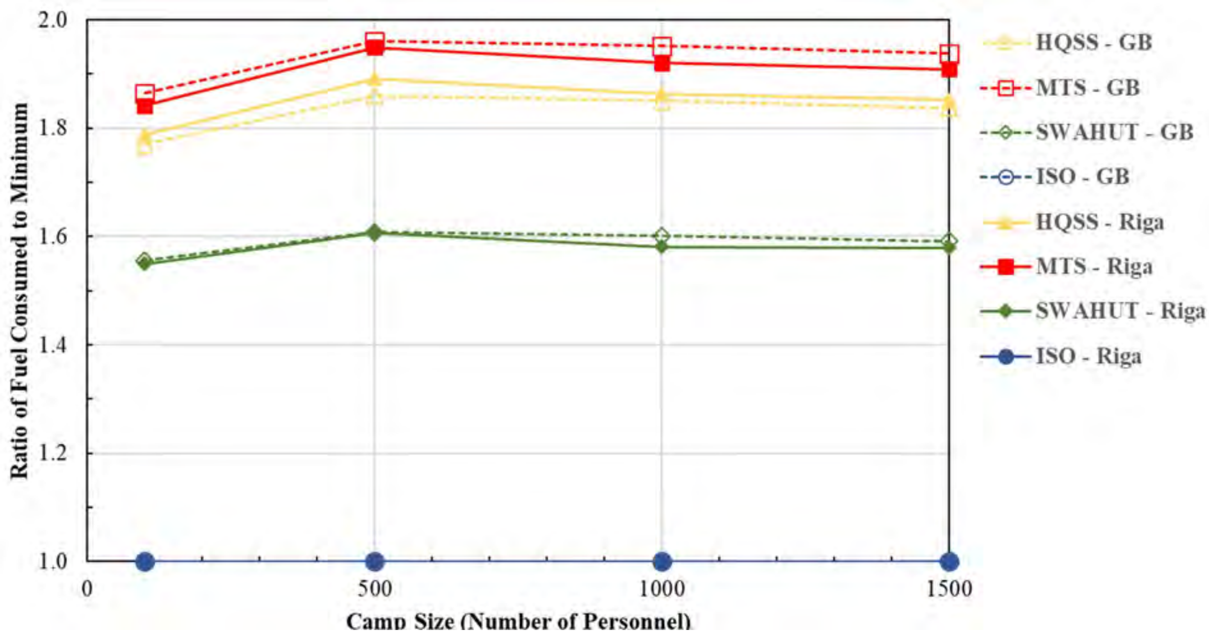

Figure 4.4 – Ratio of Fuel Consumed for Each DFI Option to the Fuel Consumed for the ISO Flatpack – Goose Bay and Riga.

The total fuel consumed each notional year varied significantly between the different types of DFI in the same climate. The fuel consumption in a 500-person MTS Lite camp in Goose Bay required nearly twice as much fuel as the same camp composed of ISO Flatpacks. The total fuel consumed also varied significantly between the same DFI in the Riga climate versus the Goose Bay climate. Over 1.5 times as much fuel was required in the Goose Bay for an identical camp than in Riga. As well, the ISO Flatpack achieved nearly a 50% reduction in fuel consumption over the MTS in both climates. These facts highlight two key points. First, a massive amount of fuel is required to support relatively small camp in a cold climate. Second, the type of DFI employed significantly impacts the fuel consumption rate within the camp.

As camp size increases, the relative savings remain constant, but the quantity of savings increases rapidly. Improving from MTS Lite to ISO Flatpack in a 1500-person camp in Goose

Bay would save 1,482,000 L of fuel every year. The savings would significantly alter the cost-benefit analysis when considering improving infrastructure standards or purchasing new DFI equipment. The total fuel consumed by each type of DFI for various camps sizes in Goose Bay and Latvia is presented in Figure 4.5.

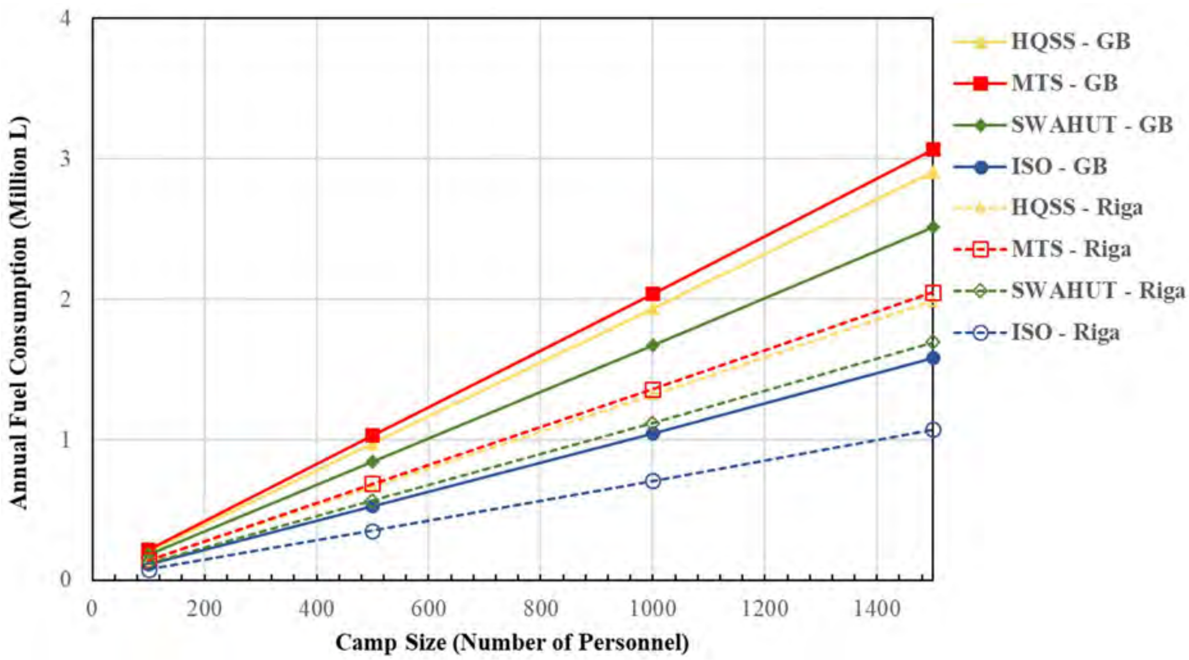

Figure 4.5 – Total Fuel Consumed in Notional Year for Various Camps Sizes Composed of Different DFI in Goose Bay and Riga.

Hot Climate

Energy consumption in the hot climates was greatly influenced by temperature mainly due to the electrical demands from air conditioners. Greater deviation was noted for individual DFI performance in different camp sizes within the same climate and between climates than in the cold climates. The fact the SWAHUT required roughly 20 to 40% less fuel than the ISO Flatpack represents a notable change in relative performance from the cold climates where the ISO Flatpack was more efficient. Although the tented structures required roughly 50 to 75%

more fuel than the SWAHUT, the relative performance was better than in the cold climates. The reasons for all of these deviations will be discussed in detail below.

The SWAHUT required less fuel despite the fact the ISO Flatpack possesses nearly 25% more insulation. The variability is likely due to significant differences in air conditioning methodology employed. The ISO Flatpack requires an individual air conditioner for each container housing four personnel. Conversely, the SWAHUT employs a single larger air conditioner but contained twice the number of occupants. Thus, double the number of air conditioners were required for an ISO Flatpack camp compared to a SWAHUT camp. Since larger air conditioners are generally more efficient, the SWAHUT proved the most energy efficient structure. Dependent upon the user demand and capacity of the generators, the increased air conditioning load necessitated additional generators in some camps but not others. Dependent upon where the electrical demand fell within the generators operating efficiency curve, additional generators could significantly change the overall efficiency of the specific scenario. As a result, the relative performance between similar DFI in different sized camps can vary based on the air conditioning equipment employed and the electrical demand compared to the rated capacity of the generators.

As is evident from Figure 4.6, the performance of the same DFI varied significantly within the same climate and between the two climates. These variations were roughly double the amount observed in similar scenarios in the cold climates. The difference is not well understood but could derive from differences in the heating and cooling equipment discussed above as well as differences in between the two climates. The Goose Bay and Riga climates possess similar seasonal characteristics where the temperatures drop significantly in the winter but are relatively hot in the summer. The simulation thus compares quite similar climate profiles but with

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different temperature extremes. As a result, the fuel consumption between the two climates deviates proportionally to the temperatures but the ratio of performance of DFI is quite similar. Conversely, the Kano climate varies significantly throughout the year with peak temperatures occurring in the fall and spring. Manila by contrast maintains a relatively consistent temperature throughout the year. The sizeable differences in seasonal characteristics create differences in DFI performance within and between the hot climate scenarios.

Although the tented structures proved highly inefficient in the hot climates, their relative performance to the other DFI was significantly better than in the cold climate. Two relevant deviations were noted between the performance of the tented structures in the hot and cold climates. First, the MTS fuel consumption exceeded that of the HQSS in the cold climate. However, the trend was reversed in the hot climate where the MTS consumed less than the HQSS. The reason for the change in relative performance is not well understood but is postulated to derive from the fact that although the HQSS possesses better insulation, it also has a larger interior volume. It could also be that the combination of these factors become less efficient as a system when an electric cooling was employed versus a more efficient diesel heater. Second, the relative performance of tents was more efficient than in the cold climate scenario. The difference can be attributed to the significantly greater energy demands that exist in cold climates. The ratios of fuel consumed for each DFI option to the fuel consumed for the SWAHUT in Manila and Kano are presented in Figure 4.6.

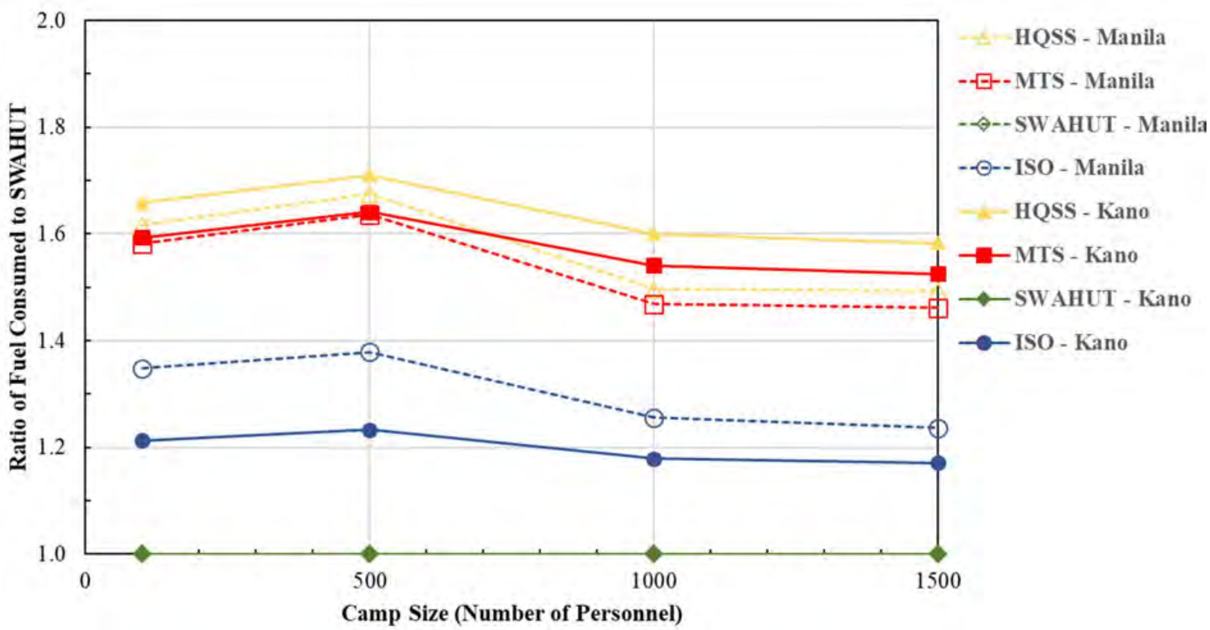

Figure 4.6 – Ratio of Fuel Consumed for Each DFI Option to the Fuel Consumed for the SWAHUT – Manila and Kano.

