

Energy Master Planning Toward Net Zero Energy Installation—U.S. Military Academy, West Point

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ABSTRACT

The U.S. Department of Defense (DoD) has established challenging goals to increase energy efficiency and reduce greenhouse gas (GHG) emissions of their installations in all five branches of the armed services with an ultimate goal of net zero energy (NZE) installations. These objectives are similar to those of some U.S. communities and college and university campuses. The Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has developed an NZE installation concept and tool, Net Zero Planner, to support NZE planning for DoD installations (Zhivov et al. 2014a; Case et al. 2013; Swanson et al. 2014). Net Zero Planner allows a streamlined energy planning process resulting in development of a road map to meet or exceed installation energy goals at the lowest life-cycle cost. The criteria for success include meeting or exceeding federal and DoD criteria for site and source energy intensity, meeting energy security requirements, and controlling electrical capacity growth requirements at a lower cost when compared to a base-case scenario using the existing master plan and current facility energy efficiency standards. This paper describes the process and the results of the implementation of the energy master planning concept and the tool at the U.S. Military Academy (USMA) at West Point, which was selected as one of eight pilot net zero installations for energy use.

INTRODUCTION

Until very recently, community planners addressed energy systems for new facilities on an individual facility basis without consideration of energy sources, renewables, storage, or future generation needs. Building retrofits under sustainment, restoration, and modernization (SRM) projects typi-

cally do not address energy conservation. Energy savings performance contract (ESPC) projects that address only “low-hanging fruit” (improved efficiency of lighting, electrical, heating, ventilating, and air-conditioning [HVAC] systems, controls, and building energy management systems [BEMSs]) will fail to maintain the current rate of energy reduction, let alone meet the rate required by the U.S. Energy Independence and Security Act of 2007 (U.S. Congress 2007), and will thereby become less economically attractive.

There is a lack of tools and case studies that address dynamics of energy systems at the community scale. The development and rapid deployment of such tools, and a dissemination of lessons learned through pilot energy master plans, are essential in achieving communities’ mid- and long-term energy goals.

Most national and international research and policy energy-related efforts in the built environment focus on renewable energy sources and energy efficiency in single buildings. Organizations that have made first efforts to evaluate and analyze international experiences with planning and implementation of low-energy communities include the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) Annex 51 (IEA 2011, 2012, 2013; Jank 2012), the German-funded EnEff Stadt project (a comprehensive approach to urban areas with local and district heating networks) (EnEff Stadt 2014), the World Bank Energy Sector Management Assistance Program (ESMAP) Energy Efficient Cities Initiative (ESMAP 2014), and the Clinton Climate Initiative C40 Program (CCI 2014). The U.S. Army is pioneering a Net Zero Installations program for selected installations [e.g., Zhivov et al. 2014b], which

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goes beyond zero energy and includes zero waste and zero water initiatives.

In community-wide energy planning, it is important to consider the integration of supply and demand, which leads to optimized solutions. The objective is to apply principles of a holistic approach to community energy planning and to provide the necessary methods and instruments to master planners, decision makers, and stakeholders. Such comprehensive decision-making and modeling tools are currently not available.

The U.S. Army Engineer Research and Development Center (ERDC) has developed an energy optimization concept and automated tool to support Department of Defense (DoD) energy policy (Underwood et al. 2008). The energy concept minimizes energy use at the building level, improves the efficiency of energy generation and distribution, and finally uses energy from renewable sources to balance fossil-generated energy to achieve a net zero fossil energy status. Energy goals will be achieved through synergy between energy use reduction in building-related systems, energy supply, and distribution systems.

USMA CAMPUS AND ANALYSIS BOUNDARIES

The U.S. Military Academy (USMA), the oldest U.S. military post in continuous use, has trained many of the United States' most prominent military figures, as well as many of the civil engineers who designed and built the networks of railroad, canal, and port facilities that were essential to the development of America's resources during the 19th and early 20th centuries.

USMA's location on the west bank of the Hudson River had a defensive and strategic importance throughout the history and birth of the United States. Both the British and Continental Armies realized the strategic importance of commanding the plateau of the west bank of the Hudson River. The military reservation is located about 50 mi (80 km) north of New York City. The site is dominated by hills and small mountains, especially in the northern and western part of campus, which are part of a region known as Hudson Highlands. The main campus and central post area (cantonment area) total 1800 acres (728 ha), only a portion of the nearly 16,000 acre (6475 ha) reservation (Figure 1). The campus is composed of approximately 700 buildings that occupy nearly 10 million ft² (930,000 m²) of gross floor area, more than 50% of which is concentrated in the central region. The campus has a central steam plant that operates year round and that provides heating and domestic hot water (DHW) for the core campus area via a steam distribution system. Of the 5.7 million ft² (530,100 m²) gross floor area in the central campus area and the south loop, about 5 million ft² (465,000 m²) are connected to the steam grid. The central plant has a steam generating capacity of 250,000 lb/h (250 Btu/min).

