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An Analysis of the Air Force Installation Development Plan and Its Energy Benchmarking Effectiveness

THESIS

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AN ANALYSIS OF THE AIR FORCE INSTALLATION DEVELOPMENT PLAN AND ITS ADAPTATION BENCHMARKING EFFECTIVENESS

THESIS

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Degree of Master of Engineering Management

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Abstract

Establishing proper, long-term metrics for measuring various resource uses, climatic threats, and sustainability are critical for a military installation's adaptation to climate change. Within the United States Air Force (USAF), the Installation Development Plan (IDP) is a comprehensive long-term base planning document, which includes an inventory of sustainable development goals including energy use and climate indicators. This study analyzed 32 different IDPs among the various installations in the continental United States, identifying regional trends and behaviors across their 16 Sustainability Development Indicators (SDI). To study the IDPs more in depth, specific focus was placed on SDI 1, which concerns energy consumption and generation. This study investigated the different variations in energy benchmarking across local climate conditions, SDI ratings, and units used. Major inconsistencies were found across these three domains. Subsequently, the study identified the remedies needed for standardized energy benchmarking, along with recommending additional adaptation strategies. These comparisons suggest a need for installations to communicate with one another and their regional cities when beginning and concluding energy measurement periods. The results of this study inform both municipal and military planners and engineers on the prominent types of climate metrics for resilience within a changing climate.

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Acknowledgements

Anything begun in vanity ends in humility.

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Jacob P. Hyman

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I. Introduction

1.1 The GAO Report and the IDP

On 12 June 2019, the GAO published a report titled "Climate Resilience: DoD Needs to Assess Risk and Provide Guidance on Use of Climate Projections in Installation Master Plans and Facilities Designs." The report analyzed 23 military installations on the basis of their measures of climate resiliency in their master plans. The report was critical of military installations, finding that only fifteen of the 23 installations in the study had considered some extreme weather and climate change effects for their plans, but the other eight had not. Additionally, only eleven of the 23 installations reviewed had designed one or more projects which would increase the resilience of already standing facilities to extreme weather and climate change affects. The GAO report concluded by calling on installations to factor in long-term climate projections that are specific to their installation's geography and climatology [1].

For the United States Air force (USAF), the Installation Development Plan (IDP) is the chief master planning document that the criticisms of the GAO report must be levied against. As part of a comprehensive planning initiative from the Air Force Civil Engineering Center (AFCEC) from 2015-2016, the IDP became the standard for all installation master plans. As of 2020, the USAF has 59 active-duty installations within the continental United States (CONUS), each with its own IDP. Each installation is strategically located to fulfill its mission within its Major Command

(MAJCOM) and contribute to the whole DoD mission of national defense. The diversity of installation placements, however, opens up installations to a variety of extreme weather conditions based on their geographical region. The IDP has incorporated into its pages an eighth chapter dedicated to climate adaptation measures, based upon the Sustainability Development Indicators (SDI). Each IDP averages a total of 16 unique SDIs, each containing distinct benchmarks and performance ratings for an installation meeting its adaptation goals (Fig. 1).

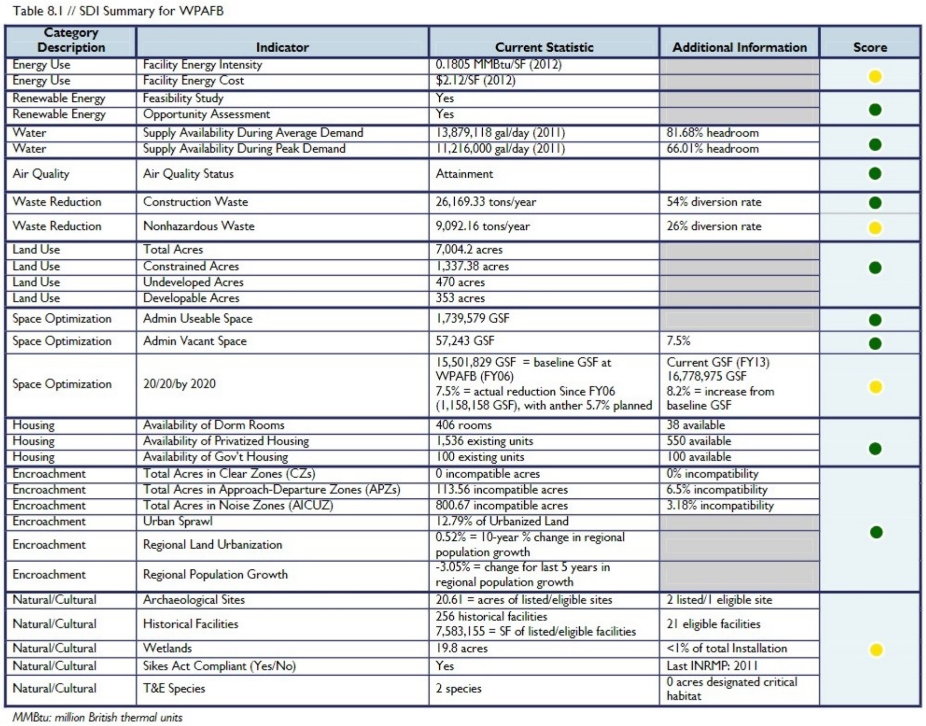

Table 8.1 // SDI Summary for WPAFB

Category Description	Indicator	Current Statistic	Additional Information	Score
Energy Use	Facility Energy Intensity	0.1805 MMBtu/SF (2012)		🟡
Energy Use	Facility Energy Cost	$2.12/SF (2012)		
Renewable Energy	Feasibility Study	Yes		🟢
Renewable Energy	Opportunity Assessment	Yes		
Water	Supply Availability During Average Demand	13,879,118 gal/day (2011)	81.68% headroom	🟢
Water	Supply Availability During Peak Demand	11,216,000 gal/day (2011)	66.01% headroom	
Air Quality	Air Quality Status	Attainment		🟢
Waste Reduction	Construction Waste	26,169.33 tons/year	54% diversion rate	🟢
Waste Reduction	Nonhazardous Waste	9,092.16 tons/year	26% diversion rate	🟡
Land Use	Total Acres	7,004.2 acres		🟢
Land Use	Constrained Acres	1,337.38 acres		
Land Use	Undeveloped Acres	470 acres		
Land Use	Developable Acres	353 acres		
Space Optimization	Admin Useable Space	1,739,579 GSF		🟢
Space Optimization	Admin Vacant Space	57,243 GSF	7.5%	🟢
Space Optimization	20/20/by 2020	15,501,829 GSF = baseline GSF at WPAFB (FY06) 7.5% = actual reduction Since FY06 (1,158,158 GSF), with anther 5.7% planned	Current GSF (FY13) 16,778,975 GSF 8.2% = increase from baseline GSF	🟡
Housing	Availability of Dorm Rooms	406 rooms	38 available	🟢
Housing	Availability of Privatized Housing	1,536 existing units	550 available	
Housing	Availability of Gov't Housing	100 existing units	100 available	
Encroachment	Total Acres in Clear Zones (CZs)	0 incompatible acres	0% incompatibility	🟢
Encroachment	Total Acres in Approach-Departure Zones (APZs)	113.56 incompatible acres	6.5% incompatibility	
Encroachment	Total Acres in Noise Zones (AICUZ)	800.67 incompatible acres	3.18% incompatibility	
Encroachment	Urban Sprawl	12.79% of Urbanized Land		
Encroachment	Regional Land Urbanization	0.52% = 10-year % change in regional population growth		
Encroachment	Regional Population Growth	-3.05% = change for last 5 years in regional population growth		
Natural/Cultural	Archaeological Sites	20.61 = acres of listed/eligible sites	2 listed/1 eligible site	🟡
Natural/Cultural	Historical Facilities	256 historical facilities 7,583,155 = SF of listed/eligible facilities	21 eligible facilities	
Natural/Cultural	Wetlands	19.8 acres	<1% of total Installation	
Natural/Cultural	Sikes Act Compliant (Yes/No)	Yes	Last INRMP: 2011	
Natural/Cultural	T&E Species	2 species	0 acres designated critical habitat	

MMBtu: million British thermal units

Figure 1. Wright Patterson Air Force Base (WPAFB) 2014 IDP's generalized SDI table. Featuring each SDI's key benchmark(s) and ratings, SDI ratings exist to motivate an installation to act when rated sub-standard.

The current extent of these SDIs and the adaptation efforts they inspire has been seen lacking according to the GAO. Action must be taken to assess their lacking robustness as the effects of climate change on government assets becomes increasingly pronounced.

1.2 The Diversity of Climatic Threats

In 2005, Keesler AFB, Mississippi (Fig. 2) was hit with intense flooding due to Hurricane Katrina. The installation's security forces building was flooded to a depth of three feet and the base club flooded with eight feet of water. Additionally, of the 1,800 base homes, nearly 1,000 were destroyed by flood waters [2]. Research has predicted that intense storms will become more prevalent with climate change, increasing the risk of flooding in conjunction with sea-level rise [3, 4].

In 2016, Vandenberg AFB, California (Fig. 3) faced wildfires which consumed over 10,000 acres of California forests, serving power to on-base facilities and restricting base access to emergency personnel only. The fires also threatened United Launch Alliance and SpaceX launch pads [5]. As heat waves and drought enable wide-spread forest fires, and other extreme weather events become more frequent, climate security is continually framed as a national security issue [6, 7].

As recent as 2018, Tyndall AFB, Florida (Fig. 4) was destroyed by Hurricane Michael. While expecting a Category 2 hurricane, Michael escalated to a Category 5 within just a few hours before reaching land. A damage assessment of the base found that 484 buildings were destroyed or damaged beyond repair, approximately half of the buildings on base. The USAF allocated $648 million to immediate repairs, with still more allocated to fully revive the installation [8]. Increases in hurricane strength and frequency have been attributed to anthropogenic climate change, and inadequate building codes and adaptation plans can leave installations unnecessarily vulnerable. [9, 10]

The IDP and its SDIs, as the standardized master plan and climate adaptation initiative of the USAF, must be assessed and refined to better adapt to climatic threats. The installation, however, does not exist in isolation. Surrounding towns and cities which serve USAF installations are challenged with the same diversity of

Figure 2. The Keesler Marina, submerged under floodwater

Figure 3. The encroaching wildfire near Vandenberg

Figure 4. Destruction of Hurricane Michael on Tyndall

threats. Municipal and state governments have taken interest in incorporating climate adaptation strategies into their own master plans due to adaptation being most appropriately implemented at the local level where the specific realities of climate change occur [11]. As the IDP shares much in common with a city master plan, it is well positioned to borrow from the wealth of city planning and climate adaptation research in its continued refinement.

1.3 State and Local Master Planning and Adaptation Benchmarks

Master planning on the state and local level focuses in on the major threats that an area is facing based on its unique geography and climatology. Acting as collaborative documents between both public and private stakeholders, master planning can help orchestrate long-term growth and sustainability in the face of climate change. A master plan's ability to implement adaptation measures include advocating for the increase in building, road, and bridge design standards based on projected increases in heat-waves or storm strength and the cataloging of infrastructure metadata [12]. Climate Adaptation Plans (CAPs), separate from a city's general plan which specialize in laying out long-term climate adaptation strategies also can inform IDP development with their explicit focus on emissions of Green House Gasses (GHG), energy consumption, agriculture, and waste production [13].