Each type of DFI consumed considerably less fuel in the hot climate than the cold climates resulting in a narrower range of fuel consumption between different types of DFI. The most economical option in Goose Bay and Riga required 66% and 152% more fuel than the Manila scenario. Energy consumption in deployed camps is therefore considerably greater in cold climates than hot. However, improving from MTS Lite to SWAHUT in a 1500-person camp in the hot climates would still save roughly 300,000 to 400,000 L of fuel every year. Although the total fuel consumed varied within plus or minus 6% for identical camps in either climate, the tented structures required more fuel in Kano but the semi-permanent structures required more fuel in Manila. The deviations are likely due to differences in climate and cooling equipment. The total fuel consumed by each type of DFI for various camps sizes in Goose Bay and Latvia is presented in Figure 4.7.

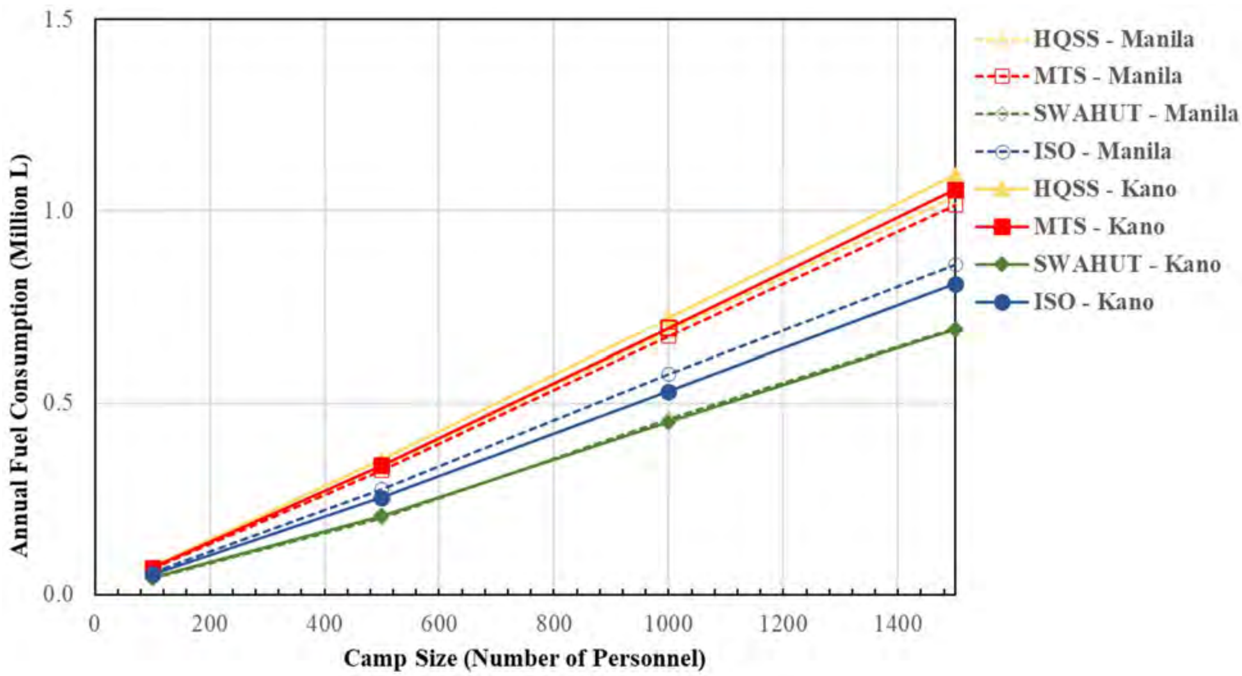

Figure 4.7 – Total Fuel Consumed in Notional Year for Various Camps Sizes Composed of Different DFI in Manila and Kano.

Sensitivity Analyses

The notional year data discussed above provided an estimate of the anticipated fuel consumption per year for a given set of conditions within each camp. As was evident from the assessment, minor differences between each scenario resulted in significant differences in overall energy efficiency. To assess the impact of key variables within the simulation, a variety of sensitivity analysis were conducted. These include the impact of internal temperatures, external temperatures and electrical generation equipment.

Temperature Sensitivity Analyses

The first component of the temperature sensitivity analysis involved adjusting the internal temperature set point of the DFI, the thermostat setting on the heating or cooling system, by 3°C towards the extreme ambient temperature. The change would be analogous to an energy manager controlling heating and cooling to reasonable levels within a building or facility. The heating temperature in cold weather climates was reduced from a set point of 21°C used in the base scenario to 18°C in the modified scenario. Similarly, the cooling set point was increased from 23°C to 26°C for hot weather climates. The second component of the temperature sensitivity analysis involved adjusting the exterior temperatures 1°C towards the extreme. The change would be analogous to the average temperature being 1°C colder in a cold climate and 1°C hotter year in a hot climate.

To simplify the assessment, the temperature sensitivity analysis focused on the 500 and 1500 size camps in all four climates. The results will be presented as a ratio of the annual fuel consumed in the modified scenario to the original 500 or 1500 “base” scenario for the specific climate. For example, the results from a 500-person ISO Flatpack camp with modified interior temperature will be compared to the results of 500-person ISO Flatpack camp with the original interior temperature for each individual climate. The results will be presented separately for cold and hot climates to correspond with the notional year assessment.

Cold Climate Temperature Sensitivity Analyses

The DFI performed similarly when the interior temperature was reduced by 3°C in the cold weather climates. The decrease in interior temperature created between 11 to 12% and 14 to 15% savings in Goose Bay and Riga respectively. Despite similar relative decreases in fuel consumption, significantly larger volumes of fuel were saved in tented camps than semi-permanent camps. Decreasing the interior temperature created sizeable fuel savings, particularly in larger camps.

A reduction in external temperature of 1°C created a consistent response across all types of DFI in the cold climate. The fuel consumption increased 3 to 4% in Goose Bay and 4 to 5% in Riga. Although the relative increase in fuel consumption was similar for all DFI, the actual fuel increases were significantly larger for the tented structures compared to the semi-permanent. The assessment indicates that variations in winter temperatures that occur from year to year will significantly alter fuel consumption in deployed camp. The total fuel consumed and ratios of fuel consumed between base and modified scenarios for the cold weather climates are presented in Table 4.2.

Location	Scenario	Total Fuel Consumed (Thousand L)				Ratio to Base Scenario			
		Goose Bay		Riga		Goose Bay		Riga	
		500	1500	500	1500	500	1500	500	1500
HQSS	Base	958	2,847	656	1,955	1.00	1.00	1.00	1.00
	Exterior	996	2,959	689	2,052	1.04	1.04	1.05	1.05
	Interior	846	2,517	561	1,675	0.88	0.88	0.86	0.86
MTS	Base	1,011	3,005	676	2,015	1.00	1.00	1.00	1.00
	Exterior	1,052	3,127	711	2,118	1.04	1.04	1.05	1.05
	Interior	890	2,648	577	1,722	0.88	0.88	0.85	0.85
SWAHut	Base	816	2,408	542	1,621	1.00	1.00	1.00	1.00
	Exterior	844	2,510	565	1,691	1.03	1.04	1.04	1.04
	Interior	715	2,136	453	1,359	0.88	0.89	0.84	0.84
ISO	Base	527	1,526	358	1,030	1.00	1.00	1.00	1.00
	Exterior	547	1,583	376	1,081	1.04	1.04	1.05	1.05
	Interior	471	1,357	309	881	0.89	0.89	0.86	0.86

Table 4.2 – Total Fuel Consumed and Ratio of Fuel Consumed Between Base and Modified Temperature Scenarios for Each DFI Option – Goose Bay and Riga.

Hot Climate Temperature Sensitivity Analyses

The relative savings generated from an increase in interior temperature of 3°C were considerably greater in the hot climate than the cold climate, although a larger variance in fuel consumption was observed between and within the two hot climates than occurred for the two cold climates. The increase in interior temperature created between 16 to 26% and 11 to 21% fuel savings in Manila and Kano respectively. The results indicate that reducing air conditioning? standards in hot climates creates sizeable savings in fuel consumption. Despite a higher ratio of savings in the hot climates, the actual fuel savings in the cold climates were two to three time greater than the hot climates in most scenarios.

An increase in external temperature of 1°C generated larger relative savings in the hot climates than cold climates. Greater variability was also observed in this analysis between the individual DFI performance within and between the hot climates. These variances mirror the response observed in the interior temperature analysis. The increase in exterior temperature created in additional fuel requirements of 7 to 13% in Manila and 6 to 9% in Kano. The additional fuel requirements were also significantly greater for the tented structures. The results indicate that seasonal fluctuations in hot climates can be anticipated to increase fuel consumption in deployed camps by approximately 10%. The total fuel consumed and ratios of fuel consumed between base and modified scenarios for the hot weather climates are presented in Table 4.3.

Location	Scenario	Total Fuel Consumed (Thousand L)				Ratio to Base Scenario			
		Manila		Kano		Manila		Kano	
		500	1500	500	1500	500	1500	500	1500
HQSS	Base	316	988	335	1,045	1.00	1.00	1.00	1.00
	Exterior	352	1,085	363	1,124	1.11	1.10	1.08	1.08
	Interior	242	782	277	881	0.76	0.79	0.83	0.84
MTS	Base	309	966	321	1,005	1.00	1.00	1.00	1.00
	Exterior	347	1,071	350	1,087	1.13	1.11	1.09	1.08
	Interior	227	744	259	830	0.73	0.77	0.81	0.83
SWAHut	Base	218	645	189	641	1.00	1.00	1.00	1.00
	Exterior	236	693	203	678	1.08	1.07	1.07	1.06
	Interior	181	544	163	568	0.83	0.84	0.86	0.89
ISO	Base	258	810	237	810	1.00	1.00	1.00	1.00
	Exterior	285	884	253	884	1.11	1.09	1.07	1.09
	Interior	191	641	203	641	0.74	0.79	0.86	0.79

Table 4.3 – Total Fuel Consumed and Ratio of Fuel Consumed Between Base and Modified Temperature Scenarios for Each DFI Option – Manila and Kano.