By its nature, installation energy master planning for a large installation like USMA can become very complex. Clarity and alignment over the scope is essential, and the scope of

the USMA Net Zero Energy (NZE) analysis was agreed upon and determined at the beginning of the project. The baseline year selected was an average between 2010 and 2011 with the planning horizon from 2013 to 2020.

At the beginning of the project it became clear that it would not be technically and financially feasible to meet the 2020 NZE goal on the entire post. Therefore, reasonable boundaries for an NZE area were established so that the goal would be achievable. The following criteria and logic were used in defining the preliminary NZE boundary:

- Density of buildings—selection of a densely populated area with a high energy demand would allow for lower costs in distribution modernization and lower distribution heat and cooling losses.
- Grid connection—buildings will be clustered by their connection to the thermal grid.
- USMA will maintain control over building energy use.
- USMA will set priorities for building stock modernization.

In the process of defining the NZE boundaries, the USMA community was divided into five clusters using the two heating grids and their possible enlargements as well as the density and usage of buildings as criteria for boundaries

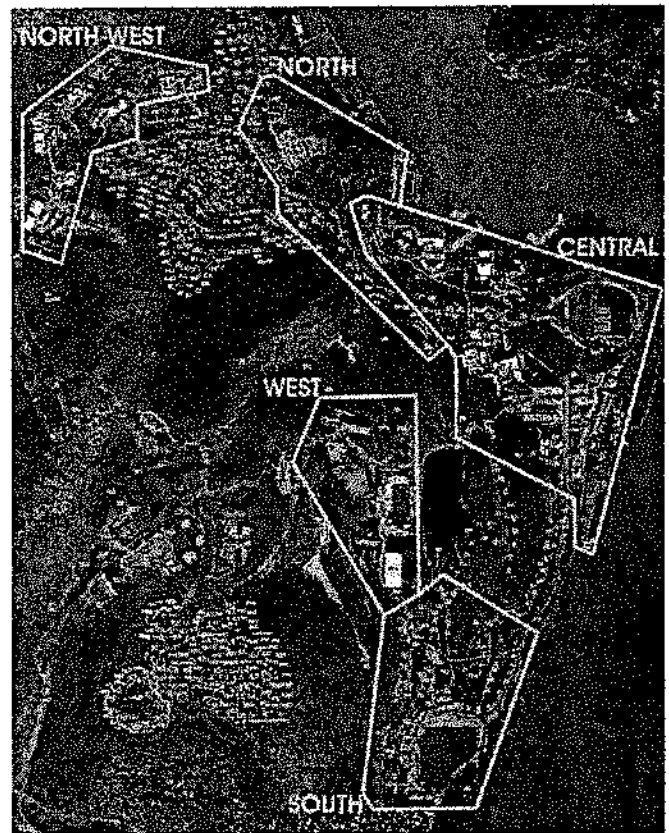


Figure 1 Site map with existing heating grids and rough cluster boundaries.

(Figure 1). Based on these criteria, the project working team agreed during the kickoff meeting with USMA management to select the central cluster of buildings as the NZE study area. The central cluster of buildings comprises USMA's core campus/academic area, with its 44 highly visible and significant educational and training buildings and barracks, which comprise the heart of the installation. All buildings within this cluster are connected to the central energy plant (CEP) and represent the major part of the installation's energy use. In the near future, an additional barracks building will be constructed within this area and connected to the central plant, making the total number of buildings in this area 45. Furthermore, most of the potential funding for building modernization is planned for buildings located in this area. The high density of buildings within the central cluster results in high heating and cooling demands, especially considering new requirements for air-conditioning in barracks. Also, the heating grid on the central-area scale can become beneficial for the scenario that includes cogeneration of heat and electricity, which can become critical in achieving NZE within a cluster this size. Due to the privatization of a number of buildings located on the south loop, which are currently connected to the central heating grid but are located at a significant distance from the current CEP, it was decided that these buildings will be disconnected from the central grid and that they would not be included in the NZE area. In the future, the south cluster of buildings can be provided with its own source of heat and be added to the NZE area.

The 44 buildings included in the central area have a gross floor area of about 50% of the total gross floor area of the entire USMA. The USMA SRM budget is limited; according to the information provided by the Directorate of Public Works (DPW), only a few buildings have potential for being funded for major renovation. Also, a number of buildings that have steam heating systems will be converted to hot-water heating systems. These two categories of buildings have been analyzed for cost-efficient energy saving potential.