The adaptation strategies of master plans are informed by their benchmarks. Consisting of numerous social, economic, and geographic descriptors, benchmarks can be either quantitative or qualitative measures of things that may be affected by climate change. Benchmarks include an area's population, average energy consumption per household, and average petroleum consumption per automobile as examples. These values can then inform adaptation action based on their criticality, but with poor access to these descriptive data, or emphasis put on the wrong types of data, cities risk an inaccurate reading of their most effective adaptation options [14]. This borrowing from climate adaptation master planning is welcome by the DoD, as reflected in the 2014 Climate Change Adaptation Roadmap which sought to "collaborate with internal and external stakeholders on climate change challenges" [15].

To remedy the failures identified within the GAO report, this thesis approaches the IDP and SDIs through the lenses of city and state master planning efforts, by assessing the effectiveness of the 16 SDI's adaptation methods and standards, with a specific focus on the rating methodology for an installation's energy consumption.

1.4 Research Hypothesises

For the GAO report to be implemented effectively, an in-depth analysis of the IDP is needed to assess how it currently measures climate change and recommends adaptation efforts. This tactical breakdown of the IDP involves an analysis of multiple CONUS IDPs and how they incorporate climate change adaptation into their master plans, a close study of the benchmarks of the SDIs, and the comparing of the SDI benchmark values against reputable academic research and local adaptation initiatives to identify deficiencies. This thesis aims to accomplish said IDP tactical breakdown for better USAF readiness towards climate change.

To realize this IDP tactical breakdown, the thesis and its goals are broken into multiple parts. The research hypothesises for this thesis are as follows:

1. Current literature has a wealth of information to discuss how cities can adapt to climate change, but how much overlap do they have with planning efforts of an AF installation?
2. The average 16 SDIs that each installation has base their benchmarks off of certain EOs and AFIs. How well do those EOs and AFIs reflect benchmarking recommendations from the literature?
3. An investigation of SDI 1 will be conducted, analyzing installation energy consumption quantities and how they correlate to the SDI's rating. Will their be discontinuities between installations and their rating methods, and if so, what can they do to become standardized?

The answering of these questions will show how cutting edge the IDP is in climate adaptation, and if it is equally effective at each installation. It is expected that the installations will have overlap with the climate adaption literature. It is also expected that there will be questionable overlap with how well the SDIs incorporate literature recommendations. Finally, it is expected that there will be some discontinuities between installations in their energy benchmarking and rating methods.

1.5 Thesis Organization

First, Chapter II titled "Climate Change Adaptation Today" answers question one. It serves as a literature review of research concerning urban environment's and their methods of adapting to climate change. The chapter is broken into subsections focusing on how climate change affects an urban environment's resources of water, energy, air quality, public use and structures integrity, natural and cultural resources, city space and planning, and poverty and city growth. Additionally, these subsections address the policy and organizational strategies used by the governments of urban environments to adapt to climatic threats.

Next, Chapter III titled “Assessing the Installation Development Plan” answers question two. It studies the IDP and its respective SDIs by an analysis of over 30 sampled CONUS installations. The chapter introduces the 32 sampled installation’s IDPs and uses their data to present the average 14 SDIs found across all IDPs. Each SDI is described by the values it benchmarks and the executive orders and regulations which structure its captured data. The SDIs and their benchmarks are then compared against the literature discovered in Chapter II to see if their recorded values are the most apt for assessing an installations success of climate change adaptation.

Finally, Chapter VI titled “The Future of the IDP For Effective climate Adaptation - An Energy Benchmarking Analysis” answers question three. It provides an in-depth case study of SDI I: Energy Consumption. This case study compares the SDI I ratings and subsequent energy benchmarking data from the sample IDPs against one another to determine rating methods between USAF installations. GIS visualizations with Köppen-Geiger climate zones are featured to help reveal trends between CONUS installation’s energy consumption patterns. This section concludes by assessing SDI I’s rating methods, and where appropriate, makes general recommendations to the other SDIs for future iterations of the IDP.

II. Part 1 - Climate Change Adaptation Today

2.1 Introduction

Climate change poses threats that affect the makeup of our urban environments. With threats such as rising sea-levels leading to an increase in climate migration, and heat stress accelerating infrastructure degradation, there is a need for urban environments to actively plan for adaptation [16, 17]. A changing climate affects a military installation similarly to a civilian city, therefore a study of relevant literature is beneficial to direct an installation's own planning [18]. Extensive studies exist on the state of climate projection planning and climate change impacts in the urban environment, with the field consistently refining as it matures. For this literature study, firstly the key areas of urban climate adaptation will be identified. Then the literature in each area will be studied to see what recommendations they give to urban environments for adaptation planning. Finally, the study will compare how these recommendations align with areas that installations must be prepared for, allowing for a transition to the next chapter's discussion on the IDP.

2.2 Identifying Key Areas of Climate Planning

In 'Planning For Climate Change In Urban Areas: From Theory to Practice' by Wamsler, the concept called the City-Disaster Nexus is introduced [19]. The Nexus is a theoretical framework which links climatological threats to a city's 'urban fabric'. This 'urban fabric' is the physical structure and layout of the city that interfaces with the non-built elements of the city including its urban ecosystem, society and culture, and economy and governance. Wamsler's study, being published recently within the past 10 years, and having over 200 citations, it is an important framework for identifying the key areas of climate planning. Wamsler's study was used as a framework for analysis and applicability of current research to DoD installations. It is important to note that the ‘society and culture’ and ‘economy and governance’ categories were not used in this analysis. These are because their sub-sections differed too much from a military installation’s economics and governance and social and cultural makeup for the comparison to be helpful. Only the ‘urban fabric’ and the ‘urban ecosystem’ were considered. The categories used for this study then, for ‘urban fabric’ were: population densities, land coverage and vegetation, the organization of structures in its surroundings, and infrastructure condition. The categories for ‘urban ecosystem’ were: precipitation, waste and waster water, air quality, and energy.

2.3 The Urban Fabric

Population Densities.

Sea-level rise poses a risk to cities in increasing their population density due to climate migrants. Planning for climate migration firstly concerns major European and Asian cities, but the United States also needs to prepare for migrants from Central America and the Caribbean Islands [20]. Incorporating climate migrant projections into planning documents has been a challenging task for cities, since the scope of the problem requires communication with state and national governments [21]. Still, cities proximate to anticipated migratory lands should regularly monitor their land use and housing access in anticipation of climate migrants [22]. While CONUS installation’s may not have to concern themselves with directly receiving climate migrants, however cities or towns surrounding installations may directly host them, affecting the municipal lives of airmen and their families.

Land Coverage and Vegetation.

Threats to land coverage and vegetation include the encroachment of urban sprawl onto forests and vegetative terrain, reducing GHG absorption and weakening regional biodiversity. Certain degrees of sprawl are helpful in ecosystems such as lengthy rivers, however sprawl into plains and forests can threaten native species with invasive ones, disrupting the ecosystem's GHG absorption capabilities [23, 24]. Multiple planning recommendations have been proposed for cities to reduce sprawl and preserve vegetation. This includes utilizing transportation policy to minimize the construction of new roads through taxing existing but failing roads, and improving public-transit to make downtown travel more mobile [25]. Additionally, the adoption of explicit Sprawl Reduction Planning Policies (SRPPs) such as long-term conservation easements, transfer of land from urban to rural authorities, and density bonuses can be employed by municipalities [26, 27]. Just like a civilian city, changes in the scope of an installation's mission may require them to make impervious vegetative lands, increasing installation sprawl and decreasing GHG absorption.

Structure Placement.

The placements of structures in reference to their surroundings can create unique challenges for climate adaptation. Increasing temperature turns the concentrated placement of buildings and human activity into urban heat island (UHI). UHIs pose a threat to urban life, directly threatening human life due to dehydration and heat stroke [28]. There are recommendations to combat UHIs by not changing the built environment, but by changing human activity in it such as green public transportation, cultivation of urban vegetation such as roof-top gardens, and diversifying commercial land use across the city instead of concentrated business districts [29]. Building placement also bleeds into urban society and culture as access to transportation, housing, fresh food, and work is relative to socioeconomic status (SES). Lower SES communities tend to be places containing food deserts, concentrations of industrial capital and its pollutants, and lacking public transportation [30]. Installations already design their buildings with reference to their placement of one another, needing to manage both mission essential buildings, recreational facilities, and residential homes.

Infrastructure.

Finally, the built environment is concerned with the state of infrastructure. Infrastructure included but not limited to roads, bridges, administrative buildings, public transportation, and parks are all threatened by climate change. Sea level rise, extreme precipitation, and increases in temperature pose vulnerabilities to concrete and asphalt degradation especially towards the later half of the 21st century [31, 32]. Public investment will have to meet the accelerated degradation of decades old bridges due to both increased temperatures and higher flood intensity [33, 34]. To adapt to concrete degradation, cities are recommended to create new construction codes requiring higher cover thickness, and stronger quality concrete construction [35]. Due to the scope of large cities, their current tax rates and federal grants may not be enough to adapt its infrastructure. Because of this, there are recommendations for cities to defer to and sponsor private investment in infrastructure [36]. Many AF bases also have old infrastructure in the forms of historic buildings, or heavily used infrastructure such as an airfield which are threatened by changes in precipitation and rises in temperatures.

2.4 The Urban Ecosystem

Precipitation.

Climate change affects precipitation by making rainy seasons more time-constricted and the intensity of rainfall more intense [37, 38]. This threatens cities with variable access to drinking water, and an increased risk of flooding. Recommendations to city planning for increased flooding risks details designing future urban spaces to accommodate intense flooding through strengthening of building codes, and higher elevated buildings [39]. To secure drinking water with a variable precipitation season, cities are recommended to adapt rainwater harvesting (RWH) systems at levels of both commercial and residential use [40].

Air Quality.

Air quality is dramatically affected by climate change. One of the contributing factor of climate change, GHGs, are created within urban environments. Automotive-travel, air-travel, industrial factories, and power generation are all major sources of different principal pollutants [41]. The travel of these air pollutants causes ozone degradation and can effect areas outside of a cities boundaries, but initial consequences are felt firstly within the urban environment. Public health is negatively affected as principal pollutants may aggravate respiratory systems especially in children, the elderly, and people with existing asthma and cardiovascular problems [42, 43]. Additionally, high quantities of industrial air pollutants can produce smog, reducing sunlight absorption by plants, producing low vitamin D levels in humans, and increasing rates of automotive accidents [44]. Recommend city planning initiatives to improve air quality include traffic control policies, razing automotive emission standards, and giving tax incentives to reducing a building's energy footprint or supplementing its energy consumption with renewables [45]. Installations must already monitor and mitigate the gaseous byproducts that aircraft exhaust from negatively affecting the health of airmen and their families living and working on base.

Energy.