Assessment of Temperature Sensitivity

Restricting the interior temperature of DFI creates sizeable fuel savings in deployed camps. Greater savings than those estimated from the simulation are likely achievable as heating and cooling set points are loosely controlled on operations. Observations from operations within the I-CUT program indicate that air conditioning and heating equipment are run at maximum output for the majority of each heating or cooling day.[120] Furthermore, the simulation did not account for air conditioning loads in Riga or Goose Bay. It is likely that air conditioning would eventually be provided in Riga since the climate is similar to Ottawa. Thus, the overall fuel consumptions would be significantly greater than estimated in this study.

Minor increases and decreases in the external temperature create between 6 and 13% additional fuel demand. The relative change from temperature variations are greater in hot climates than cold climates. However, since more fuel is consumed overall in cold climates, the amount of the increased demand is greater in cold climates. Although the data from the simulation are indicative of annual performance, significant variances in fuel consumption would occur on operations as the average temperature can vary much more than 1°C from year to year. Energy monitoring and controlling measures would assist in identifying and managing the variances.

Electrical Generation Sensitivity Analysis

Each scenario was simulated using both variable speed generators and single speed generators. The methodology allowed the impact of different electrical generation configurations to be assessed. Since different sized generators were employed in the scenarios dependent upon the electrical demand in the camp, the impact of properly sizing generators to

[120] Capt Williams, “Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19", p. 4.

electrical demand was also inferred from the data. Since a distinct difference in performance was observed between small and large camps, the results will be presented separately for 100 and 500 person camps and 1000 and 1500 person camps. The findings will be presented in terms of the annual fuel consumed by the single speed generator with a load bank and variable speed generator for each scenario as well as a ratio between the two.

The generators used in the simulations were selected based on the peak demands from each camp. Multiples of 60 kW generators were used for loads up to 180 kW. For loads higher than 180 kW, multiples of 300 kW generators were employed. Each scenario was modelled with both variable speed generators as well as single speed generators combined with a load bank. The load bank added resistance in the system until the single speed generators were operating at 60% of their capacity. Although the single speed generators are very inefficient below 60% load, they are more efficient than variable speed generators at higher loads. Thus, the variable speed generators are typically more efficient than single speed generators when the electrical demand varies frequently by a large amount. Conversely, the single speed generators are more efficient where a constant demand exists near the maximum generator capacity.

The fuel efficiency of a single speed generator is thus significantly impacted by even relatively minor changes in electrical demand. The performance of single speed generators is thus more closely correlated to the ratio of electrical demand compared to the generator efficiency rather than camp size, type of DFI or even climate. As a result, the findings are a high variable. To mitigate variability within the results, the results will be presented in terms of the number of scenarios that fall within certain ratios of performance. As an example, the small camp results would be communicated as ‘six of the thirty-two 100 and 500 person scenarios required over 50% more fuel with the single speed generators than the variable speed generators.

Camp Size

A distinct difference between the performance of the single speed and variable speed generators was noted between the small 100 and 500 person camps and the larger 1000 and 1500 person camps. The single speed generators were considerably less efficient in the small camps requiring 30% more fuel than the variable speed generators in twenty-three of the thirty-two small camp scenarios. The difference in fuel demand between the generators did not exceed 30% in any of the thirty-two large camp scenarios. In fact, the fuel consumed by the single speed generator was within 5% of the fuel consumed by the variable speed generator in twenty of the thirty-two large camp scenarios.

The difference in performance between small and large camps is likely due to the fact that single speed generators in small camps have less flexibility to adjust to electrical demand. For example, a 120 kW single speed generator farm composed of two 60 kW generators would not require a load bank with demands between 72 kW and 120 kW. However, as has been observed in the I-CUT program, the demand can vary as much as four times between night and day. [121] The 120 kW peak demand in the day could thus be reduced to a 30 kW load at night. Although the demand could be met with a single 60 kW generator, a load bank would be required throughout the night since the demand would only constitute 50% of the generator capacity. In a larger camp, there is greater flexibility to adjust the generator farm. For example, an 800 kW peak daytime load could be provided with three 300 kW generators. Although the demand at night would drop to 200 kW, two generators could be turned off resulting in one generator operating at 66% capacity negating the requirement to operate the load bank. The

[121] Capt Williams, "Annual Report 1 ESU Energy Monitoring Report Fiscal Year 18/19", p. 7.

larger operating ranges that occur with larger generators allow adjustments to be made to minimize the use of the load bank. Significant fuel savings are achieved as a result.

The difference in fuel consumption between single speed and variable speed generators in small camps was significantly greater in hot climates. The single speed generator required over 30% more fuel than the variable speed in all sixteen of the hot climate small camps scenarios. Seven of these scenarios required more than 50% more fuel amongst which four required twice as much fuel. In the cold climates, the single speed generator required 30% or more fuel in only seven of the sixteen scenarios with the ratio of only three of these scenarios exceeding 50%. The reduced difference in the cold climate was likely caused by the employment of diesel heaters that would have caused the electrical demand to remain much more consistent between the night and day. Since the electrical demand varies more between the day and night in hot climates due to air conditioning requirements, the load bank was heavily engaged wasting fuel throughout the night to balance the load.

The single speed and variable speed generators performed more consistently in the larger camps although the variable speed was frequently more efficient. The variable speed generators were more efficient in twelve of the thirty-two large camp scenarios. No discernable patterns were evident between climate, DFI type of camp size. The differences were likely due to the electrical demand coincidentally falling within a poor operating range for a single speed generator. The differences highlight the relevance of properly sizing electrical generating equipment on operations, particularly in small camps where the load is more variable. The total fuel consumption calculated for single speed and variable speed generators in all scenarios are presented in Table 4.4.

Camp Size	Type of DFI	Total Fuel Consumed (kL)											
		Goose Bay			Riga			Manila			Kano		
		SS	VS	Ratio (SS/VS)	SS	VS	Ratio (SS/VS)	SS	VS	Ratio (SS/VS)	SS	VS	Ratio (SS/VS)
100 Person	HQSS	277	205	1.35	213	140	1.52	92	70	1.32	101	74	1.37
	MTS	288	216	1.34	218	144	1.51	91	69	1.32	99	71	1.40
	SWAHut	200	180	1.11	154	122	1.27	87	43	2.01	87	45	1.96
	ISO	156	116	1.35	134	78	1.71	87	58	1.49	87	54	1.62
500 Person	HQSS	1003	978	1.03	697	668	1.04	453	333	1.36	494	353	1.40
	MTS	1057	1031	1.03	718	688	1.04	445	326	1.37	485	339	1.43
	SWAHut	948	846	1.12	733	567	1.29	433	199	2.17	433	206	2.10
	ISO	733	526	1.39	368	353	1.04	433	275	1.58	433	254	1.70
1000 Person	HQSS	1933	1932	1.00	1323	1321	1.00	715	686	1.04	761	721	1.06
	MTS	2039	2037	1.00	1364	1361	1.00	704	674	1.04	737	694	1.06
	SWAHut	1708	1672	1.02	1222	1121	1.09	494	459	1.08	526	450	1.17
	ISO	1179	1044	1.13	906	709	1.28	616	576	1.07	611	531	1.15
1500 Person	HQSS	2905	2905	1.00	1990	1988	1.00	1023	1038	0.99	1074	1095	0.98
	MTS	3064	3063	1.00	2051	2049	1.00	1003	1016	0.99	1037	1056	0.98
	SWAHut	2506	2515	1.00	1749	1695	1.03	736	695	1.06	719	692	1.04
	ISO	1676	1581	1.06	1236	1073	1.15	861	860	1.00	810	810	1.00

Table 4.4 – Total Fuel Consumed for Camps Powered by Single Speed (SS) and Variable Speed (VS) Generators and Ratio of Fuel Consumed between SS and VS.

SUMMARY

The notional year results identified the significance of various inputs on the fuel consumption in deployed camps. A strong correlation was observed between temperature and fuel consumption with semi-permanent infrastructure performing significantly better than tented structures. The results indicate that sizeable savings of fuel can be achieved each year through the employment of higher standards of DFI. Interior and exterior temperatures were identified to impact fuel consumption significantly. Reducing comfort standards within DFI a few degrees created large savings in fuel while more extreme exterior temperatures were identified to create substantial increases in fuel demand. Furthermore, the design of an electrical generating system was observed to have a stronger correlation to fuel consumption in deployed camps than climate or DFI type. In order to properly assess the relative impact of the efficiency of different types of

DFI in different climates over the life cycle of an operation, scenarios based on the notional year data presented herein will be assessed in the following chapter.

CHAPTER 5: OPERATIONAL SCENARIOS

GENERAL

Multi-year deployment scenarios were created by cumulating the notional year results in order to compare the cost to operate different DFI in different climate regions with time. The employment of operational scenarios allows more realistic life cycle cost comparisons to be made. The operational scenarios were created based on procurement costs, transport costs as well as the fuel costs to operate the deployed camp. Each scenario was assessed in both permissive and non-permissive environments to determine the significant of operating environment on DFI life-cycle costs. The operational scenarios will be presented in three sections. First, the costing data employed will be highlighted to identify the sources of information and the range of values used. Second, the operational scenarios will be presented in order to highlight the relative performance of each type of DFI in each climate region and operating environment. Finally, the results will be assessed in the discussion section to highlight key trends and observations.

COSTING METHODOLOGY

Due to the sizeable number of variables associated with the costs in each scenario, simplifying assumptions were required. The time, wages and support costs associated with a construction element were not considered due to the variability of these costs between each region and type of DFI. It is assumed that CAF engineers would install each type of DFI thus reducing some variability. The costs associated with storage and maintenance of DFI will also not be considered as reasonable estimates were not available. Thus, the higher costs to construct structures such as the SWAHUT and ISO Flatpack will be somewhat offset in this assessment by the storage costs associated with tented structures that are setup quickly but require storage. The methodology employed to derive the costs employed in the scenarios is presented below. Refer to Annex A for a detailed summary of the costing methodology employed.

Non-Permissive Scenarios.

The non-permissive scenarios are analogous to a COIN operating environment, such as the CAF campaign in Kandahar Province, Afghanistan rather than major combat operations. The assessment is deliberately simplistic in nature aiming to provide an indication of the impact of operating in non-permissive environment on the life cycle comparison of different DFI options. The analysis will be centred on the increased fuel costs associated with additional force protection measures required to transport resources in theatre.

Procurement Costs

Procurement costs were based on invoices obtained from the Material Group at the Assistant Deputy Minister of Materials or from construction costs obtained from recent operations. As the intent of this study is to determine the relative significant of climate costs on DFI decisions rather than conduct a rigorous costing exercise, the costs employed in this study aim to replicate the average costs incurred by the CAF. Thus, a single cost was selected for each type of DFI despite the fact procurement costs vary significantly with time and region dependent upon market conditions. Assumptions were employed where inadequate costing data was available as detailed in Annex A. It is important to note that the tented structures initially cost significantly more than the SWAHUT and ISO Flatpack. The DFI procurement costs employed are summarized in Table 5.1.

Type of DFI	Procurement Cost
HQSS	$24,560
MTS	$27,200
SWAHUT	$17,500
ISO	$11,800

Table 5.1 – DFI Procurement Costs.