USMA ENERGY GOALS

Energy goals established and agreed upon with USMA leadership address the following strategic areas:

- Energy efficiency
- Electrical grid peak reduction
- On-site energy generation
- Annual production of renewable energy equals total energy use

The combination of these goals that must be implemented in a cost-effective and balanced way presented a challenge to the research and analysis.

Energy Efficiency

By 2020, the site energy use at the installation will be 40% less than the 2011 baseline. This includes thermal energy (gas,

oil, etc.) supplied to the installation in addition to the electrical energy purchased from the grid.

Supply Security

The current level of energy reliability will be improved and on-site power generation will be at least 40.9 MBtu/h (12 MW) (considering that some cooling load will be provided by absorption chillers). The installation currently has only 8.9 MBtu/h (2.6 MW) of on-site power generation capability.

Carbon Footprint

By 2020, the installation should strive for zero greenhouse gas (GHG) emissions from both on-site stationary sources (Scope 1, i.e., from sources owned or controlled by a federal agency) and purchased electricity (Scope 2, i.e., resulting from the generation of electricity, heat, or steam purchased by a federal agency). GHG emissions are calculated consistently with the White House Council on Environmental Quality Guidance for Federal Greenhouse Gas Accounting and Inventories (White House 2012).

Based on an analysis conducted at ERDC-CERL, a definition of *net zero energy installation* has been proposed based on current realities at Army installations (Zhivov et al. 2014a):

The amount of fossil fuel based energy used over the course of a year is equal to the amount of energy from renewable energy sources that are exported from the installation to a power or thermal grid for external users' consumption.

Under this definition, net zero balance includes a combination of thermal and electrical energies presented in terms of primary (source) energy used (Figure 2). This should not be confused with the installation site energy, which is a combination of thermal energy (gas, oil, bio-mass, solar, etc.) and electricity produced on-site from renewable sources and purchased from the grid. The total site energy is composed of energy used by end users (e.g., by buildings, external lighting systems, etc.), losses in distribution systems, and conversion losses in energy equipment (boilers, chillers, engines, etc.). In addition, net zero energy balance does not include renewable energy credits purchased by installation or installation investment into renewable energy technologies installed outside the boundaries of the installation and connected to the grid.

Energy Economics

The net investments aimed at achieving energy goals will achieve an internal rate of return (IRR) of at least 5%, or approaching twice the current return on 30-year U.S. Treasury Bonds. Note that the IRR calculation in the Integrated Energy Management Plan (IEMP) integration uses the standard Microsoft® Excel® IRR function (Microsoft 2013).

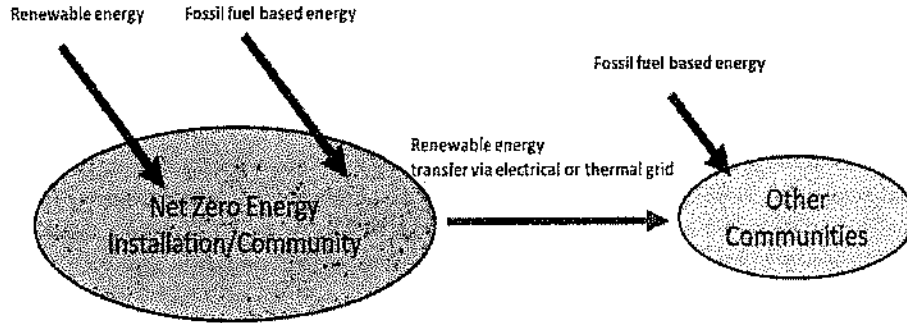


Figure 2 Schematic of NZE installation concept.

Table 1. Baseline Energy Use for NZE Area Buildings Connected to CEP

Utility	Cost	Usage	Site Energy, MMBtu/yr	Source Energy, MMBtu/yr	Site Energy, MWh/yr	Source Energy, MWh/yr
Gas	\$3,673,631	4,770,949 ccf	487,591	510,508	142,863	149,578
Electricity	\$3,477,866	143,011 MMBtu (41,902,000 kWh)	143,011	477,657	41,902	139,953
Total	\$7,151,497		630,602	988,165	184,765	289,531

Calculation Notes:

Site-to-source: natural gas = 1.047; electricity = 3.34

ccf to Btu = ccf(100 cf)(1022 Btu)/1,000,000 MMBtu = MMBtu

Energy price per year:

Natural gas = \$/ccf = (4,770,949 ccf) × (\$0.77/ccf) = \$3,673,631 per year

Electricity = \$/kWh = (41,902,000 kWh) × (\$0.083/kWh) = \$3,477,866 per year

Table 2. Baseline Distribution of Energy within the NZE Area

Energy Use	Cost, \$	MMBtu/yr	MWh/yr
A. Thermal energy use by building	2,267,740	300,991	88,190
B. Thermal energy distribution losses on-site	610,274	81,000	23,733
C. Thermal energy conversion losses at the CEP (boiler efficiency at 81.1%)	729,707	96,852	28,377
D. Electricity from on-site generation	65,910	8748	2563
E. Electricity from grid	3,477,866	143,011	41,902
Total purchased energy	7,151,497	630,602	184,765

USMA BASELINE

The baseline is a snapshot of USMA's NZE area energy profile (site and source energy) as an average of 2010 and 2011 in the following categories, for the NZE boundary discussed previously: 1) end uses, 2) building functions, 3) distribution losses on site, 4) steam network losses, 5) on-site electrical use, 6) conversion losses on-site (gas turbines, boilers, and steam turbines), 7) off-site conversion and distribution losses, 8) purchased natural gas, and 9) purchased electricity.

The total energy consumed by categories 1–6 is the site energy use. The total of categories 7–9 contributes to the source energy use. Data sources and estimation approaches are

compared to available metering and monitoring data. Table 1 lists the baseline energy use for NZE area buildings connected to the CEP. Table 2 lists the baseline distribution of energy within the NZE area. Figure 3 shows a schematic of baseline energy uses and wastes at the NZE area. Figure 4 shows energy uses and losses in the NZE area baseline. These values were calculated with known pipe insulation and estimated amounts of missing insulation. These calculations were supported with actual summer nighttime steam consumption with no steam usage. Condensate and steam losses were based on known measured makeup water quantities.

END-USE—BUILDING FUNCTION

Forty-four buildings that currently exist in the NZE area can be divided into 18 building types (not including the CEP building, which was excluded because it requires very little heating and no cooling throughout the year). Each of the 18 typical building types was modeled for energy use. Based on

field survey information and design drawings, the models prescribed the buildings as having

- massive masonry walls with little insulation,
- reasonable insulation in the roof,
- relatively high air infiltration,
- normal lighting levels,