Improving air quality is closely connected to urban travel, and therefore connected to energy consumption and production [46]. Common urban energy consumption and production involves the gathering and burning of fossil flues into electrical or automotive power, increasing GHG levels. In addition to negative environmental affects, heavy reliance on fossil fuels places city well-beings at the hands of geopolitical energy conflicts and the uncontrollable economic and social instabilities that it accompanies [47]. Increasing green energy production and consumption is a common recommendation for cities. However, green energy production projections struggle to match the current rates of total energy consumption without intervention of federal green energy subsidies, fossil taxes, and general energy reduction [48]. Common city planning recommendations for energy reduction include imposing local carbon taxes and increasing the diversity of transit ranging from electrical busses, bike infrastructure, and improved walkability [49, 50]. With energy adaptation, installation's large energy requirements have already encouraged them to look into switching to low impact fossil fuels such as WPAFB's transition to natural gas, or green energy supplementation.

Wastewater and Waste.

Wastewater and waste management is also a part of the urban ecosystem. Waste generation and disposal follows any urban environment, but its scope is increased with urban sprawl, as larger distances mean more sewer and travel networks to maintain for proper disposal. Suburban cities and their associated standards of living tend to generate larger quantities of waste than densely packed urban environments [51].

The wastes that this sprawl produces includes landfill waste emissions and the travel emissions that make these landfills possible. These emissions join the other GHGs that cities produce and increase poor health and ozone weakening outcomes [52]. Wastewater systems similarly contribute to climate change through fossil fuel energy consumption, and through GHG emissions production through the water reclamation process. Wastewater treatment and reclamation was blamed for an average of 56% of GHG emission in the water industry [53]. Urban planning recommendations for wastewater and waste management adaptation include municipally supported composting systems and switching to biogas energy alternatives for wastewater reclamation [54]. Concerning waste production, installation's currently import most of their food, off site, however their is room to utilize the large green-spaces of installation to use as composting areas for nominal installation food production and minimization of waste.

2.5 Conclusion

There are a number of climatic threats that are threatening a city, and of which adaptation recommendations have been given. A city can be divided into it's urban fabric, its structural and physical elements, and its urban environment, its ecological and natural resource elements. These distinctions can be broken into specific threats that a city faces including: increasing population densities, shrinking land coverage and vegetation, harmful structure placement, weakening infrastructure, variable precipitation, worsening air quality, unsustainable energy, and increase wastewater and water. Comparing these threats and their adaption recommendations to the operations of a military installation show that their is considerable overlap. Climate adaptation planning observations and recommendations can serve as a good judge against the effectiveness of the IDP's SDIs.

III. Part 2 - Assessing the Installation Development Plan

3.1 Introduction

The IDP is a strategic document, whose objectives are implemented by different documents and components of the base. The Installation Development Plan (IDP) is an AF master planning document, similar to a city master plan and as such contains similar information on long-term goals and strategies to facilitate resiliency. The mass adoption of the IDP was promoted by the Air Force Civil Engineering Center (AFCEC) as part of a comprehensive planning initiative. From 2015-2016, the AFCEC set a goal for the creation of 30-40 new IDPs for installations that had not had them over the next five years [55]. Since that initiative, many more installations have placed their master planning data into an IDP.

The IDP is updated on average every five years as the installation's mission is continuously refined and as new base commanders exert their influence over the future goals of the base. The IDP is made up of a total of ten sections, organized in a top-down approach (Fig. 5). Firstly, the IDP establishes how the installation mission fits in strategic alignment with the goals of the DOD, then details the installation's geographical setting and planning constraints, listing off the condition of its existing infrastructure, taking note of its sustainability efforts, looking towards what future developments could happen with installation infrastructure. Finally, it establishes an implementation timeline and ranking of future projects for the installation, forecasting out, in some cases, 20 years.

IDP creation has been handled primarily by third party contractors who specialize in land use and master planning. Some of these contractors for IDP creations include large names such as AECOM, Woolpert, and Jacobs, but over 10 different contractors were found between the sampled IDPs. These contractors collect the data for the IDP

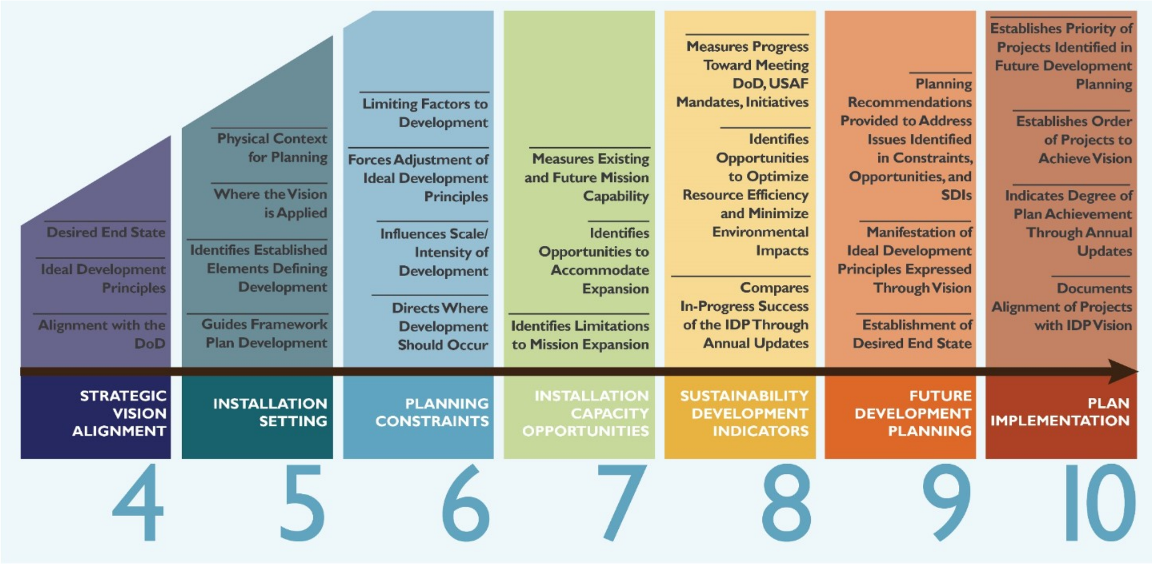

Figure 3.1 // IDP Roadmap

Figure 5. Figure from Vandenberg AFB's IDP featuring its chapter breakdown. Notice chapter eight, the Sustainability Development Indicators. Peeling back this chapter will be the focus of this research.

through in-person installation visits, involving meetings with base leadership and key stakeholders. The data they collect is then formatted into the standardized IDP layout, prepared for them by AF leadership.

Contractors base an installation's long-term growth goals off of the United Facilities Criteria (UFC) 2-100-01 requirements. UFC documents are federal level regulations must set building and design standards for DoD assets, of which UFC 2-100-01 focuses on an installation master planning. UFC 2-100-01 was created in 2005 but has had subsequent addendum's in 2012 and 2019. The criteria describes the purpose of an installation master plan and what information it should contain.

The scope of the IDP is directed towards amassing the information from smaller documents titled Area Development Plans (ADPs), of which an installation could have multiple, depending on its size. The IDP aggregates and presents their information as a network of planning considerations that run across the installation. UFC 2-100-01 gives clarification in bullet B-3.2.8 as to what AF sustainability indicators must look like.

These indicators include metrics on air quality, water conservation, encroachment, and of note, energy use. The IDP formally incorporates B-3.2.8 as items called Sustainability Development Indicators (SDIs). SDIs sit towards the end of the IDP in its eighth chapter. Each IDP has an average of 15-18 individual SDIs, depending on the preference of the contractor which designed it. These SDIs rate an installation's preparedness for a change in operating status due to an external or internal threat.

The SDIs follows a measure, compare, and predict framework. The SDIs measure empirical data related to their topic, compare the data to the goal established in the previous IDP, and predict how the data will change in the future due to base expansions and other exterior factors. Each SDI is ranked based on the data it presents and how that translates to sustainable operations with one of three general ratings.

[56] (Fig. 6). SDIs can also be ranked as having insufficient data when the installation cannot draw a conclusion on its state of sustainability. In all, the SDIs are key to understanding AF installation climate preparedness. However, not every IDP is made equally. There are variations between installations and the number of SDIs for which they account. Across CONUS installations based on contractor recommendations. To properly determine the effectiveness of the SDIs, these variations between installations must be considered.

3.2 Installation Selection Methodology

To account for the variability of SDI quantities between installations, a sample of 32 installations were selected across CONUS. Specific bases were picked to achieve a representative sample of the total types of climatic threats for which USAF installations are expected to adapt. Secondly, a large enough sample of installations would

EXCEEDING ●

Trend is improving when compared to prior year – or exceeding current strategic goals

STATUS QUO ●

Trend remains the same when compared to prior year or trending toward meeting strategic goals

CAUTIONARY ●

Trend is not improving or worsening when compared to prior year or is failing to meet strategic goals

NOT APPLICABLE/ INSUFFICIENT DATA ●

Cannot be quantified to provide measure or additional data/information is needed

Figure 6. WPAFB IDP's 2014 SDI Stoplight Ratings Explanations

reveal the most prevalent SDIs across the nation, and analyze those SDIs that are common across installations. The most recent IDPs for each installations were collected via Sharepoint file transfer from the AFCEC. Their data are made anonymous to avoid any attribution of official information.

The number of SDIs between the 32 IDPs sample ranged between 15 to 18, with an average and median of 17. The various SDIs are generally similar across all installations, with a few exceptions. The variation in number of SDIs is due to those contractors which combine certain SDIs together. These SDIs being Space Optimization, Facilities, and Housing and External Sustainability and Climatic Vulnerability. Of the installations, 44% left Space Optimization, Facilities, and Housing together, while the remainder listed them as separate IDPs. These same ratios also apply to those installations who separated the External Sustainability and Climatic Vulnerability SDIs.

To reconcile these SDI variations and establish a standard to judge the SDI against itself, Vandenberg AFB's collection of SDIs was chosen. This was chosen for two reasons. Firstly, Vandenberg's has the most up-to-date IDP, having a publish date of January 2019. Secondly, all of its 16 SDIs are reported as scoring 'exceeding'. The following subsections identify each SDI, its definition, executive orders (EOs) and the Air Force Instructions (AFIs) that inform its adaptation goals.

3.3 The Sustainable Development Indicators

SDI 1: Energy Use.

SDI 1: Energy Use accounts for the total annual energy use of an installation. The SDI uses data gathered from the installation's Civil Engineering Squadron (CES) and presents the energy use as an energy intensity per facility area, using some variation of units of energy over area. Considering energy use as an SDI became important with the adoption of EO 13423, titled "Strengthening Federal Environmental, Energy, and Transportation Management" and signed into order by President Bush in 2007. The EO required federal agencies to reduce energy intensity by three percent each year. This EO was super-seeded however in 2015 by EO 13693, titled "Planning for Federal Sustainability in the Next Decade" under president Obama. This EO reduces the reduction in energy intensity to 2.5 percent each year. Installations conform themselves to these EO requirements, and measure their adaptation progress in SDI 1 by measuring energy use. The metrics used for this measure include energy intensity, average cost per square foot of energy consumption on the base, a flat yearly cost, and comparable metrics to whatever previous FY was set as the initial baseline year. The SDI compares the actual percentage of energy reduction from the baseline year to the projected, and states whether the installation exceed, met or failed the baseline FY's energy goals. The SDI predicts future energy usage through the creation of formulas which account for the energy use per capita, energy use per square footage, cost of energy per square footage, and the total cost of energy across the entire base for future years. The prediction section also states that in accordance with AFI 90-1701 titled Energy Management, that all new buildings on an installation designed after 2020 shall be ”net-zero” energy facilities.