Transport Costs

Transport costs were based on the Global Sustainment Sealift Contract (GSSC) as well as the operating cost of a C17 as presented in the DND Cost Factors Manual. The costs were estimated based on a departure from the seaport in Montreal or airport in Trenton to the city of the applicable scenario. Quantities of materials were estimated for each camp size, including heating and cooling equipment, as well as the number of shipping containers required to hold all of the equipment. It is important to note that the SWAHUT possesses the largest movement requirement since one sea container is required to move the materials for a single structure. Conversely, eight HQSS can be transported in two sea containers since a separate container is required to move the heaters or air conditioning units. The details of the methodology employed to develop the planning values are presented in Annex A. Table 5.2 summarizes the number of DFI included in a 500-person camp as well as the amount of DFI that can fit into a single 20-foot ISO shipping container.

Type of DFI	Accommodations and Ablutions Required	Shelters/ Container	Number of Heaters or A/C per Container
HQSS	79	8	8
MTS Lite	79	5	8
SWAHut	157	4	included with SWAHut
ISO Flatpack	79	1	included with ISO FP

Table 5.2 – DFI Requirements for a 500-Person Camp and Number of Equipment per 20 Foot ISO Shipping Container.

As Goose Bay is accessible by road, sea and air, all three options were costed for the scenario. Since Manila and Riga are located overseas, but are collocated with sizeable seaports and airports, only sea and air movement were considered. Two options were considered for movement to Kano. A movement by air direct from Trenton to Kano as well as a movement by sea to the port in Dakar, Senegal followed by a subsequent movement by air from Dakar to Kano. Ground transport between Dakar and Kano was not considered due to poor road infrastructure that exists in the region. Although each feasible movement option was assessed for each scenario, only the most economical means was employed in the assessment. Table 5.3 presents the transportation costs estimated for each scenario employed in the assessment. Note the Kano sea cost includes the cost for air movement from Dakar to Kano.

Type of DFI	Goose Bay	Riga	Manila	Kano
Sea				
HQSS	$ 98,500	$ 56,000	$ 130,000	$ 786,283
MTS Lite	$ 128,050	$ 72,800	$ 169,000	$1,012,678
ISO Flatpack	$ 197,000	$ 112,000	$ 260,000	$1,572,565
SWAHut	$ 389,075	$ 221,200	$ 513,500	$3,044,133
Air				
HQSS	$ 442,855	$ 1,505,707	$ 2,967,129	$1,948,562
MTS Lite	$ 569,385	$ 1,935,909	$ 3,814,880	$2,505,294
ISO Flatpack	$ 885,710	$ 3,011,414	$ 5,934,257	$3,897,124
SWAHut	$ 1,708,155	$ 5,807,727	$11,444,639	$7,515,882
Land				
HQSS	$ 70,000	-	-	-
MTS Lite	$ 91,000	-	-	-
ISO Flatpack	$ 140,000	-	-	-
SWAHut	$ 276,500	-	-	-

Table 5.3 – Estimated Transportation Costs for Sea, Land and Air. Note the most Economical options are highlighted in green for each scenario.

Fuel Costs

Permissive environment fuel costs were obtained from in-situ CAF personnel where feasible and online sources were utilized when CAF data were not available. Non-permissive fuel costs were estimated based on a ratio of 320% of the permissive fuel costs. The methodology used to develop this ratio was based on the Fully Burdened Cost of Energy (FBCE) study completed by Defence Research and Development Canada and is presented in Annex A.[122] The fuel costs and sources employed in this study are presented in Table 5.4.

Location	Source	Cdn $ per L	
		Permissive	Non-Permissive
Latvia	globalpetrolprices.com[123]	1.66	5.31
Goose Bay	CO 5 Mission Support Squadron[124]	0.92	3.04
Manila	globalpetrolprices.com[125]	1.01	3.23
Kano	Opendataforafrica.org[126]	0.89	2.85

Table 5.4 – Diesel Costs for Permissive and Non-Permissive Operating Scenarios for the Locations Simulated.

OPERATIONAL SCENARIOS

The first year of the scenario for a given camp size and climate was composed of the notional year results discussed in detail in the previous chapter. Each additional year was generated by cumulatively adding another notional year to the subsequent year. Since the notional year results are based on the Typical Meteorological Year (TMY) data, annual variability of energy consumption is minimized within the assessment period. The reduced variability allows the relative significance of costs associated with procurement, transport and non-permissive operating environments to be more effectively assessed.[127] Each scenario was

[122] Ghanmi, “Fully Burdened Cost of Energy in Military Operations.", pp. 403-413.
[123] “Diesel Prices around the World, 13-Jan-2020 | GlobalPetrolPrices.Com,” GlobalPetrpPrices.com, accessed January 14, 2020, https://www.globalpetrolprices.com/diesel_prices/.
[124] Major Andrew Vandor, “RE:Deployed Force Infrastructure Cost,” November 15, 2019.
[125] “Diesel Prices around the World, 24-Feb-2020 | GlobalPetrolPrices.Com,” GlobalPetrpPrices.com, accessed March 1, 2020, https://www.globalpetrolprices.com/diesel_prices/.
[126] “Diesel Price Watch - March 2019 - Nigeria Data Portal,” accessed March 22, 2020, https://nigeria.opendataforafrica.org/bvinzi/diesel-price-watch-march-2019.
[127] It is important to note that the time and processing capability required to support the simulation of 10 year scenarios was a limiting factor in selecting the notional year methodology employed in the NRCan study.

assessed over a 10-year period based on the NATO Tier III semi-permanent timeframe that ranges from 6 months to 10 years. In order to approximate the camp size most commonly employed by the CAF on recent operations, the scenarios only considered the 500-person camp.

Operational Scenarios Results

Results from the operating scenarios will be presented for each climate region independently. Both the permissive and non-permissive scenarios will be discussed in order to contrast the performance of DFI under the different conditions. The timeframe where the cost to operate a given DFI falls below that of another type of DFI will be highlighted to reflect buy-back periods. A graph summarizing costs with time for each DFI will be presented to illustrate the relative performance between DFI in both the permissive and non-permissive environments.

Goose Bay

The SWAHUT possessed the lowest initial operating costs due to the low procurement cost combined with the availability of inexpensive ground transport. The least expensive ground transport costs also allowed the initial costs for the ISO Flatpack to be less than those of tents. Although the SWAHUT was the most economical option for the first year of the scenario, the ISO Flatpack was more economical from the second year onward due savings incurred from improved energy efficiency. The relative performance between the DFI remained consistent after the second year. The relatively inexpensive diesel cost of 0.92/L reduced the difference in operating costs between the different DFI. The costs with time for each option are presented in Figure 5.1.

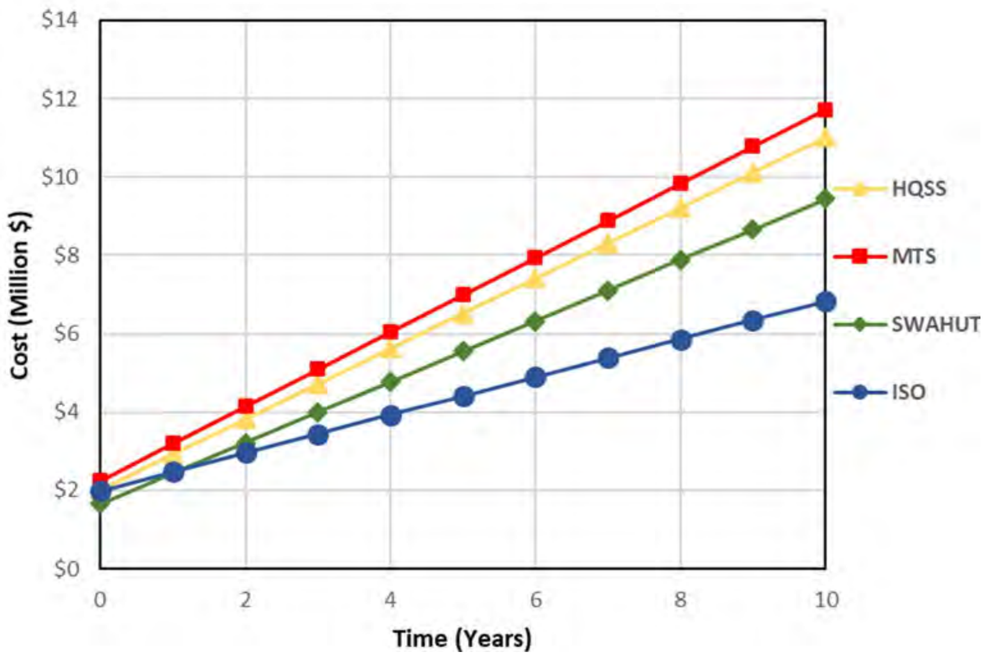

Figure 5.1 – DFI Costs with Time for Permissive Operating Environment in Goose Bay.

The costs in the non-permissive environment are considerably greater than the permissive environment and the difference increases substantially with time. Since transport and procurement costs are identical between both environments, the SWAHUT was also initially the most economical option in the non-permissive environment. However, the ISO Flatpack became more economical after only a single year of the scenario instead of two. There were no changes in the relative performance of each type of DFI after the first year of operations. The diesel cost of $3.04/L amplified the magnitude of difference between the cheapest and most expensive options compared to the non-permissive environment. The costs with time for the non-permissive Goose Bay scenario are presented in Figure 5.2.

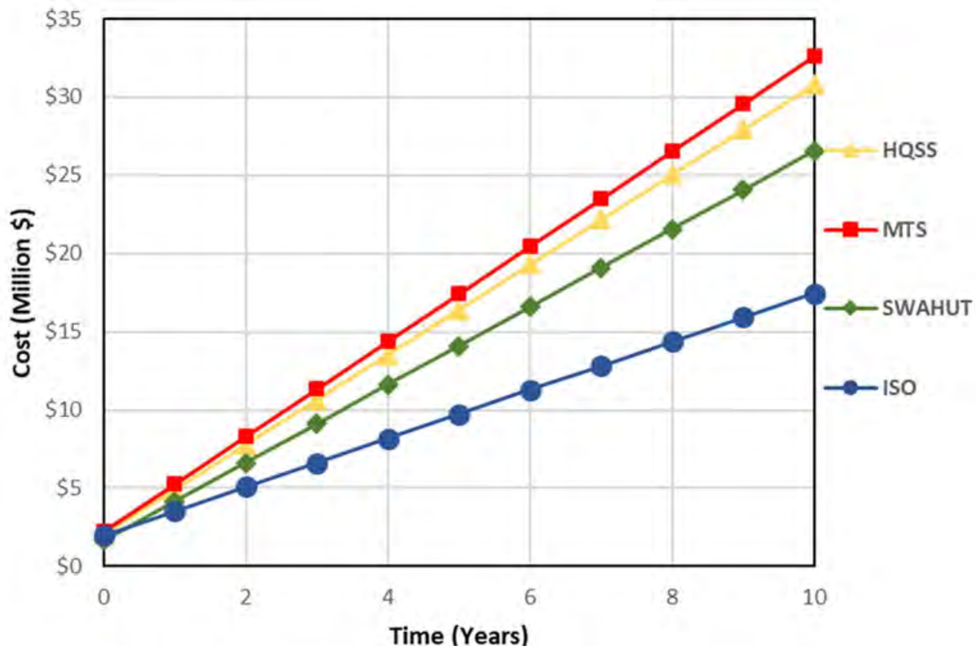

Figure 5.2 – DFI Costs with Time for Non-Permissive Operating Environment in Goose Bay.