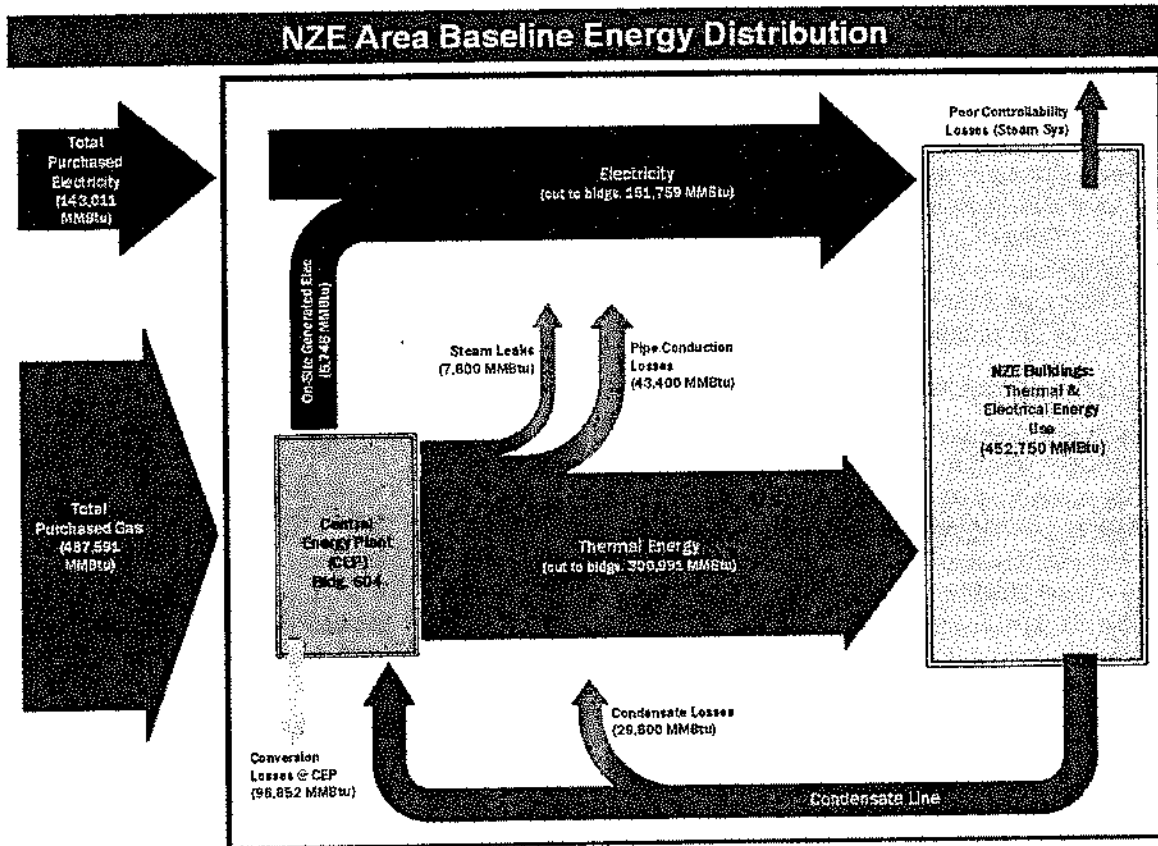


Figure 3 Schematic of baseline energy uses and wastes at NZE area.

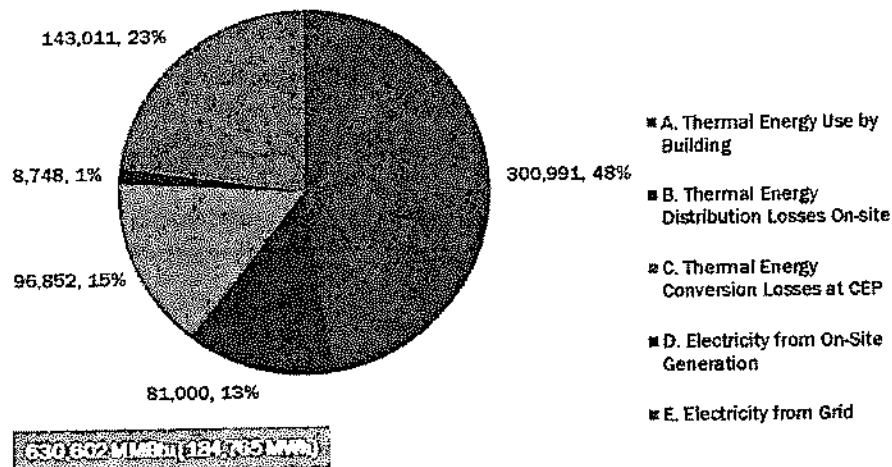


Figure 4 NZE area baseline energy uses and losses.

- normal use of DHW,
- a normal occupancy schedule for the building function, and
- an HVAC system selected with normal sizes for equipment.

The results of the model runs provided annual and peak energy use for the HVAC, lighting, DHW, and miscellaneous electrical systems for these buildings. Once the annual energy use and peak energy demand of the typical buildings were estimated in values per square foot (square meter) of building area, the energy use of the 44 buildings in the NZE group could be determined. The annual energy use values for each building were estimated by multiplying the energy use per unit of building area for each system by the specific building area. These total values were then compared and adjusted to the annual fuel use by the CEP and the peak heating demands on that plant. It was estimated that 10% of the building heating would be saved. Tables 3 and 4 list the adjusted baseline total and peak energy use by the buildings.

CONVERSION AND DISTRIBUTION LOSSES

The gas utility purchase records provided by USMA-DPW for the CEP for 2010 and 2011 state that the CEP consumed an average 5,005,500 ccf of natural gas, or 511,600 MMBtu (149,935 MWh) per year. The results of distribution loss analysis shown in Table 5 and Figure 5 indicate that the 81,000 MMBtu (23,738,757 kWh) per year in losses are due to pipe conduction losses and condensate, steam, and other leaks in the current steam distribution system. Thermal energy is measured via fuel and steam metering. Makeup water is measured directly. Only a small fraction of the makeup water is attributable to boiler blowdown.

ESTABLISHING THE BASE CASE AND ALTERNATIVES

After establishing the baseline, the base case and four potential scenarios were developed for USMA as long-term energy use reduction solutions for the campus to meet energy goals. Alternatives were selected starting with a historic type of system used at the installation and its modification (district hot- and chilled-water system), using guidance set forth in a recent Army memorandum (Aycock 2013) decentralized solution, and a variety of options available from the NZE tool database. Other alternatives were discussed but not evaluated. Heat pumps, for example, were not feasible at this site because the site is on bedrock, which makes the use of ground-source heat pumps cost-prohibitive. The criteria used to select these alternatives were total operating costs, life-cycle costs, and sustainability.