SDI 2: Renewable Energy.

SDI 2: Renewable Energy accounts for the diverse ways that an installation uses renewable energy to supply a percentage of its energy needs. The current renewable energy standard that AF installations are being held to is also EO 13693. The SDI also abides by 42 United States Code (USC) § 6374, titled ‘Alternative Fuel Use by Light Duty Federal Vehicles’. The USC details FY goals to transition petroleum fuel in ground vehicles to alternative fuels at varying percentages per FY. This SDI judges how well the installation is meeting the goals of EO 13693 and 42 USC 6374. The SDI measures this success by checking if the installation has run a renewable energy transition feasibility study and opportunity assessment and details the ground vehicle flue consumption of petroleum and alternative fuel sources in units of MMBtu/yr and the percentage of ground vehicle fuel used which is from an alternative source. The SDI compares the current years data with the previous baseline FYs goals and also details the specifics of how the installation sources its alternative energy. The SDI predicts how the installation will meet the goals specified in EO 13693 through detailing future alternative energy projects that the base is considering and lists the different planning factors and constraints that will be faced in these future projects.

SDI 3: Water Quantity (Supply).

SDI 3: Water Quantity (Supply) details how the installation conserves its supply of potable water to meet goals established in AFI 90-1701 and EO 13693. AFI 90-1701 titled ‘Energy Management’ sets the goal to reduce an installation’s potable water use by 26 percent by FY20 using FY07 as a baseline. SDI 3 compares the average supply headroom to the supply peak headroom for either the installation if the installation produces the majority of its own potable water or the local water authority if it outsources the majority of its potable water. Various potable water metrics are measured, all based on water availability during either average or peak demand from the supply average gallons per day (gpd), the percent headroom in both average and peak demands, and the supply and demand gpd at peak demand. The results compares the current FY's data to previous FYs to see any positive or negative changes in water consumption to meet the AFI and EO's goals. The SDI predicts whether in future years the installation's current water consumption will change and if so what steps need to be taken.

SDI 4: Water Quality.

SDI 4: Water Quality accounts for the potable water quality on the installation and the quality of the storm water that it dispels into local waterways. This SDI does not contain any quantitative values to help determine optimal water quality but instead it describes qualitative facts about an installations water quality. These qualitative statements vary between installations, for example, Vandenberg describes possibly using poor-quality water for fire-fighting while Wright-Patterson talks much about its 50 year old piping system and how the metal pipes are contributing to alkalinity of the water. Of organizational note, this SDI does not structure itself in the measure, compare, and predict pattern unless the SDI is rated either status quo or cautionary. If the SDI scores one of these two ratings, the SDI is then broken into the three traditional sections.

SDI 5: Wastewater Quality and Quantity.

SDI 5: Wastewater Quality and Quantity measures an installation's daily wastewater intake and output. This SDI measures the average daily waster-water discharge supply, average headroom and a total headroom value, similar to factor of safety which accounts for fluctuations between wastewater supply and demand. It also measures wastewater discharge capacity through comparing the average supply and demand in gallons per day of peak and average wastewater discharge. There are no references to any AFIs or EOs as baselines for the general rating.

SDI 6: Potable Water Intensity.

SDI 6: Potable Water Intensity measures how much drinking water an installation consumes and receives annually. It references EO 13693 alongside the other energy and water SDIs, which requires installations to reduce their potable water consumption by 36 perfect through FY25, with a baseline of FY07. The SDI measures potable water in the metrics of Mgal/SF annually, and compares a percent reduction from baseline to target value to assess if the installation has met its EO goal.

SDI 7: Air Quality.

SDI 7: Air Quality keeps track of the six principal pollutants defined by the Clean Air Act (CAA) that an installation produces. The CAA was declared in 1970 is the comprehensive federal law that regulates air emissions from stationary and mobile sources. Among other things, this law authorizes the Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) to protect public health and public welfare and to regulate emissions of hazardous air pollutants [57]. These hazardous air pollutants which the CAA defines are broke into six principal pollutants: Nitrogen Dioxide, Ozone, Sulfur Dioxide, Particulate matter, Carbon Monoxide, and Lead. The SDI compares the CAA permitted tons/year of pollutant to its actual output for each of these six principal pollutants.

SDI 8: Waste Reduction.

SDI 8: Waste Reduction measures the different types of waste that an installation produces in accord with EO 13693. The EO requires at least fifty percent of nonhazardous solid waste be diverted while pursuing net-zero waste opportunities. Additionally, it requires an installation to divert at least fifty percent of nonhazardous construction and demolition material debris. The SDI captures non-hazard solid waste and construction debris percent reduction goals and their actual diversion rates. The same metrics in units of Tons/Years instead of percentage are given.

SDI 9: Space Optimization, Facilities and Housing.

SDI 9: Space Optimization, Facilities and Housing measures the reduction of facility space an installation has accomplished in accord with the "20/20 by 2020" plan. Headquarters Air Force (HAF) created a strategic plan in 2008 that called to improve energy efficiency by shrinking AF facilities by 20 percent. This goal was also set to happen by FY20 (thus the name "20/20 by 2020"). The IDP measures quantities related with the "20/20 by 2020" plan in the form gross square foot measurements of facility space disposed, but the SDI also captures space optimization values. It lists all the different housing types and the quantity of housing an installation has.

SDI 10: Encroachment.

SDI 10: Encroachment measures the overreach of an installation if it is expanding into agricultural and conservation land. The SDI measures encroachment effects off of Accident Potential Zones and Air Installation Compatible Use Zones (APZ and

AICUZ). APZs are areas where aircraft have the threat of crashing and causing damage. AICUZs are areas where noise and other aircraft related hazards are considered in the land planning). Their is no AFI nor EO listed dealing with encroachment issues; however, the installations tend to increase their values closer to zero to be viewed as successful.

SDI 11: Airfield.

SDI 11: Airfield measures an installation's Pavement Condition Index (PCI) rating. The PCI is a numerical rating resulting from an airfield condition survey and it represents the severity of surface distresses. Airfields with low PCIs can pose a threat to pilots and aircraft. The failing PCI percentage is that of 55 percent or less. Installations measure both the total percent of their runway under that threshold and to the average PCI rating of the entire installation.

SDI 12: Environmental Impact Analysis Process (EIAP).

SDI 12: Environmental Impact Analysis Process (EIAP) measures if an installation has conducted any environmental impact assessments and what their results were. Signed into law in the 1970s, the National Environmental Protection Agency (NEPA) required federal agencies to consider potential impact on the environment implementing actions or expending resources. The Air Force accomplishes NEPA's requirements through doing an Environmental Assessment (EA). The EA is a written document that provides an analysis sufficient to determine whether to prepare an Environmental Impact Statement (EIS) or a Finding of No Significant Impact (FONSI). Whenever an installation desires to do a major project, an EA must be undertaken. The SDI measures the number of EAs and EISs completed within a 10 year time-frame and all EISs currently in progress. The SDI does not list-out each

EA or EIS in detail, only their quantities.

SDI 13: Natural/Cultural Resources.

SDI 13: Natural/Cultural Resources measures the quantity and quality of natural and cultural resources that an installation possesses in accordance with AFI 32-7065. AFI 32-7065 titled Cultural Resources Management was penned in November of 2014. The AFI emphasized that the AF identify, manage, and maintain important cultural resources in a spirit of stewardship for the benefit of current and future generations. These natural and cultural resources vary between installations, but they can include keeping track of the number of archaeological sites, historic districts, historic facilities, threatened and endangered (TE) species, wetlands, and agricultural out-leases. This SDI does not feature a general ranking, since different installations may have more or less natural and cultural resources based on forces outside of their control such as surrounding history. The SDI does not account for how an installation is properly managing its natural and cultural resources, such as if TE species are maintaining stability or are decreasing. It does however, feature the expenditures on TE species protection, making no judgement if the quantity spent was previously undefined or sufficient to maintain the number of species successfully.

SDI 14: Community Planning.

SDI 14: Community Planning measures the community planning efforts of an installation by accounting for current and future land use methods. The long-term sustainability of an installation also depends its ability to accommodate additional facilities and developments. This SDI measure the total acreage that an installation is on, and breaks it up between constrained, underdeveloped, and developed areas. The SDI then breaks the land use down into sub-categories such as industrial, administrative, airfield, housing, commercial, medical, open space and recreational, launch operations, and training acreage. Theses sub-categories are also broken down into constrained, undeveloped, and developed acres. Of note, the SDI does not contain expected growth of different land-use types, only the quantities of pre-existing areas.

SDI 15: External Sustainability.

SDI 15: External Sustainability measures an installation's urban profile and its problems such as traffic, air pollution, central-city poverty, and the degradation of scenic areas. Specifically, the SDI measures sprawl index, regional land urbanization, regional population growth, increase in regional growth rate, and housing affordability. Of note, this SDI often describes its sources for its information, including census, county, region, national, and GIS data. This SDI does not have any specified AFIs or EOs which direct what benchmarks it records. This SDI also does not have a general rating.

SDI 16: Climatic Vulnerability.

SDI 16: Climatic Vulnerability measures the quantity and quality of rising climatic threats that an installation faces. The AF must be sensitive to potential threats front he natural environment because a base's mission can be severely impeded by climatic events. These climatic threats that the SDI accounts for includes but are not limited to: floods, earthquakes, wildfires, landslides, tornadoes, sea level rise, temperature rise, precipitation pattern changes, storm surges, and droughts. For some of these benchmarks, quantitative values are given, such as for earthquakes, the seismicity percent of a 30-year likelihood of magnitude 6.7 earthquake (benchmark taken directly from Vandenberg, making note of its Californian positioning). Other benchmarks, however, are simply qualitative, with many only listing an 'impact index' of either low, medium, or high. The SDI does not show how it derived these ratings, however, it does reference its sources which commonly include, county hazard mitigation plans, GIS flood plain analysis, and the DoD Annual Energy Management and Resilience Report. The SDI does not have any specified AFIs or EOs which direct what benchmarks it records. This SDI also does not have a general rating.

3.4 Consistencies and Differences Between SDIs and the Literature

Comparing the methods of the SDIs to the 'urban fabric' literature review shows that their is considerable overlap between areas of concern. While cities are not concerned with an airfield in the same way that an installation is, utilizing the PCI to measure concrete degradation and lifespan correlates to the urban fabric concern for infrastructure. The encroachment and natural and cultural resource SDIs measures the installation's sprawl, surrounding vegetative spaces, and biodiversity. Items concerning the urban ecosystem match up as well. Water quantity (supply) identifies with the precipitation category, wastewater quality and quantity and waste reduction correlates with the wastewater and waste category, and air quality is a direct match and employs GHG benchmarking and reduction strategies as the literature recommends. There are SDIs that did not directly correspond to literature recommendations. SDI 12, the EIA assessment does not fit squarely with literature recommendations, and feels out of place as an SDI in general. It does not measure a climate risk, but documents if a environmental analysis has been conducted.