Riga

Due to similar transportation costs, the DFI demonstrated similar responses and relative performance in the Riga scenario as compared to Goose Bay. The ISO Flatpack surpassed the SWAHUT as the most economical option in the second year of operation due to the increased energy efficiency. The relative performance between the DFI remained consistent after the second year. The higher fuel costs of $1.66/L simply magnified the difference in costs between the most economical and most expensive options as compared to the Goose Bay scenario. The costs with time for each DFI are presented in Figure 5.3.

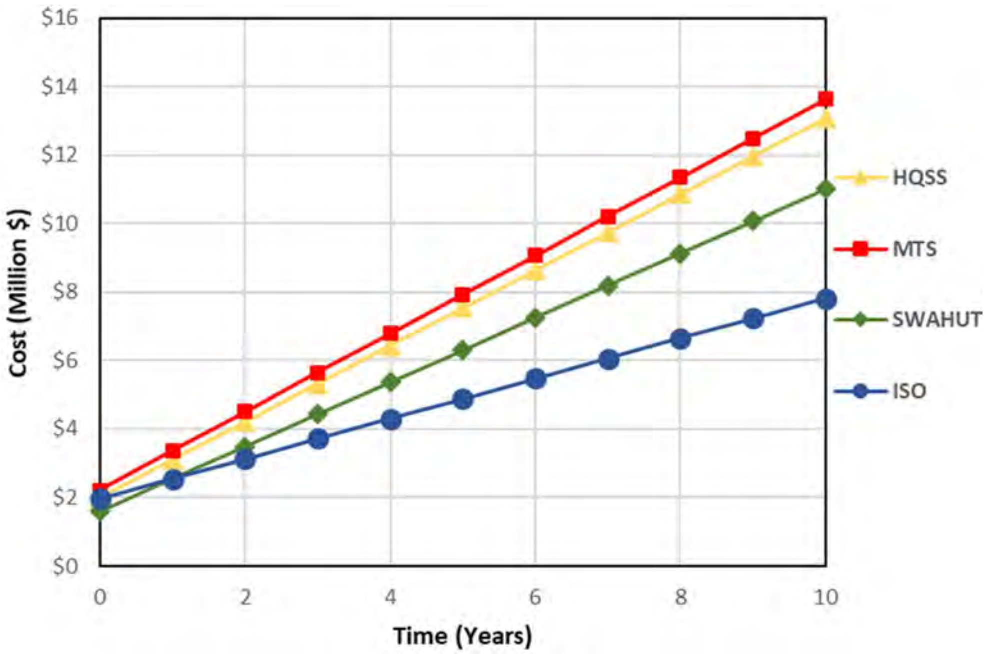

Figure 5.3 – DFI Costs with Time for Permissive Operating Environment in Riga.

The ISO Flatpack became the most economical option within the first year of the non-permissive scenario in Riga as compared to one year in the permissive environment. There were no changes in the relative performance of each type of DFI after the first year of operations. The very high fuel cost of 5.31/L created the greatest deviance between the most economical and most expensive options. The costs with time for the non-permissive Riga scenario are presented in Figure 5.4.

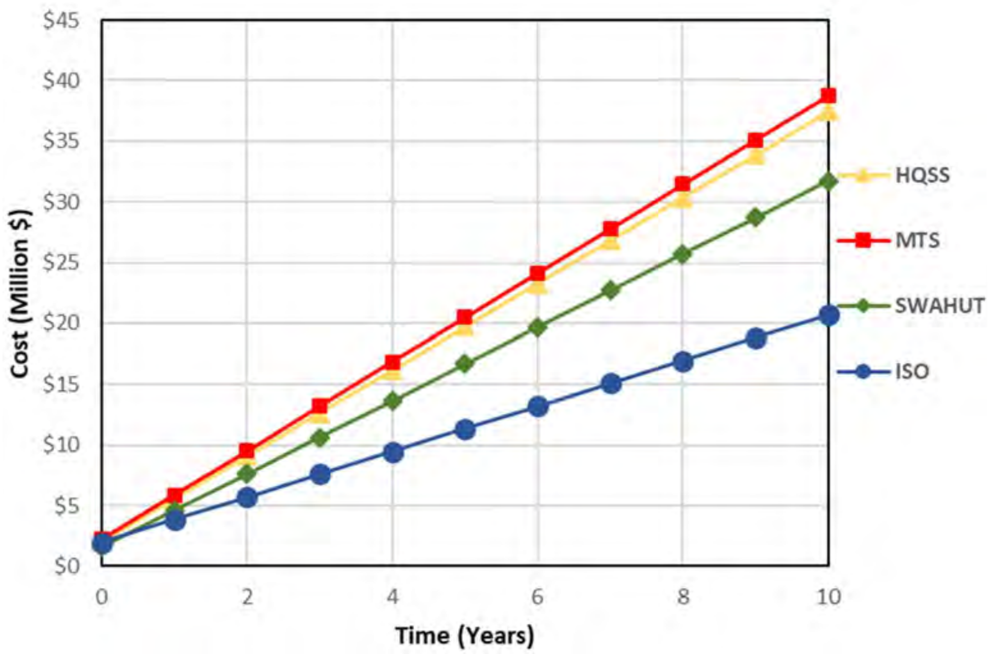

Figure 5.4 – DFI Costs with Time for Non-Permissive Operating Environment in Riga.

Manila

The SWAHUT was the most economical option for Manila over the entirety of the period considered. Although the transport costs to Manila were in the range of two to three times those of the cold climate scenarios, the transport costs constituted only a fraction of the procurement costs. The relatively inefficient transport of SWAHUT, owing to the fact only a single shelter is contained in each shipping container, was offset by the low transport costs in the region and the significantly lower procurement cost of the SWAHUT. As noted in the notional year results, the ISO Flatpack was less efficient and costlier than the SWAHUT due to the additional air conditioner units required in the camp. The relative performance between the DFI remained consistent after the second year when the ISO Flatpack became more economical than the HQSS. Both the relative and total savings were considerably less in the Manila scenario than the cold weather scenarios. The greater energy requirements in cold climates versus hot climates align with recognized trends.[128] The costs with time for each DFI are presented in Figure 5.5.

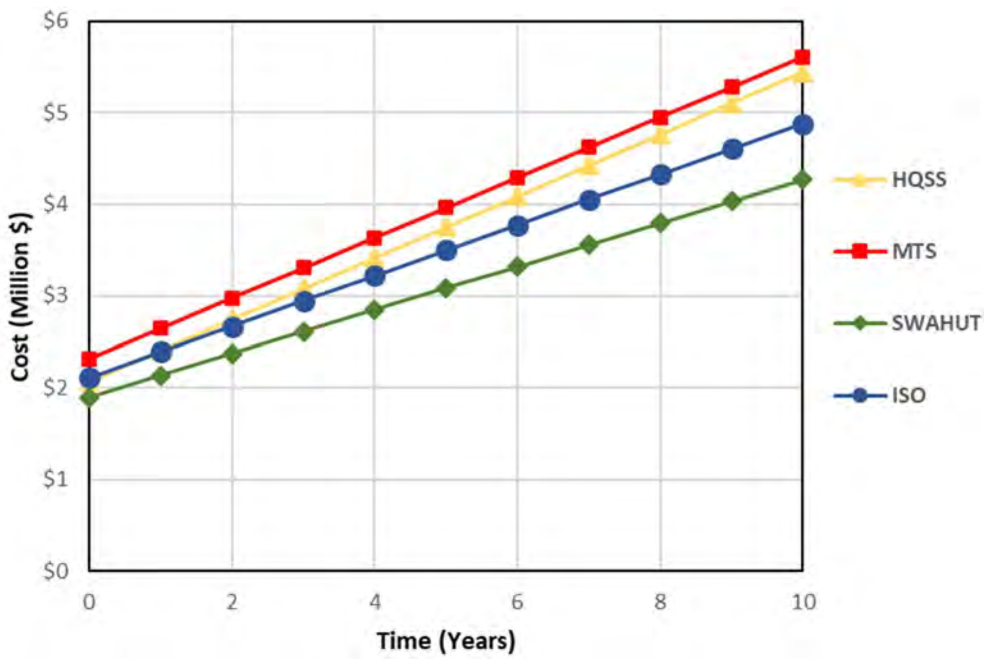

Figure 5.5 – DFI Costs with Time for Permissive Operating Environment in Manila.

The SWAHUT was also the most economical option for the entirety of the period in the non-permissive environment for Manila. The relative performance between the DFI aligned closely between the permissive and non-permissive environments. The magnitude of difference between the DFI options was greater due to the increased cost of fuel at $3.23/L. The costs to operate equivalent camps in the cold weather climates in non-permissive environments were nearly double those in the Manila scenario. Thus, the cost savings associated with DFI selection have a greater overall impact in cold climates. The costs with time for each DFI are presented in Figure 5.6.

[128] Sivak, "Air Conditioning versus Heating."

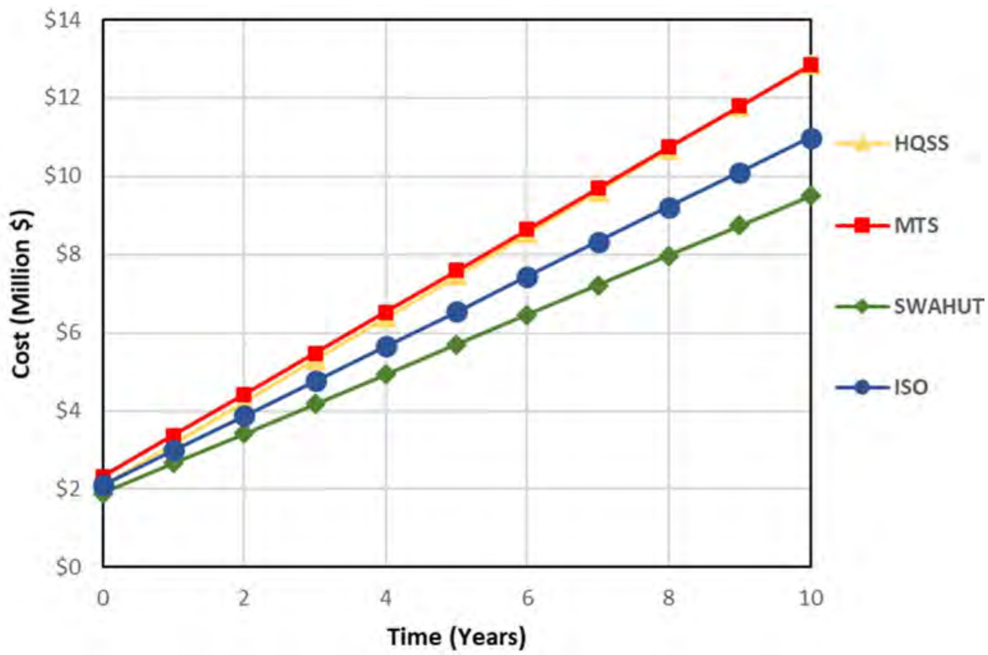

Figure 5.6 – DFI Costs with Time for Non-Permissive Operating Environment in Manila.