- *Base Case.* The base case assumes that the existing situation described in the baseline will be changed only due to already planned projects.
- *Alternative 1.* Convert the steam system to hot-water heating in buildings and decentralize the boiler system.
- *Alternative 2.* Convert buildings to hot-water heating and reuse existing boilers to convert steam to hot water.
- *Alternative 3.* Convert buildings to hot-water heating and provide a trigeneration system using reciprocal engines to generate electricity and use waste heat to provide domestic water heating, winter heating, and summer cooling.
- *Alternative 4.* Convert buildings to hot-water heating and provide a trigeneration system using gas and steam

Table 3. Baseline Total Energy Use by Buildings

Gross Area, ft ² (m ²)	Cooling, MMBtu (kWh/yr)	Other Electrical Use, MMBtu (kWh/yr)	Total, MMBtu (kWh/yr)	Space Heating, MMBtu/yr (kWh/yr)	DHW, MMBtu/yr (kWh/yr)	Absorption Chiller Heating, MMBtu/yr (kWh/yr)	Cooking Heating, MMBtu/yr (kWh/yr)	Total Heating, MMBtu/yr (kWh)
4,447,824 (413,648)	13,873 (4064889)	137,885 (40,400,054)	151,759 (44,464,944)	247545 (724,811,760)	23463 (68,699,664)	29810 (87,283,680)	173 (506,544)	300991 (881,301,648)

Table 4. Baseline Peak Energy Use by Buildings

Gross Area, ft ² (m ²)	Peak Cooling Load, MBtu/h (kWh/min)	Peak Cooling, Btu/min (kW/min)	Peak Other Electrical, Btu/min (kW/min)	Building Peak Electrical, Btu/min (kW/min)	Peak Space Heating, MBtu/h (kWh)	Peak DHW, MBtu/h (kWh)	Peak Absorption Chiller Heating, MBtu/h (kWh)	Peak Cooking Heating, MBtu/h (kWh)	Total Peak Heating, MBtu/h (kWh)
4,447,824 (413,648)	80213 (234,863,664)	38,990 (4127)	216,979 (9685)	786,179 (13,812)	119320 (349,368,960)	5927 (17,354,256)	33020 (96,682,560)	105 (307,440)	125247 (366,723,216)

Table 5. Distribution Losses from CEP out to Buildings

Distribution Losses	MMBtu/yr	MWh/yr
Steam leaks	7800	2286
Condensate leakage, condensate pipe conduction losses, and all other losses	29,800	8734
Pipe conduction losses	43,400	12,719
Total distribution losses	81,000	23,739

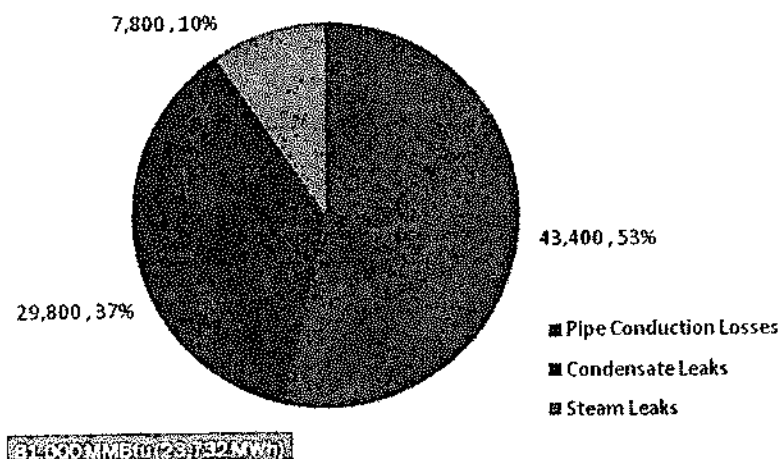


Figure 5 Breakdown of distribution losses.

turbines to generate electricity and use waste heat to provide domestic water heating, winter heating, and summer cooling.

Base Case

Compared to the baseline, the base case includes the energy impact of the building renovations recently completed or under construction, the planned new barracks building, the energy conservation projects being implemented by an ESPC contractor, and the planned renovations of the existing nine barracks buildings. The base case includes the impact of measures that will be implemented to meet new requirements for summer cooling in all new and renovated barracks. The base-case scenario can be summarized by the following list of measures:

- The CEP will continue to operate with steam distribution.
- Four existing buildings will be renovated over the 2013–2020 period.
- The Archive Library, Bartlett Hall, and Arvin Annex have been renovated.
- Under the ESPC contract:
 - HVAC control systems will be improved and expanded.
 - Lighting systems will be upgraded.
- HVAC systems will be upgraded.
- Nine existing barracks will be renovated following the example of Scott Barracks by incorporating the following:
 - High-performance building envelope
 - A cooling requirement
 - Chilled-beam and heat recovery dedicated outdoor air system (DOAS) unit air conditioning
 - Electrical-powered water-cooled chillers
 - Energy-efficient lighting
 - Demand ventilation
 - Pool covers and pump controls
 - High-performance electric motors
- New cadet barracks will be constructed:
 - Electrical-powered water-cooled chillers will be incorporated.
 - Heating will be sourced from a central power plant.
 - Energy-efficient lighting will be incorporated.
 - A hot-water solar collector system will be incorporated for domestic water heating.
- Emergency natural gas engines will be installed to cover critical electric loads of 61 MMBtu/h (18 MW).