While there is overlap between the scope of the SDIs and the literature areas, the benchmarks employed by the SDI vary in their reputability. As mentioned above, SDI 7 air quality employs benchmarking strategies of captures each unique GHG and its quantity that the installation produces. This is very reputable and aligns well with the air reduction literature recommendations. On the other hand, SDI 16 climatic vulnerability captures a wider variety of climatic threats, but denotes their risks with qualitative threat levels. These qualitative threat levels do not specify their methodology, such as how different a ‘low’ threat of tornadoes differs from a ‘high’ threat. This ambiguity is concerning as literature recommends qualitative benchmarks for climate adaptation, and also, leaves uncertainty on how SDI general ranking values were derived. While the general ranking is a qualitative value, its strategic purpose permits, allowing the commander to quickly and effectively make decisions concerning installation sustainability. Even with a good scope of adaptation and good benchmarks, an improper general ranking can leave the SDI qua SDI ineffective. This concern will be investigated in the final section.

3.5 Conclusion

The IDP dedicates a section of its contents to sustainability goals, otherwise known as the SDIs. These SDIs are contained in the eighth chapter of the IDP, with each installation having 15-18 SDIs. Each SDI bases its adaptation goals off of EOs and AFIs. The SDIs have a relatively good overlap with literature recommendations for adaptation. The benchmarks and call to preventative and preparedness in the face of climate change. The IDPs are accounting for climatic vulnerabilities but only with basic, non robust information. Additionally, IDPs have no plans for climate projections, being only concerned about the climate at the time the plan was made. The SDIs either lack or do not present methodology for their general rankings general rankings. This omission is concerning, as even if SDIs have good adaptation plans and benchmarks, an inconsistent general ranking threatens their strategic applicability. What, if any, consistent methodologies across installations are used for SDI general ratings? Answering this question will make up the discussion for the next and final chapter.

IV. Part 3 - SDI 1 Energy Benchmarking Analysis

4.1 Introduction

Part 2 detailed each IDP and descried the measured values any AFI or EOs installations gave as what guided their adaptation efforts. However, it became apparent that the SDIs are lacking a methodological explanation and reputable process to determine their general rating scores. SDI general ratings turn quantitative benchmarks into a qualitative tool. These general ratings can be used by a wing commander to alert them to areas of climate adaptation their installation is weak in, and give orders to improve the base's adaptation. The SDIs do not specify how they came up with their general ratings, even if the AFIs and EOs they used were appropriate adaptation measures. An investigation of the general ranking methodology of the SDIs then is the scope of this chapter, using SDI 1 as a case study.

SDI 1 was chosen since energy is an integral resource with multiple inter-linkages across systems and is impacted by climate change. Since an installation is, essentially an urban environment, energy resiliency is the critical area of adaptation and resilience to accomplish an installation's mission [58]. This analysis consists of identifying key benchmarks within the SDIs, and comparing their values across all 32 installation in the sample data set. Completion of this analysis will result in the creation of ArcGIS spatial and graphical figures to visualize these benchmark to general rating relationships. Based on their results, recommendations for the future of the SDIs at large will be made.

4.2 Background of SDI 1: Energy Consumption

As shown in Part 2, SDI 1 (energy consumption), has its own government standards which inform its general ratings. EO 13693 promotes building energy conservation and efficiency by reducing government building energy consumption intensity per gross square foot (Btu/SF) by 2.5% annually through the end of fiscal year 2025. This value is relative to the baseline of the agency's building energy use in fiscal year 2015 [59]. The EO also calls for federal agencies, where cost-effective, to transition building electric energy and thermal energy to clean energy. The clean energy transition goal is for installations to reach 25% of total energy intensity provided by clean energy alternatives from 2016 to 2025.

To implement these EO guidelines, SDI 1 feature a variety of data which will help to tell the story of an installation's energy consumption and its resiliency. SDI 1 generally highlights its key data as an installation's total consumption of energy over its area from a baseline year to the year of the current edition of the IDP. Additionally, the SDI tracks the percent of energy consumption the installation has observed relative to the baseline year. SDI 1 captures other data including an installations energy cost over its area and per yearly operation. It also measures the percentage of total energy an installation consumes in its local electrical grid. These pieces of information presented in a table format, more or less standardized across the different IDPs by different contractors. Taking one installation, whose IDP is in the public domain can help to visually see the way AF IDPs benchmark energy consumption. As an example, the benchmarks for Joint Base Langley-Eustis (JBLE) are shown in Tables 1 and 2.

Table 1. JBLE, 2017 SDI 1: Energy Use

Baseline (FY03)	Current Measure (FY12)	% Reduction From Baseline	Target to date
0.13 MMBtu/SF	0.0978 MMBtu/SF	24.8%	30%

Both SDIs 1 and 2 contain two data tables. The first, smaller tables give a quick glance at the values which pertain to the energy standards from EO 13693. The second, larger tables display the same and additional data in more depth to answer general questions about an installation's energy consumption and resiliency. Table 1 displays a baseline energy consumption value in MMBtu/SF and the same value at its most recent measure. While EO 13693 states that energy must be measured in Btu/SF, as will be discussed later on, the majority of installations measure and display their energy consumption in MMBtu/SF (10^6 Btu).

The energy percentage values display an installations baseline and actual energy reduction. For JBLE, its measurement period was from FY03 to FY12, so a total of 10 years. Its energy reduction over that period was 24.8%, resulting in a average 10-year change of 2.5% per year energy reduction. While this passes the 2.5 % per year reduction standards of EO 13693, JBLE was still adapting with EO 13423's 3.0% per year reduction. This is reflected by their 30% reduction goal, and the SDI 1 general ranking of 'status-quo'.

Table 2. JBLE, 2017 SDI 1: Energy Use Continued

Energy Use Subcategory	SDI	Unit of Measure	Current Value
Facility Use	Intensity (FY12)	MMBtu/SF	0.0978
Facility Use	Cost	$/SF	1.64
Facility Use	Intensity FY03 Baseline	MMBtu/SF	0.13
Facility Use	Reportable Consumption	Total MMBtu/Year	1,140,731
Facility Use	Yearly Cost	$/Year	19,114,782
Regional Capacity	Electrical Grid Reserve Capacity	% of Capacity Resources	7.80%

Table 2 provides data supplemental to SDI 1's reduction benchmarks. The table contains the installation's energy cost spread over its area and its total annual cost. These cost values don't contribute to any of the EO goals, rather serve as bookkeeping of important values for the installation. The total annual energy consumption is also featured. This value shows the installation's energy consumption not normalized over an area. This value helps compare installations energy consumption without controlling for installation size. Finally, the table also includes electrical grid reserve capacity (EGRC). EGRC measures the amount of excess energy capacity (supply) in the installations electricity region that it can consume without running out of electricity [60]. EGRC is represented as a percentage greater than its energy consumption (demand). For JBLE, having an EGRC of 7.80% means that annually, the installation can consume 7.80% more energy from local sources than its 1,140,731 MMBtu per year consumption while maintaining stable operations. EGRC is most helpful when determining how much excess energy an installation can pull in an emergency situation when consumption levels can increase above average.

SDI 1's most important values for energy benchmarking are its baseline and current measures of energy consumption and its percent reduction of energy consumption. Contained in Table 1, their importance is because they are used to measure an installation's accomplishment of EO 13693's goals. Supplemental information is contained in Table 2 such as installation energy cost and EGRC. These values are not recorded because they affect EO 13693's implementation, but because they provide bookkeeping for the installation.

4.3 Methods of Installation Selection and SDI Evaluation

Determining the Key Benchmarks and Analysis Methods.

The most pertinent benchmarking values to the energy SDIs general rating were determined to be an installation's current and baseline measure of energy consumption, and its goal and actual percent reduction of energy. These values were identified as the most important because they directly contribute to measuring the implementation of EO 13693. The term 'baseline' refers to the year that an installation began its measure of energy consumption, which can vary between installations. The current year is the year of the most recent IDP or concluding period of energy measurement of an installation. This year also varies between installations. The actual percent energy reduction is the real percent energy reduction that the installation achieved at the current year. These four benchmark values will form the foundation of this analysis.

The analysis focused on these main benchmarks as they were considered the most compatible across CONUS. As seen in Table 2, SDI 1 measures an installation's energy cost per square foot of the installation is presented. This value can vary between installations as regions of the U.S. have different concentrations of energy types, each at its own price [61]. This information would be more useful to the general rating if the energy cost trends of previous years and its projected future costs were displayed. Similarly, omitting prior year prices and future projections, annual energy cost is without context for climate adaptation. Additionally, the installation's EGRC for its region was not used for the analysis. The 'region' which the EGRC locates itself in is unspecified in the SDI. It could be assumed that these regions are the regional entity boundaries of the North American Electric Reliability Corporation (NERC) because the EGRC is often based on those boundaries [62]. However, its non-specification of 'region' left it unused in the analysis.

The installations were spatially mapped against their energy consumption and reduction amounts. This map visuallly communicated if any area of the nation had a greater number of installations reducing or increasing their energy consumption. Additionally, the energy benchmarks are evaluated against the Köppen-Geiger Climate Classification System (KGCCS). Created by climatologist Wladimir Köppen in 1884, with later additions made by climatologist Rudolf Geiger, the KGCCS is a way to define and group together the earth's varying climates. Utilizing the KGCCS has proved beneficial to predict the specific threats that an area will face with a changing climate [63, 64]. KGCCS features over 30 different climate classifications which are defined as a combination of main, sub, and minor climate zones. For the scope of this analysis, the main zones were the only zones considered, reducing the zone possibilities from 30 to 5. Mapping the installations onto these Köppen-Geiger climate zones revealed regional trends about energy consumption.