<u>Kano</u>

Due to the extremely high shipping costs, roughly six times Manila's and fourteen times Riga's, Kano was the first scenario where tented structures were the most economical option at the outset. The HQSS remained the most economical option until the tenth year when it was surpassed by the ISO Flatpack. It is clear from this result that large initial transport costs significantly improve the economics of tented options. The low fuel cost of $0.89/L reduced the difference in costs between DFI and lengthened the buyback period for the ISO Flatpack and SWAHUT. Despite greater overall costs than Manila, the savings in the Kano scenario were considerably less than in the other climates. The costs with time for each DFI are presented in Figure 5.7.

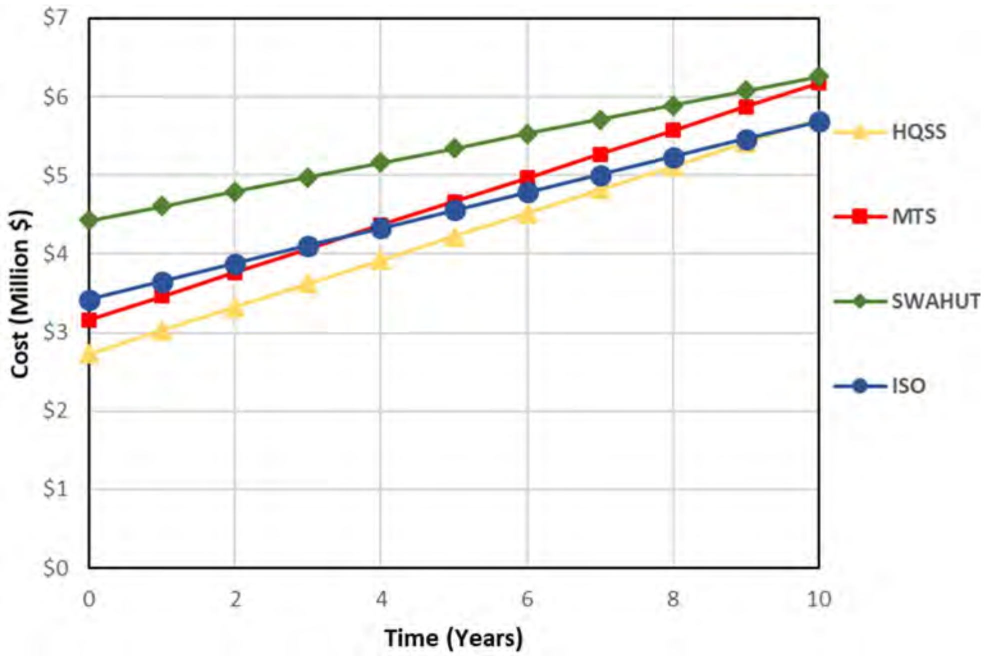

Figure 5.7 – DFI Costs with Time for Permissive Operating Environment in Kano.

The increased fuel costs in the non-permissive environment of $2.85/L greatly altered the relative performance of the DFI. Although the HQSS was initially the most economical option, the ISO Flatpack became more economical in the third year of the scenario. The SWAHUT, owing to its improved energy efficiency due to less air conditioning units, became the most economical option in the eighth year of the scenario. The savings in the Kano scenario were considerably less than in the other climates despite the higher fuel costs. The costs with time for each DFI are presented in Figure 5.8.

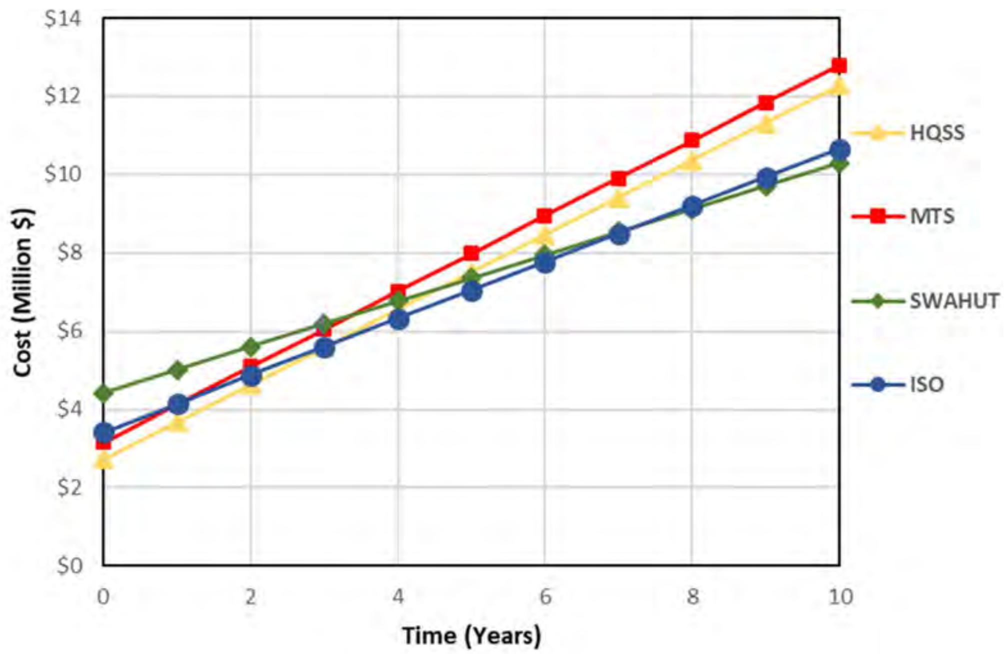

Figure 5.8 – DFI Costs with Time for Non-Permissive Operating Environment in Kano.

Discussion

A variety of trends were observed from the scenario assessments that are relevant to consider in the selection of DFI. First, the cost effectiveness of DFI varied significantly between hot and cold climates. Second, the cost effectiveness of DFI varied more in the hot climates than the cold climates. Finally, fuel and transport costs were found to impact the buy-back period significantly. Thus, upgrades to DFI produce the greatest benefits in theatres with any of the following characteristics: high fuel prices, non-permissive operating environment and cold climates. The key trends identified in the scenario assessments will be summarized herein. To facilitate discussion on the relative performance, the costs of the most economical options and the MTS lite at the two-, five- and ten-year periods for each scenario are presented in Table 5.5.

	Environment	Most Economical DFI			Costs to Operate Camp (Millions of $)								
					Most Economical Camp			MTS Camp			Savings		
		2 Yr	5 yr	10 Yr	2 Yr	5 yr	10 Yr	2 Yr	5 yr	10 Yr	2 Yr	5 yr	10 Yr
Goose Bay	Permissive	ISO	ISO	ISO	$2.96	$ 4.41	$ 6.83	$4.14	$ 6.98	$11.72	$1.18	$2.57	$4.89
	NP				$5.09	$ 9.73	$17.48	$8.31	$17.41	$32.59	$3.22	$7.68	$15.11
Riga	Permissive	ISO	ISO	ISO	$3.14	$ 4.89	$ 7.82	$4.51	$ 7.93	$13.64	$1.37	$3.04	$5.81
	NP				$5.71	$11.34	$20.72	$9.53	$20.49	$38.76	$3.81	$9.15	$18.04
Manila	Permissive	SWA	SWA	SWA	$2.37	$ 3.08	$ 4.27	$2.98	$ 3.96	$ 5.61	$0.61	$0.88	$1.34
	NP				$3.42	$ 5.70	$ 9.49	$4.42	$ 7.58	$12.85	$1.01	$1.89	$3.35
Kano	Permissive	HQSS	HQSS	ISO	$3.32	$ 4.22	$ 5.69	$3.76	$ 4.67	$ 6.17	$0.44	$0.45	$0.49
	NP	HQSS	ISO	SWA	$4.64	$ 7.05	$10.30	$5.09	$ 7.98	$12.80	$0.45	$0.94	$2.51

Table 5.5 – Comparison of Most Economical Option to MTS Lite at the 2, 5 and 10 year timeframes.

The savings in the cold weather climates greatly exceeded those in the hot weather climates. As energy consumption is traditionally greater in cold climates, the result is not surprising. The cold climate camps required between one and half to four times the amount of fuel as required in the hot climates. As a result of the greater fuel consumption, savings from the employment of high standards of DFI in the cold weather climate were between four and thirty times those in hot climates highlights. Although significant savings are achievable in hot climates, the results stress the greater relevance of energy efficiency in cold climates.

The relative performance of each type of DFI was remarkably consistent between the two cold climates but varied significantly in the hot climates. The greater variance in the hot climates is attributed to the air conditioning methodology employed as well as the difference between the Kano and Manila climates. The relatively poor performance of the ISO Flatpack in the hot climates versus the strong performance in the cold climates indicates that the structure is adequate, but the cooling system is not optimized. Thus, employing ISO Flatpacks with a single air conditioner per unit greatly reduces the energy efficiency and cost effectiveness of the system. The use of larger air conditioning units to cool multiple units concurrently would greatly improve the efficiency of the ISO Flatpack.

Diesel prices greatly influence the buy-back periods for DFI. The costs in the hot climate non-permissive environments were roughly double the costs in the permissive environments. The cost difference was greater in the cold climates with the non-permissive environment costing between two and half and three times the permissive environment. Increased fuel prices reduced the buy-back periods and increased the relative savings from employing more efficient structures. The buy-back periods were much shorter and distinct in the cold weather climates, where greater fuel was consumed, occurring within the first year or two for the ISO Flatpack. Furthermore, the savings through the employment of the ISO Flatpack in the cold climate were as much as 80% of the costs to procure, transport and operate the camp for a ten-year period. High fuel prices combined with high fuel consumption generated rapid buy back periods for higher standards of DFI.

Transport costs do not significantly impact buy-back periods of DFI where ground and sea transport are available in permissive environments. The transport costs for Goose Bay, Riga and Manila were a fraction of the procurement costs of the DFI. As a result, the transport costs were not significant. Particularly since the annual fuel costs to operate the DFI exceeded the transport costs several times over. Due to the location of Kano in the interior of Africa, multi-nodal transport was required based on sea transport to Dakar and air transport onward to Kano. Although the methodology produced a high-end estimate of the transport cost, the results are useful to illustrate the significance of transport costs on DFI selection. The results from the Kano scenario demonstrated the greatest difference in performance between DFI. The high transport costs and relatively low diesel costs resulted in the only scenario where tents were more economical over extended periods. Operating environments where transport costs are as much as procurement costs greatly favour DFI that can be packed efficiently within sea containers or air craft palettes. Conversely, transport costs are not a significant consideration when they are less than twenty-five percent of the procurement costs.

SUMMARY

The operational scenarios provided estimates of the costs of different DFI in different climates. Although numerous simplifying assumptions were required, the results generated several trends that are significant to consider in the selection and employment of DFI on operations. The scenarios constitute an initial consideration of the impact of climate and DFI associated costs within deployed camps. The results obtained serve as a start point to further explore the key trends and factors identified in this study.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

As energy consumption on expeditionary operations continues to increase at a rapid rate, energy security becomes a more relevant consideration for commanders and planners. The inefficiencies associated with energy consumption in deployed camps provide noteworthy opportunities to reduce fuel consumption. The inefficiencies are amplified by the fact the CAF expends considerable energy heating or cooling poorly insulated tented structures for extended periods on operations. Since climate is not an explicit consideration in DFI selection, the same type of DFI is utilized in all climate regions creating substantially different energy consumptions in the extreme heat versus the cold. This study examined the significance of climate and type of DFI on energy consumption and life cycle costs in deployed camps. The aim of the thesis was to confirm that designing DFI with consideration for climate would optimize energy consumption facilitating increased energy security and reduced costs to the operation.