Absorption chillers provide the large cooling load of about 9000 tons (316 MWh). The remaining load is provided

with high-efficiency chillers supported with chilled-water storage. The absorption chillers cut the demand by about 3 MW, and the combination of electric chillers and chilled-water storage reduce it about another 3 MW. The data in Table 6 summarize the base-case thermal energy use by buildings connected to the CEP and electrical energy use in the NZE area. The data in Table 7 and Figure 6 denote how the base-case energy is used in the NZE area.

In spite of additional loads due to new construction and new cooling requirements for cooling in barracks, energy conservation measures applied to new construction and renovation projects allowed for energy use reduction both by site (34.4%) and by source (26.7%). Energy costs with the base-

case scenario will be reduced by 26.6%. Energy security issues have not been resolved. Peak load remains close to the grid capacity. To meet the NZE requirement for this area, 724,179 MMBtu (212,236 MWh) must be produced using renewable energy sources.

DECENTRALIZED SYSTEMS (ALTERNATIVE 1)

The decentralized systems alternative was developed to analyze the decommissioning and decentralization of the central energy distribution network in favor of installing individual building systems across the NZE area. Some spaces may be usable, but flue access would be an issue for the boilers

Table 6. Base-Case Energy Cost and Usage

Utility	Cost	Usage	Site Energy, MMBtu/yr	Source Energy, MMBtu/yr	Site Energy, MWh/yr	Source Energy, MWh/yr
Gas	\$2,103,321	2,731,585 ccf	279,168	292,289	81,798	85,643
Electricity	\$3,087,517	126,960 MMBtu (37,199,000 kWh)	126,961	424,050	37,199	124,245
Total	\$5,190,838		406,129	716,339	118,997	209,887

Table 7. Base Case Energy Purchases by Distribution within the NZE Area

Energy Use	Cost, \$	MMBtu	MWh/yr
A. Thermal energy use by building	1,266,062	168,041	49,237
B. Thermal energy distribution losses on-site	366,164	48,600	14,240
C. Thermal energy conversion losses at the CEP (boiler efficiency at 80%)	426,642	56,627	16,592
D. Electricity from on-site generation	44,452	5900	1729
E. Electricity from grid	3,087,517	126,961	37,199
Total purchased energy	5,190,838	406,129	118,997

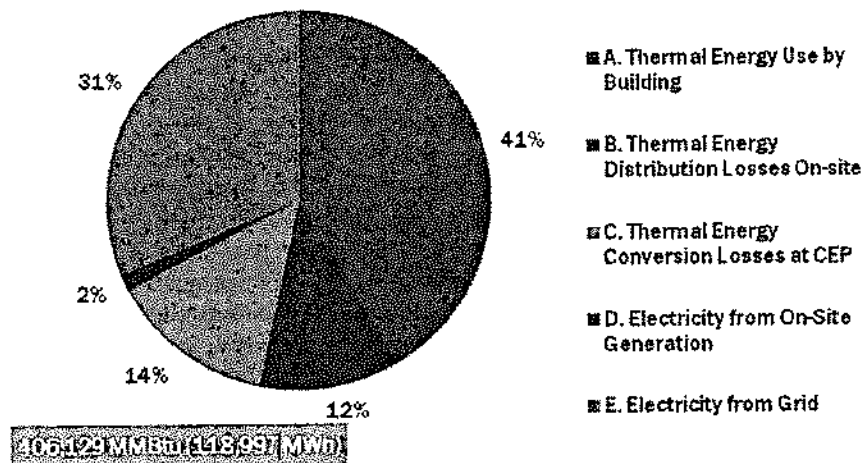


Figure 6 Base case site energy use.

and domestic water heaters. This scenario assumes that a mechanical/boiler room/building will be attached to each building. The cost of a boiler building includes matching the architecture of the adjacent building and installing two boilers, a domestic water heater, and pumps. The boilers and the water heater will be natural-gas fired. To support the new individual systems, a new natural gas (buried) piping distribution system will be required to distribute the gas in sufficient quantity to the buildings.