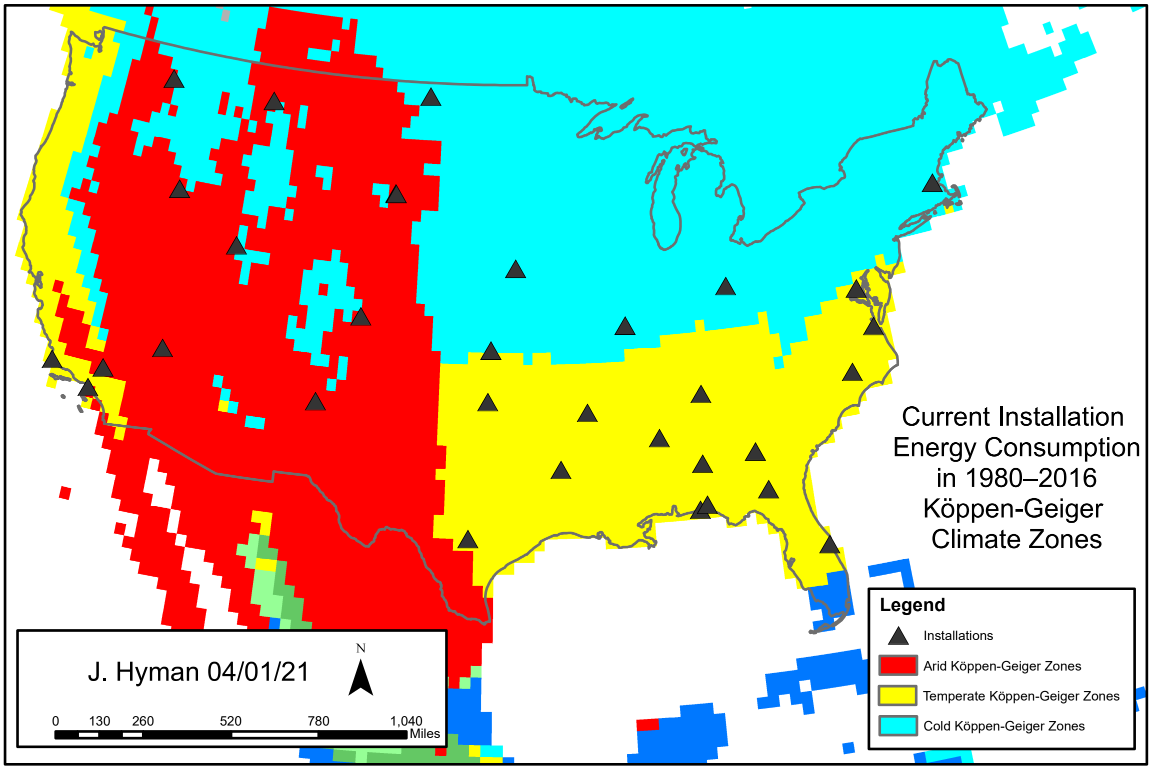

Figure 7. Köppen-Geiger plots w/ box plots for energy consumption and reduction in each region, searching for anomalies

The visualization of the installations in their Köppen-Geiger climate zones was created to see if regional placement affected the magnitude of energy consumption (Fig. 7). The region shapefiles used were made by Beck et al. [65]. The sampled installations only occupy three of the five main Köppen-Geiger Zones: arid, temperate, and cold. In the present Köppen-Geiger zones, their are 10 installations in the arid region, 15 installations in the temperate region, and 7 installations in the cold region.

Data and Unit Standardization Methods.

To cover the geographic diversity of installations across CONUS, 32 different installations were sampled for this research. Their IDPs were collected from proper

USAF sources. Once acquired, the values from the IDP's SDIs 1 and 2 were found and formatted into a CSV file. One of the key-most benchmarks to evaluate energy resiliency, yearly energy consumption, had major differences in the way that information was present amongst the 32 different installations. Their are inconsistencies between the units used to represent past and present energy consumption between installations. Energy consumption in SDI I is primarily displayed as some value of energy normalized to area (e.g.: Btu/Sf), but five of the installations displayed their energy consumption without normalizing it over the installations area. While the majority of installations did list their energy consumption as energy over an area in some variation of British Thermal Units (Btu), there were some disparities, potentially causing errors in assessments. The difference in energy units ranged from Btu measurements went from Btu, MBtu (Btu$\times 10^3$), to MMBtu (Btu$\times 10^6$) (Figure 8). Note from Figure 8 that the majority of installations used units of MMBtu/SF, however this is only under two thirds of the sampled installations. There is also negligible difference between the unit distribution for the baseline and current values; both are equally non-standardized. These non-standardized units are sub-optimal for benchmark comparisons, as they could lead to misinterpretations of the values and inaccurate comparisons.

The non-standardization of these units are believed to be caused by mixing up Btu notations. There is an ambiguity because the prefix "M" is regularly used to indicated one million of a unit in the metric system. This rule is not the same with Btus; however, military planners may have assumed that the units operate the same as other metric system units. Assuming all the installation's energy values had representative units, eight of the 32 installation's energy consumption went to a negligible value when converted to MMBtu/Sf. To correct this mistake, a conversion methodology was employed to estimate the real units of an installation's energy consumption based

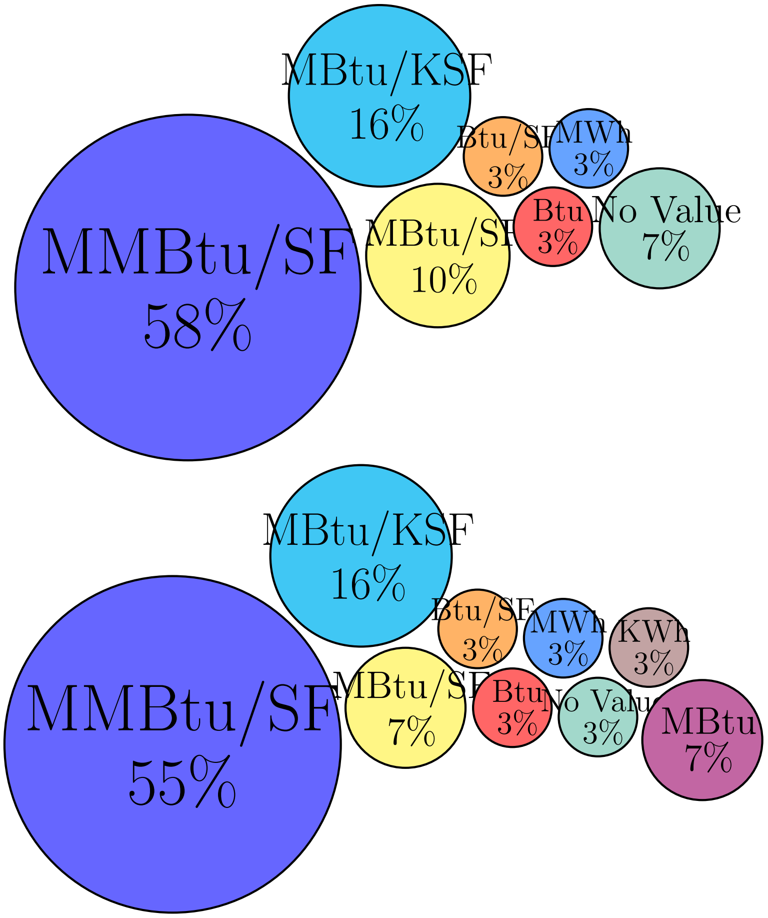

Figure 8. The unit diversity between SDI 1's 'Current Value' (top) and 'Original Baseline' (bottom) after following the unit standardization method.

on its magnitude.

The aforementioned process was as follows:

1. Is value divided by an area? If yes, move to 2, if no, exclude values from dataset.
2. Is value in units of MMBtu/SF? If yes, add to dataset, if not, move to 3.
3. Assume that present units are incorrectly stated, but that the value's magnitude is in MMBtu/SF. Does value fall between 0.01 and 0.09 (relative energy range from properly reported MMBtu/SF)? If yes, add to dataset. If not, move to 4.
4. If your value is in units of MBtu/Ksf, assume that the energy magnitude is correct, but that the area is actually in ksf. Divide by 1,000. Does values fall

between 0.01 and 0.09? If yes, add to dataset. If not, move to 5.

5. Assume presented units are valid, and manually convert to MMBtu/SF. Does value fall between 0.01 and 0.90? If yes, add to dataset. If not, exclude value from dataset.

Based off of this methodology, the majority of the units appeared as realistic energy over area values. With the values standardized, the aforementioned analysis of the values was now performed by means of GIS spatial analysis and graphical analysis.

4.4 Results of the SDI Rating Analysis

Being able to see an installation's actual energy reduction from its benchmark date and its present energy consumption helps to reveal how well installations are actually accomplishing some type of energy reduction, and if their is any trend between energy reduction and magnitude of consumption. Installations with a larger magnitude of energy consumption might find it difficult to reduce their consumption due to energy heavy operations. Likewise, it might be easier for an installation with a lower magnitude of energy consumption to reduce their energy since their operations are smaller in scope. Figure 9 shows that the above hypothesis is largely false, and that installation energy consumption is not related to energy reduction. The figure displays the installations colored by their percent energy reduction, and sized in scale to one another off of their present energy consumption. There is no legend for size, because the installations are sized in direct proportion to their energy magnitude. The specific values are less important that the relative size comparisons.

Figure 10 utilizes the same legend colors as Figure 9, but graph each installation's percent energy reduction and current energy consumption against one another. The top graph shows that all but six installations achieved some level of energy reduction.

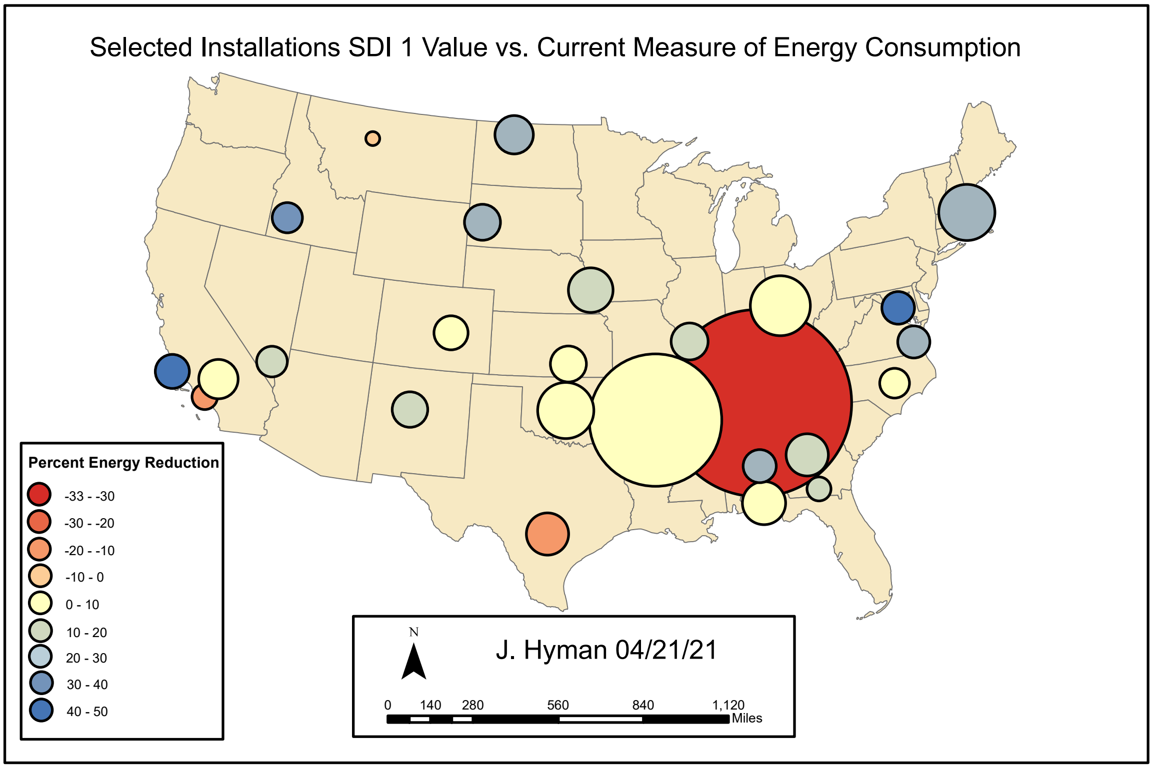

Figure 9. The size of the point refers to the current level of energy consumption and the color of the point refers to the percent reduction in energy from baseline, with the cooler colors increasing their energy consumption and the warmer colors decreasing their energy consumption. Most all installations have a relative size to one another, but their are two installations with incredibly large energy consumption's compared to the other installations.