Information drawn from the literature, policy, current operations and simulation studies were used to inform the study. An assessment of current CAF DFI practices and doctrine demonstrated that climate is currently not a key planning consideration in the selection of DFI. Furthermore, the I-CUT reports highlighted the exceptionally inefficient behaviour that occurs on operations as well as significant limitations in the sizing of electrical generation equipment. The results of the NRCan simulation provided foundational data that allowed the relative importance of climate and key variables, such as electrical generation and heating or cooling equipment, on the energy consumption in deployed camps to be understood. DFI with greater insulating properties, such as the SWAHUT and ISO Flatpack, were shown to consume considerably less fuel than tented structures in all scenarios. The results also quantified the sizeable inefficiencies that occur on operations due to poorly sized electrical generation and cooling or heating equipment. In many scenarios, equipment selection proved a more relevant factor than climate or the type of DFI employed.

The foundational data was subsequently extrapolated into operational scenarios facilitating comparisons of life cycle costs between a variety of different camps founded in different climate regions. Transport, fuel and procurement costs were presented in tandem with DFI operating costs over extended periods allowing the buy-back period for higher standards of DFI to be determined. Costlier DFI with greater insulation were shown to rapidly become more economical in most scenarios. Furthermore, the energy consumption in cold climates was significantly higher than in hot climates. The scenarios also identified that the additional costs associated with operating in a non-permissive environment greatly alter the life cycle cost analysis. Significantly higher fuel costs, associated with non-permissive operating environments, facilitated enormous reductions in operating costs when more efficient DFI was employed. Although transport costs were generally insignificant when an SPOD existed in close proximity to the deployed camp, tents were shown to be more economical than more efficient DFI when large amounts of air transportation are required. This results presented in this study clearly demonstrated that climate is a key consideration in DFI procurements and selection of DFI standards for operations. Furthermore, consideration of climate in DFI selection was observed to create sizeable reductions of energy consumption in deployed.

Simulation of deployed camps was demonstrated to serve as a useful tool to assess energy efficiency and support DFI related decisions. However, further study to validate the results of the simulation study on operations is required. Subsequent simulation studies into the operational, maintenance and support areas of deployed camps would provide a more complete understanding of energy consumption on operations. Inclusion of metering and simulation in future studies will facilitate greater accuracy of the results allowing DFI costs and energy consumption to be optimized. The substantial fuel savings that can be achieved and gains in resiliency will serve as reserves that can be invested towards other relevant operational capabilities.

The following recommendations are presented in order to improve the planning and management of DFI on CAF operations and should be incorporated into CAF doctrine.

1) Climate and operational scenarios should be considered in the life cycle analysis conducted during procurement of DFI equipment.
2) Simulation of deployed camps should be conducted prior to both theatre opening and major upgrades to DFI on operations.
3) Doctrinal consumption rates should be updated based on metered values observed on operations, and unique rates should be established for different climates.
4) CAF electrical generation methodology used to size equipment to support deployed camps should be revised based on electrical demands observed on operations for each given climate.
5) CAF heating and cooling equipment selection should consider overall camp efficiency in conjunction with the efficiency of individual equipment.
6) Metering of electrical, water, and fuel consumption of operations should be expanded to inform doctrine, planning and assessments.

The costs associated with DFI and energy continue to increase. DFI remains a sizeable requirement, and significant cost, for the majority of CAF operations. As such, the doctrine, planning tools and life cycle analysis must be modernized. When saved, energy is a resource that can be invested elsewhere. It is time to end wasteful practices in deployed camps and invest the savings in improved operational capabilities.

APPENDIX A

OPERATIONAL SCENARIOS COSTING METHODOLOGY

The operational scenarios were based on procurement, transport, fuel and operating costs. The operating costs were established from the NRCan simulation study and are discussed in detail in Chapter 4. The remaining costs were estimated based on information obtained from sources internal to DND wherever feasible. A variety of simplifying assumptions were required in order to simplify the assessment as well as develop costing data where accurate sources were not available. The costing methodology employed to create the operational scenarios is detailed below.

Procurement Costs

The procurement costs were based on estimates provided by the Assistant Deputy Minister Materials Group where available. Quotes from projects or contractors were provided where information was not available within DND. The procurement costing methodology is presented below.

HQSS. The HQSS project is currently in the implementation phase. As such, procurement cost data are easily accessible and reliable within the current market. The cost of an individual plans shelter, as employed in the simulation study, is $24,560.48 if purchased as part of the current large scale procurement comprising thousands of tents.[129] The cost will rise to $42,437.18 during the in-service support phase of the project.[130] The initial cost of $24,560 will be utilized as the construction of a 500-person camp would necessitate a bulk purchase.

[129] Andrew Plater, "RE: HQSS Plans Shelter Cost," March 11, 2020.
[130] *Ibid*.

MTS Lite. A single MTS Lite currently costs approximately $47,000.[131] However, the tents are no longer manufactured in scale and quotes for large scale procurements are not available. In order to replicate CAF bulk procurement practices, the quote for a single tent will be used as the basis to estimate the cost for a bulk procurement. The similarity between HQSS and MTS Lites, such as metal frames and canvas skin combined with the fact they are made by the same manufacturer, will be leveraged to assist in the estimation. The close cost to procure and individual HQSS ($42,437) and MTS ($47,000) during the in-service support reinforces the similarities of the structures. Thus, the ratio of the large-scale procurement to individual procurement costs for HQSS of 0.579 will be applied to the MTS Lite individual procurement cost to obtain an estimate of $27,200 per tent for a large scale procurement.

SWAHUT. The materials for two SWAHUT in Niger cost the CAF slightly less than $35,000.[132] As the shelters were constructed by Allies as a training activity, the construction costs were not recovered or recorded. The cost of a single SWAHUT will be estimated as $17,500.

ISO Flatpack. Cost data exists for a variety of containerized structures constructed on CAF operations within the previous five years. However, this study will focus on data pertaining to accommodations facilities in order to better correlate with the camps simulated in the NRCan study. The costs include an accommodations structure in Erbil, Iraq completed at a cost of roughly $417/m^2 in 2017[133], an accommodations building constructed on AASAB, Kuwait completed at a cost of roughly $853/m^2,[134] and a quote of $807/m^2 to provide ISO Flatpacks to

[131] Weatherhaven, "Price Quotation," August 17, 2018.
[132] Major Dan Arcouette, "RE: Op NABERIUS - Materials," October 10, 2018.
[133] Major Tyler MacLeod, "Cost," February 11, 2017.
[134] Captain Eric Dodd, "RE: Accommodations Building Kuwait," March 11, 2020.

Latvia in 2017[135]. It is clear the procurement and construction costs in the Middle East are considerably less than in Europe. Since the cost of the ISO Flatpack in Latvia included only procurement costs, the total cost would be considerably greater due to construction. As such, the $807/m^2 should represent an intermediate cost between the cost to obtain completed structures in the Middle East and the estimated completed costs in Europe. The costs of a single ISO Flatpack will be estimated as $11,800 per unit based on a cost of $807/m^2.

Transport Costs

Transport costs were estimated based on a simplified move assessment. As such, movement limitations and restrictions including international regulations or lack of material handling equipment were not considered. In reality, some DFI equipment, such as electrical generation equipment, may not be able to be moved by air due to the size of the equipment. However, the assessment will provide an indication of the relative magnitude of costs between the different movement means.

Air Movement. Air movement costs were calculated using the $25,306 per hour rate for a C17 presented in the CAF costing manual multiplied by the flying time between the two locations as determined by flighttime-calculator.com.[136] Although the capacity of a C17 varies significantly based on the volume, weight and physical characteristics of the items moved, a planning factor equal to the quantity 3 x standard 20 foot ISO shipping containers per flight was employed.[137]

[135] Major Matt Arndt, “Costing - Adazi,” February 13, 2017.
[136] Department of National Defence, “Cost Factors Manual - Volume II - Equipment and Facility Costs” (Government of Canada, 2015 2014), p.3.
[137] Lion Capt JP, “RE: Movement Cost Data,” June 14, 2019.

<u>Sea Movement</u>. Sea movement costs were based on the Global Sustainment Sealift Contract (GSSC).

<u>Ground Transport</u>. Ground transport of equipment from storage locations to the Canadian Point of Disembarkation (POD) or from the POD in theatre to the proposed operating locations were not considered since reliable data was not available. Furthermore, since the CAF stores DFI equipment in Laval, the distance to move to the seaport is minimal and the large costs to move equipment by air far outweigh those of local ground transportation. Additionally, local ground transportation costs in theatre would not be significant compared to the original movement from North America since most of the cities considered are co-located with an Air POD (APOD) or Sea POD (SPOD). The only exception is Kano which incorporated multi-nodal transport. Ground transport costs for Goose Bay were obtained from the Happy Valley-Goose Bay Marine Port Study commissioned by the Labrador North Chamber of Commerce.

<u>Move Requirement</u>. The movement requirements were calculate based on the number of individual DFI required within each camp divided by the number of DFI systems that can fit in a standard 20-foot ISO shipping container. For each camp, the costs to move the accommodations, ablutions and heating or cooling equipment were estimated. Heating and cooling equipment was included in the assessment as the equipment is included in the ISO Flatpack and SWAHUT configurations but must be moved separately for tented structures. Since a single heater or air conditioner is required for each tented structure, the heating and cooling equipment constitutes a sizeable movement requirement. In reality, additional equipment, such as electrical generation and distribution equipment, would be required to be moved. However, the amount of additional equipment is relatively similar for each type of DFI and was thus excluded from the assessment.

Non-Permissive. It is important to note, that the local ground transport costs would be significantly higher in a non-permissive environment and thus alter the relative significance of the costs. However, the lack of data identifying transport costs in non-permissive environments within the CAF or literature necessitate simplifying assumptions. Thus, it will be assumed that the camps in all scenarios are co-located with the POD minimizing local ground transport requirements. This assumption aligns with the situation on both the Kandahar Airfield, Afghanistan and the airfield in Gao, Mali. As a result, transport costs will be identical in the permissive and non-permissive scenarios. In reality, the costs in the non-permissive environment would be significantly higher. However, the additional fuel costs employed will account for some of the difference and the results will be useful to identify a lower bounded understanding of the relative importance of operating environment on life cycle costs.

Fuel Costs

Fuel costs for the permissive environment are detailed in Chapter 5. The methodology used to develop the fuel costs for the non-permissive environment was based on a study by the Defence Scientist Ahmed Ghanmi. The study aimed to capture the true cost to deliver fuel to the furthest outposts within the CAF area of operations in Kandahar, Afghanistan. The Author estimated that the FBCE for the CAF in the Kandahar region ranged between 200% to 500% of the delivery cost of the fuel dependent upon the distance to the delivery point and the amount of air security resources employed.[138] As such, a low to mid-range estimate of 320% the fuel costs of the permissive environment will be used to estimate the non-permissive fuel costs. This value corresponds to an increase of 40% over the minimum 200% value presented by Ghanmi and is intended to represent the types of operations where air security requirements are minimal and

[138] Ghanmi, "Fully Burdened Cost of Energy in Military Operations.", pp. 413.

savings could be achieved with minimal impact to operational capability. Costs were converted to Canadian funds where required using google currency converter.[139]

[139] "Google Currency Converter - Google Search," accessed April 16, 2020, https://www.google.com/search?q=google+currency+converter&rlz=1C1GCEA_enCA863CA863&oq=google+currency+cov&aqs=chrome.1.69i57j0l7.4372j1j1&sourceid=chrome&ie=UTF-8.

BIBLIOGRAPHY

Arcouette, Major Dan. “RE: Op NABERIUS - Materials,” October 10, 2018.

Arndt, Major Matt. “Costing - Adazi,” February 13, 2017.

Ahmed Ghanmi. “Fully Burdened Cost of Energy in Military Operations.” Defence Research and Development Canada - Centre for Operational Research and Analysis, 2012.

Bowes, LGen S. “CJOC Implementation Plan Integrated Camp Utility Technologies (I-CUT).” CJOC, 2017.

Breton, Stéphanie, Jalomi Maayan Tardif, Eric McDonald, and Martin Kegel. “Report of a Simulation-Based Study of the Power and Energy Requirements for Deployed Camps.” Natural Resources Canada, July 10, 2019.

Burdett, Capt, Shawn . “RE: I-CUT Annual Report,” March 11, 2020.

Canada, and Department of National Defence. *Defence Energy and Environment Strategy: Harnessing Energy Efficiency and Sustainability : Defence and the Road to the Future.* Ottawa: National Defence, 2017. http://publications.gc.ca/collections/collection_2018/mdn-dnd/D2-394-2017-eng.pdf.

Canada, and Department of National Defence. *Strong Secure Engaged - Canada’s Defence Policy.*, 2017. http://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2017/17-23/publications.gc.ca/collections/collection_2017/mdn-dnd/D2-386-2017-eng.pdf.

Canada, Department of National Defence, and Canadian Army Land Warfare Centre. *Canada’s Future Army, Volume 1: Methodology, Perspectives and Approaches.*, 2015. http://publications.gc.ca/collections/collection_2017/mdn-dnd/D2-354-1-2015-eng.pdf.

Canadian Joint Operational Command. “CFJP 3-12.2 Force Beddown 1st Edition.” Minister of National Defence, 2015.

Dempsey, Major John. “Engineer Camp Costs,” February 8, 2020.

Desrochers, Andrew. “RE: Movement Costs,” January 9, 2020.

Dodd, Captain Eric. “RE: Accommodations Building Kuwait,” March 11, 2020.

Eady, David S., Steven B. Siegel, R. Steven Bell, and Scott H. Dicke. “Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys.” *Army Environmental Policy Institute*, September 2009, 23.

Defence, National. “Operation IMPACT.” Education and awareness. aem, August 19, 2014. https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-impact.html.

Defence, National. “Operation NABERIUS.” Education and awareness. aem, October 20, 2017. https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-naberius.html.

Defence, National. “Operation REASSURANCE.” Education and awareness. aem, May 1, 2014. https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-reassurance.html.

Department of National Defence. “Cost Factors Manual - Volume II - Equipment and Facility Costs.” Government of Canada, 2015 2014.

“Diesel Price Watch - March 2019 - Nigeria Data Portal.” Accessed March 22, 2020. https://nigeria.opendataforafrica.org/bvinzi/diesel-price-watch-march-2019.

GlobalPetrpPrices.com. “Diesel Prices around the World, 13-Jan-2020 | GlobalPetrolPrices.Com.” Accessed January 14, 2020. https://www.globalpetrolprices.com/diesel_prices/.

GlobalPetrpPrices.com. “Diesel Prices around the World, 24-Feb-2020 | GlobalPetrolPrices.Com.” Accessed March 1, 2020. https://www.globalpetrolprices.com/diesel_prices/.

Harding, BGen C.M.. “Update 002 - FY 19/20 Implementation Plan Integrated Camp Utilities Technologies (I-CUT).” CJOC, August 26, 2019.

McDonald, Eric. “RE: Simulation Report,” February 10, 2020.
“FORCE-SIM v3.0 Software End-User License Agreement.” Natural Resources Canada, May 30, 2019.

Ghanmi, Ahmed. “Fully Burdened Cost of Energy in Military Operations.” In *2012 First International Conference on Renewable Energies and Vehicular Technology*, 405–14, 2012. https://doi.org/10.1109/REVET.2012.6195304.

Ghergari, Vrenti, Lily Wang, and Abderrahmane, Sokri. “Development of Cost Breakdown Structure for Defence Acquisition Projects.” DRDC – Centre for Operational Research and Analysis, May 2016.

“Google Currency Converter - Google Search.” Accessed April 16, 2020. https://www.google.com/search?q=google+currency+converter&rlz=1C1GCEA_enCA863CA863&oq=google+currency+cov&aqs=chrome.1.69i57j0l7.4372j1j1&sourceid=chrome&ie=UTF-8.

Kreiger, Megan A. "ERDC/CERL TR-15-19 'The Structural Insulated Panel "SIP Hut": Preliminary Evaluation of Energy Efficiency and Indoor Air Quality,'" 2015, 128.

Legresley. James. "FW: RTC Equipment Reduction," October 22, 2019.

Lion, Capt JP. "RE: Movement Cost Data," June 14, 2019.

MacLeod, Major Tyler. "Cost," February 11, 2017.

McCready, Steve. "RE: RTC Return," March 6, 2018.

McGee, Joshua B., Manuel D. Rossetti, and Scott J. Mason. "Quantifying the Effect of Transportation Practices in Military Supply Chains." *The Journal of Defense Modeling and Simulation* 2, no. 2 (April 1, 2005): 87–100. https://doi.org/10.1177/154851290500200204.

Mtltimes.ca. "Canadian Army Steps in to Help with U.S. Asylum Seekers," August 10, 2017. https://mtltimes.ca/Montreal/montreal/canadian-army-steps-help-u-s-asylum-seekers/.

Moore, David B. "Lean, Mean, and Green: An Expeditionary Imperative." *United States Marine Corps Command and Staff College Marine Corps University*, April 29, 2010, 52.

NATO. "NATO Standard ATP-3.12.1.4 Deployed Force Infrastructure Edition A Version 1." NATO Standardization Office, August 2018.

NATO Science for Peace and Security. "SMART ENERGY TEAM (SENT) COMPREHENSIVE REPORT: On Nations' Need for Energy in Military Activities, Focusing on a Comparison of the Effectiveness of National Approaches to Reduce Energy Consumption," May 6, 2015, 64.

NATO Standardization Agency. "AECTP-230 Climatic Conditions." NATO, May 2009.
Natural Research Council Canada. *National Energy Code of Canada for Buildings 2017*. Government of Canada, 2017.

Natural Resources Canada. "Who Creates Savings - Good Practice Guide 84 Managing and Motivating Staff to Save Energy." Ottawa: Government of Canada, 2012.

Navarro-Galera, Andrés, Rodrigo I. Ortúzar-Maturana, and Francisco Muñoz-Leiva. "The Application of Life Cycle Costing in Evaluating Military Investments: An Empirical Study at an International Scale." *Defence and Peace Economics* 22, no. 5 (October 2011): 509–43. https://doi.org/10.1080/10242694.2010.508573.

Odding, Cohn.. "Original Report ASAB Electrical Issues August 2017," October 23, 2018.

"Pacific Modular - From Flat Pack and Telescopic Solutions to 5 Star Modular Hotel Designs, Pacific Modular Can Tailor Make the Perfect Solution for You." Accessed April 2, 2020. http://www.pacmodular.com/poducts_flat_pack.html.

Picard, Andre. "RE: Life Cycle Management Costs," January 16, 2020.

Plater, Andrew. "RE: HQSS Plans Shelter Cost," March 11, 2020.

Prabhakaran, Major Aarthi. "FW: Deployed Force Infrastructure Costs," November 8, 2019.

Putnam, Nathan Hassan. "Computer Tools for Designing Self-Sufficient Military Base Camps," 2012. https://repositories.lib.utexas.edu/handle/2152/ETD-UT-2012-08-6252.

Regnier, Eva, Jay Simon, Daniel A Nussbaum, and Laura K Whitney. "The Fuel Multiplier in Multi-Stage Supply Chains." *The Journal of Defense Modeling and Simulation* 12, no. 1 (January 1, 2015): 5–17. https://doi.org/10.1177/1548512913515362.

Rouleau, LGen M.N.. "CJOC Integrated Camp Utilities Technologies (I-CUT) Programme Annual Report 2018." CJOC, July 23, 2019.

Samaras, Constantine, William J. Nuttall, and Morgan Bazilian. "Energy and the Military: Convergence of Security, Economic, and Environmental Decision-Making." *Energy Strategy Reviews* 26 (November 2019): 100409. https://doi.org/10.1016/j.esr.2019.100409.

"Sea Hut." Accessed April 2, 2020. http://constructionmanuals.tpub.com/14044/css/Sea-Hut-262.htm.

Sivak, Michael. "Air Conditioning versus Heating: Climate Control Is More Energy Demanding in Minneapolis than in Miami." *Environmental Research Letters* 8, no. 1 (March 2013): 014050. https://doi.org/10.1088/1748-9326/8/1/014050.

Tisa, Paul C. "Department of Defense Energy and Logistics: Implications of Historic and Future Cost, Risk, and Capability Analysis." Ph.D., Carnegie Mellon University, 2016. https://search.proquest.com/docview/1846530473/abstract/167DBFE1E8D544C7PQ/1.

Treasury Board of Canada. "Archived - Guideline on Cost Estimation for Capital Asset Acquisitions." Accessed February 4, 2020. https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=30094&section=html.

"Typical Meteorological Year." In *Wikipedia*, February 12, 2020. https://en.wikipedia.org/w/index.php?title=Typical_meteorological_year&oldid=940419233.

Vandor, Major Andrew. "RE:Deployed Force Infrastructure Cost," November 15, 2019.

Wald, General (USAF Ret) Charles F. “Energy Security - Americas Best Defense. A Study of Increasing Dependence on Fossil Fuels in Wartime, and Its Contribution to Ever Higher Casualty Rates.” Deloitte LLP, 2009.

Weatherhaven. “Price Quotation,” August 17, 2018.
“Weatherhaven - Products.” Accessed April 2, 2020. https://weatherhaven.com/Products

Williams, Capt Nathan. “Annual Report 1 ESU Energy Monitoring Fiscal Year 18/19.” 1 Engineer Support Unit, 2019.

Williams, Capt Nathan, Sqn. “Installation and Energy Monitoring Report - Op IMPACT 2018,” November 28, 2018, 5.

Williams, Capt Nathan. “Installation and Energy Monitoring Report - Op NABERIUS 18,” October 5, 2018, 5.

Williams, Capt Nathan. “Installation Report 1 ESU Energy Monitoring Op REASSURANCE, Lativa,” May 24, 2019, 7.

Willscot, “Https://Www.Willscot.ca/Mobile-Offices/Office-Trailers.” Accessed April 2, 2020. https://ef349129d2344efda14e2e8340afcede.pages.ubembed.com/882ae900-2318-41d8-82ba-1e3696d1d5c0/a.html?closedAt=0.