The average energy reduction was 10.7%. Nine installations reduced their energy by 0-10%, seven by 10-20%, five by 20-30%, only one by 30-40% and two by 40-50%. This 10.7% average does normalize the consumption values over the different measurement periods of the installations. Because of this, this average cannot be used to assess the installation's successfulness in implementing EO 13693. From the lower graph in Figure 10, it shows that their is no distinguishable trend between the level of reduction and magnitude of energy consumption. This is important to show that no matter the magnitude of energy consumption, installations have relatively the same abilities to reduce energy according to EO 13693's guidelines.

Fixing the unit inconsistencies for energy consumption allowed the visualization

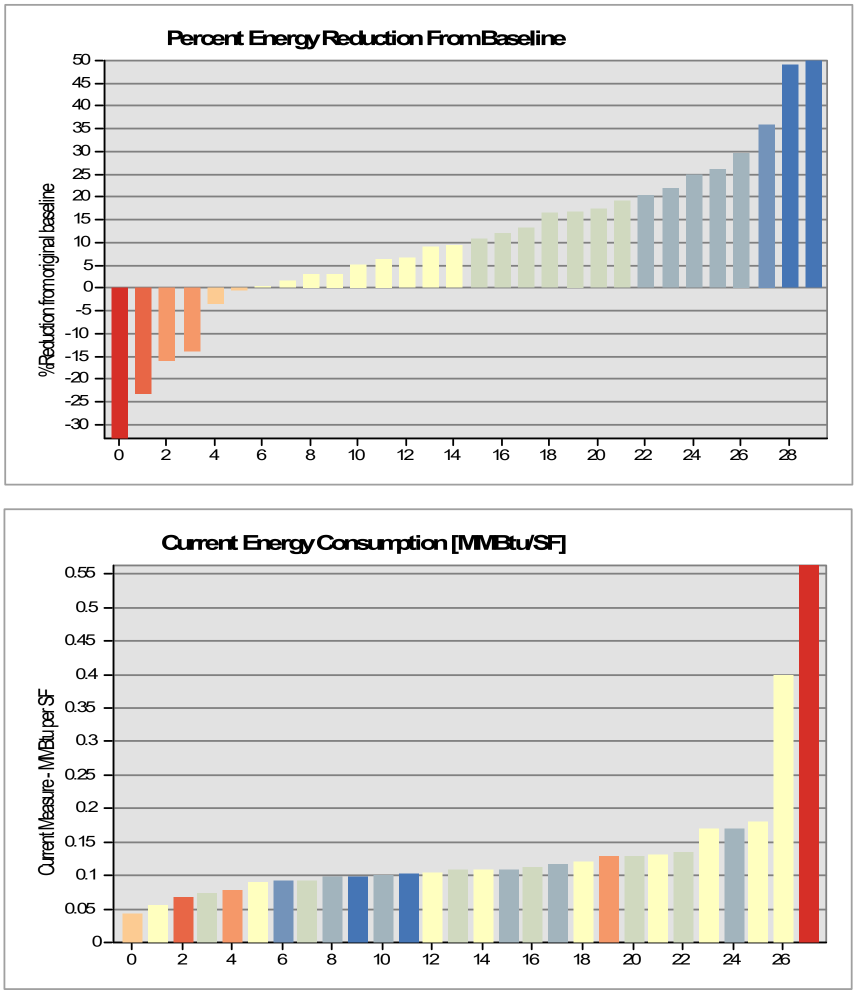

Figure 10. Graphs which utilize the same legend as Figure 9. The top graph shows the average energy reduction of 10.7%. The bottom graph shows that there is no relationship between the magnitude of an installation's energy consumption and its percent energy reduction.

of Köppen-Geiger climate zones and their average energy consumption magnitudes. This is seen in Figure 11. The mean energy consumption in MMBtu/SF is 0.09 for arid installations, 0.1 for temperate installations, and 0.116 for cold installations. Noteworthy is that this figure shows that each climate region's current energy consumption is lower than its original energy consumption. This reduction however does not account for the different lengths of time between the an installation's baseline and current years. The sample population of installations over their baseline-to-current times, have a net energy reduction in each climatic region. This does not directly correlate to EO 13693 compliance. Noteworthy however is that the arid region's energy consumption was decreased and tighter in range. This could possibly be because of increased USAF solar energy collection in the arid climate region [66]. Longer summers due to climate change avail arid regions to harness the longer daylight hours for energy. It may also be because of changing scopes of mission within the arid region, affecting energy consumption levels.

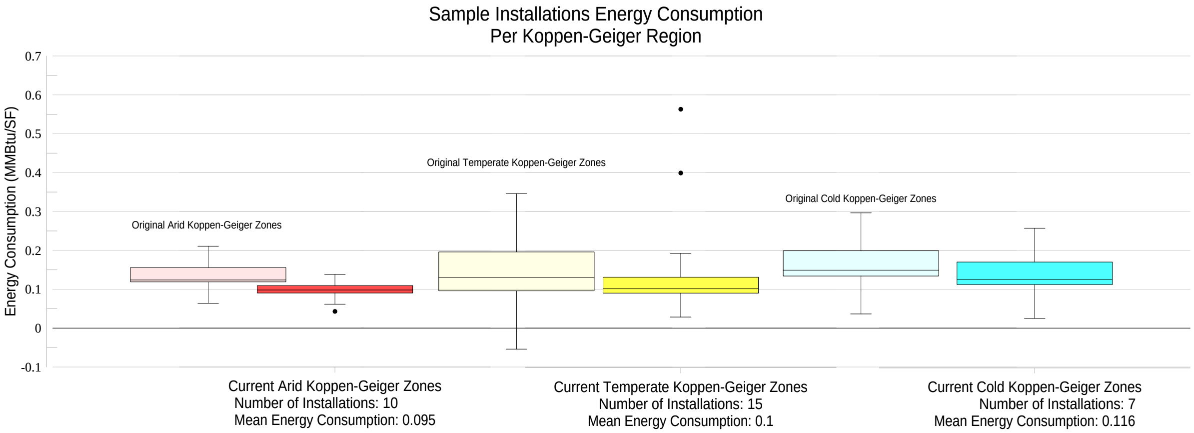

Figure 11. There is a net reduction in energy consumption between the installations in their climate zones, however this does not reflect whether installations achieved their DoD and AFI level goals in energy reduction.

The spatial visualizations of the installations were supported by graphs which compare the energy SDIs values across the sample population. The first of these, (Fig. 12) mapped the installations general SDI ratings against their most recent measure of energy consumption on the x-axis, and the percent of energy reduction achieved from their consumption baseline. The installations grouped themselves vertically along the present energy consumption average of around 0.13 MMBtu/SF.

The second graphical figure (Fig. 13) mapped the installation's percent reduction in energy consumption from their baseline on the x-axis and their target energy reduction percent on the y-axis. This figure is a predicted versus actual visualization

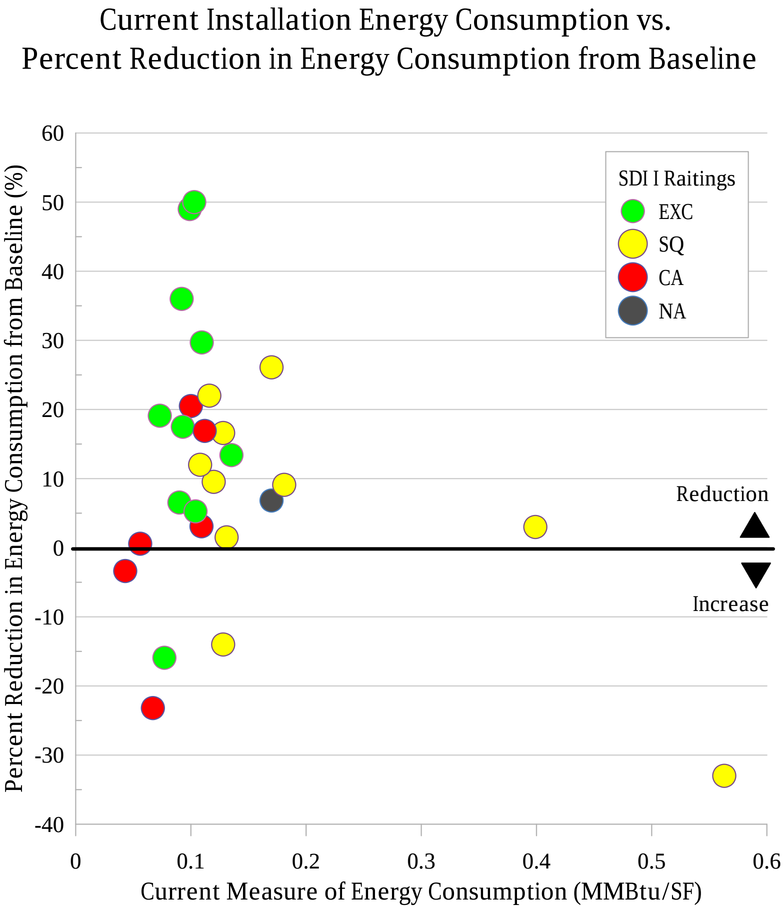

Figure 12. The current measure of energy consumption for each installation is plotted against its actual reduction in energy consumption given in percent. Five installations increased their energy consumption, with the SDI rating varying between installations. Those installations which reduced their energy consumption have decent rating grouping, though their is two cautionary rated installations which reduced their energy consumption by one fifth amongst excellent and status quo bases.

of the installation's energy reduction.

These figures revealed some adaptation concerns. Firstly in Figure 12, there are two installations which ranked themselves as 'cautionary' but had a percent energy reduction from their baseline, around 20% reduction. They however did not achieve their targets to date reduction goals as can be seen in (Fig. 13). The fact that they did not achieve their target goals may be the reason why they did not present themselves as 'EXC' or 'SQ', however this begs to ask the question how important is it that an

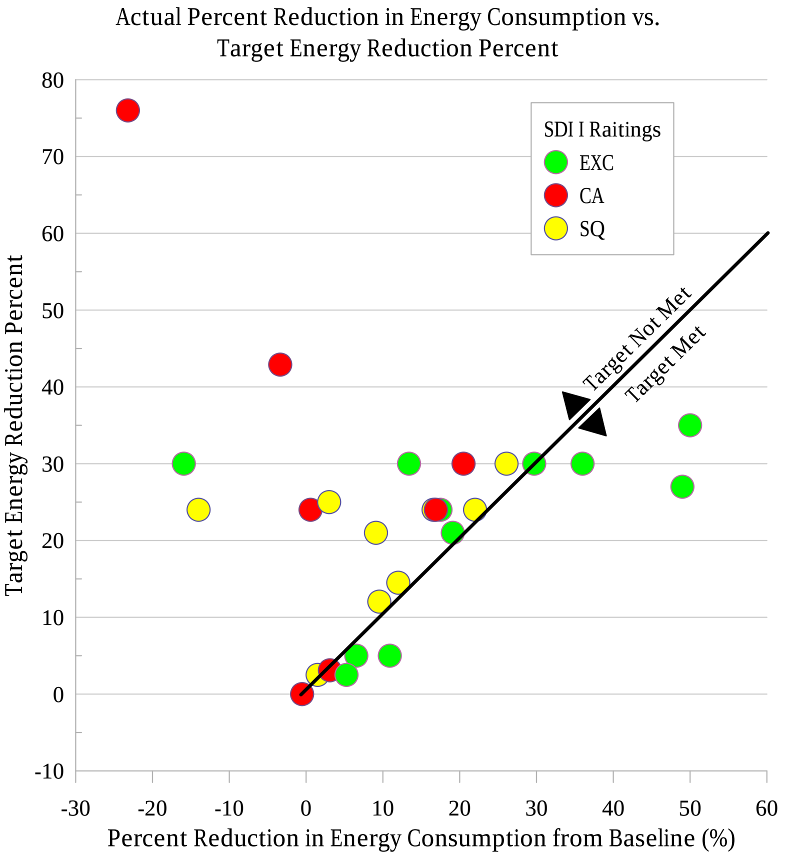

Figure 13. The actual percentage of energy consumption reduced is plotted against the goal percentage for each installation. Only nine installations from the sample met their goal, with one having a goal of zero change, two just barely achieving their goal, and six exceeding theirs. The only installations which exceeded their target were rated excellent, however not all excellent rated installations exceeded their target. Their is noticeable inconsistency between the ratings and groupings of installations which did not meet their target.

installation achieves its set energy reduction goal? They set their minimum reductions based on EO 13693, but the time-frame they give themselves from baseline to current varies depending on the installation's preference. This inconsistency between baseline and current dates poses a major problem for comparison across installations.

These figures also revealed inconsistencies between labeling preferences in SDI 1. What is meant by labeling preferences is how an installation would record its energy consumption change. Study of the SDIs showed that some installations would measure their energy reduction results as a 'Reduction from baseline' while others show an 'Increase from baseline'. This minor change in language may seem harmless as long as it is read and understood, however it becomes an issue when their is a lack of standardization of the use of positive and negative values to communicate reduction in energy. In (Fig. 12), an installation can be seen which has an excellent rating, but increased its energy consumption by 15%. This installation labeled 'reduction in energy' as a negative 15 Based on the excellent SDI rating, their is a likelihood that the value is mislabeled and that the negative reduction was actually a positive reduction. Assessing this specific installation required additional work because its baseline energy consumption value was represented in MBtu, while the current measure of energy consumption is measured in MBtu/SF. Finding the installation's area from elsewhere in the IDP, the energy consumption was found to increase from the baseline to the present year, so the negative representation of the value in (Fig. 12) is correct. This is confusing as to why the SDI was given an excellent rating, and additionally why the installation listed a negative value as 'reduction in energy consumption. This leads to the belief that their may have been errors on the side of the installation planner, stemming from a lack of standardization with other IDPs.

4.5 Discussion on Analysis and Recommendations for the Future of the IDP

The most revealing point from this analysis is that their appears to be no consistent methodology of general ratings between installations. Their are installations with very similar energy consumption and reduction values, but different general ratings. Figures 12 and 13 highlight this by showing that their is not an even cascade from 'excellent', to 'status-quo', to 'cautionary' ratings, but instead a slight lead of excellent ratings followed by a cacophony of ratings. It may appear that there is no rating methods employed at all, however there may be rating methods applied, just not consistently across all installations.

For SDI 1, the installations rate themselves off of the standards between EO 13693 and AFI 90-1701, but they don't all identify the same cut-offs between the general ranking levels. That information is not contained with those strategic adaptation goals, but instead is left to the installation to decide for themselves. Installations may identify general ranking cut-offs similar to other installations (this tends to be the case for high energy-reducing installations), however installations tend to be more subjective when they are low reducers or energy adders. They are more likely to give themselves a higher general ranking, when comparatively against the sample installations, it appears that their ranking should be lower. This is a symptom of a lack of some more standardized and rigours energy rating method between installations. While installations do abide by AFIs and EOs to set their sustainability goals, those guides do not tell installations how to assess their success if they only partially achieve their goals. This calls on some Air Force wide energy wide rating method which would help installations methodologically judge their progress if they only achieve partial reduction success. This rating method would need to account for regional differences between installations, and pull from a consistent past of energy consumption [67]. It is recommended that the installations, starting at the least at general Koppen-Geiger regions, have additional communication with one another when deciding general rankings for their SDIs. This could also be extended to municipalities within proximate distances to the installations, and climate communication networks are already something that civilian cities are attempting [68]. This network would first require regional installations to set similar installation measurement dates and communicate with one another the more regularly their energy consumption and reduction statistics. This is a process that does not appear to currently occur, however structuring it into the life of the IDP would prove more standardized, rigours, and valuable general rankings to help commanders make well-informed decisions.

While this analysis of the first two SDIs cannot authoritatively talk about the effectiveness of the other SDIs, it does raise the question of their effectiveness. Are their similar inconsistencies between unit variations and non-standardized general rankings in the other SDIs? If so, how are they hurting IDP climate adaptation efforts, and how can they be remedied? These are important questions for future research of the IDPs and their SDIs.

4.6 Conclusion

The SDIs did not show consistent methodologies between their general rating methods. This presented a concern for strategic planning decisions. For this reason, SDI 1 was evaluated as a case study to see what, if any standard methods were employed to produce its general rating. A sample population of 32 IDPs were utilized, and the energy consumption and reduction values were considered as the main benchmarks. Issues with standard units were revealed, showing that many installations are confused with representing different degrees of magnitude of British Thermal Units. Once the units were standardized, spatial and graphical analysis were conducted. Köppen-Geiger climate regions were created, showing that there was a net decrease in installation energy consumption, but that this was not in time with EO 13693. The graphical figures revealed that there is no standard rating methods between installations for their SDI 1 general rating. To improve this issue, recommendations were given such as having installation's start their 'baseline' measurement periods at the same time, and having them network with themselves and municipalities in similar Köppen-Geiger regions to compare their energy reduction values. This comparison could help to generate more accurate and helpful general rating values. While this analysis only concerns the first SDI, future research is recommended to analysis the remaining SDIs so to strengthen their general rating methods.a

V. General Conclusions

The 2019 GAO report observed that many military installations were not effectively incorporating adaptation planning in their master planning documents. For the AF, these criticisms must be levied against the IDP and its SDIs. This thesis analyzed current literature and its climate adaptation recommendations, compared them against the benchmarking methods of the SDIs, and analyzed SDI 1 to assess how its strategic general ranking is derived. Utilizing Wamsler's City-Disaster Nexus as a framework, it was found that the SDIs overlap well with recommended adaptation strategies from the literature. The domains of 'urban fabric' and 'urban environment' match to the physical and environmental resources that an installation must protect to accomplish its mission. The adaptation strategies are practically implemented in the 16 SDIs EO and AFI guidelines. Each SDI gives itself a strategic general rating, to communicate its performance to a commander for strategic decision making. The thesis found that the SDIs overlap well with their adaptation strategies that the literature recommends. The SDIs are measuring the right benchmarks. However, the SDIs are quiet on how they decide general ranking values for SDIs. This is concerning, because even with good adaptation strategies, and good benchmarks, poor methods for determining the general rating make the SDI strategically ineffective. To assess the SDI general rankings, we investigated SDI I's rating methods. We discovered unit inconsistencies and unspecified regional measurements, and variability between measurement periods. Köppen-Geiger climate mapping was used to approximate the 'regions' of the SDIs. It revealed contrary data to research on climate change in these regions. Installations vary heavily in interpreting their EO performance into general rankings. This is concerning for effective SDI use. For the SDI 1, the thesis recommends that installations have consistent units, communicate with one another and align their energy measurement periods to start and end at the same time.

While the benchmarks the IDP pulls from are good, the data used does not have the proper time-scale ore regional focus needed for good adaptation. Installations must pull from their backlog of data, not just the most recent baseline year and the current year. Utilizing the full history of an installation's energy data could then actually make climate projections useful for adaptation planning. Climate projections should be used, but only once the installations populate their IDPs with more data from previous years. Benchmark units must also be standardized going forward. The thesis recommends limiting the number of contractors that the AF commissions to make their IDPs 4-5 contractors. This will limit the variability in IDP format and units. Additionally, shifting SDI comparability between MAJCOMs and instead to Köppen-Geiger regions would be more effective for climate adaptation. Bases are more likely to benefit from comparing energy consumption within their regions even if their missions may be different. This could even lead to discussions on shifting installation missions when it is prudent, to be shared within the Köppen-Geiger regions. The reliance on AFIs and EOs, while helpful to get all AF installations on the same metrics, change too frequently to serve as long-term benchmarking goals. This appears to be a chronic issue with a federalized national defense. Even a homegrown AF adaptation document would still be held at either the DoD or MAJCOM level, and with MAJCOMs recommended to be poor comparison regions, this problem will persist. Issues will continue to persist because AFIs and EOs goals are set mostly for cost adjustments, with hopeful climate change adaptation benefits. If the SDI 1 is to actually be used to adapt to climate change, follow on research should look into feasible ways to shift AF climate planning away from AFIs and EOs as a primary source, and instead towards regional and state adaptation goals. While this thesis only gives recommendations for SDI 1, follow on research should investigate in depth the other SDI's general ranking methods and what improvements could be made to them. With standardized general ranking methods, improved adaptation strategies, better benchmarks, and a MAJCOM to Köppen-Geiger region shift, the IDP can adapt itself to be a more effective tool for climate adaptation.

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14. ABSTRACT

Establishing proper, long-term metrics for measuring various resource uses, climatic threats, and sustainability are critical for a military installation's adaptation to climate change. Within the United States Air Force (USAF), the Installation Development Plan (IDP) is a comprehensive long-term base planning document, which includes an inventory of sustainable development goals including energy use and climate indicators. This study analyzed 32 different IDPs among the various installations in the continental United States, identifying regional trends and behaviors across their 16 Sustainability Development Indicators (SDI). To study the IDPs more in depth, specific focus was placed on SDI 1, which concerns energy consumption and generation. This study investigated the different variations in energy benchmarking across local climate conditions, SDI ratings, and units used. Major inconsistencies were found across these three domains. Subsequently, the study identified the remedies needed for standardized energy benchmarking, along with recommending additional adaptation strategies. These comparisons suggest a need for installations to communicate with one another and their regional cities when beginning and concluding energy measurement periods. The results of this study inform both municipal and military planners and engineers on the prominent types of climate metrics for resilience within a changing climate.

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