The buildings that currently use steam absorption chillers will remain on steam heat. They will not be converted to hot water. Decentralized steam boilers will be installed to serve these buildings. Air-cooled chillers will be provided for all buildings that do not currently have cooling, and they will be added as part of future building upgrades to meet the new cooling requirement.

Under this option, 18 MW of natural-gas-fired electrical emergency generation will be provided to serve as emergency backup for the entire West Point campus. This backup capacity will be generated from three new 20 MMBtu/h (6 MW) natural-gas-fired engine generators that will be installed near the laundry/hospital area.

Operation and maintenance activities for the decentralized equipment will be much higher than with the CEP options, as there will be many more pieces of equipment (boilers) overall in the campus to maintain. Additional maintenance and operational costs will occur for the added chillers and for the emergency generation equipment.

The decentralized systems scenario can be summarized by the following list of measures:

- Base-case renovation and new construction projects will be completed.
- Central power plant with steam distribution will be shut down.
- Building heat will be provided by individual building natural-gas-fired boilers, including:
 - New or expanded mechanical/boiler rooms at each building for new boilers.
 - Some buildings remain on steam to reduce first cost and to be able to use steam for absorption chillers.
 - Building HVAC and DHW systems that used steam are converted to hot water.
- Buildings requiring new hot-water radiators and/or unit heaters will also receive improved building envelope:
 - Increased wall and roof insulation
 - New or added high-efficiency windows
- Emergency natural gas engines will cover critical electric loads of 61 MMBtu/h (18 MW) installed.

The breakdown of the total 325,995 MMBtu (95,540 MWh) of energy to be purchased by USMA for the NZE area within the decentralized systems alternative is as follows:

- A. Thermal energy used by buildings (154,542 MMBtu [45,292 MWh]: 47.41%):
 - 104,972 MMBtu (30,764 MWh): 32.20% is heat losses in buildings
 - 26,760 MMBtu (7843 MWh): 8.21% is used for heat to the absorption chillers for building cooling
 - 22,637 MMBtu (6634 MWh): 6.94% is used for DHW within buildings
 - 173 MMBtu (51 MWh): 0.05% is used for cooking heat
- B. Thermal energy conversion losses in boilers (38,592 MMBtu [11,310 MWh]: 11.84%)
- C. Electricity purchased from the grid (132,861 MMBtu [38,928 MWh]: 40.76%)

The decentralized electrical annual consumption for NZE buildings totals 132,828 MMBtu/h (38,928 MWh), which is the general demand by buildings and electrical chillers for the NZE area. The energy associated with emergency electrical generation (natural gas consumption and electricity produced) was not incorporated within the calculated energy use for the decentralized systems alternative. The data in Table 8 summarize the decentralized heating and cooling alternative for the NZE area.

In spite of additional loads due to new construction and new requirements for cooling in barracks, energy efficiency measures applied to new construction and renovation projects allowed for energy use reduction both by site (48%) and by source (35%) compared to the baseline, and energy costs with the decentralized heating and cooling scenario will be reduced by 35%. Energy security issues will be resolved by installing an emergency generator providing 61 MMBtu/h (18 MW) power capacity. Peak load remains close to the grid capacity.

Compared to the base case, additional improvements in buildings related to conversion from steam to hot-water heating in buildings will improve efficiency of temperature control in these buildings and thus reduce the heating load. In addition, decentralization will eliminate distribution losses, which will result in a significant reduction in site and source energy and therefore overall energy cost by \$2.5M or 34% as compared to the baseline. However, this scenario will require significant additional investments compared to the base case and will have a high life-cycle cost with a payback exceeding 40 years. To meet the NZE requirement for this area, 645,967 MMBtu (189,314 MWh) must be produced using renewable energy sources.

CENTRAL STEAM-TO-HOT-WATER-SYSTEM CONVERSION (ALTERNATIVE 2)

According to this scenario, building heating systems and the campus steam piping distribution system will all be converted to a hot-water system. The steam piping in the tunnels will be replaced with a pre-insulated steel hot-water piping system, which will greatly reduce the piping heat losses

Table 8. Summary of the Decentralized Systems Conversion Alternative

Alternative	Site Energy		Source Energy		Energy Cost, \$	On-Site Power Generation	
	MMBtu	MWh	MMBtu	MWh		Btu	MWh
Decentralized heating and cooling	325,995	95,540	645,967	189,314	4,686,143	0	0
Baseline	630,602	184,811	988,165	289,603	7,151,497	750,446	2563
Base case	406,129	119,025	716,339	209,938	5,190,838	506,251	1729

Alternative	Maintenance Costs, \$/yr	Capital Costs, \$	% of Mission-Critical Power Generated On-Site	Peak Power		Grid Capability to Meet Peak Power	Life-Cycle Cost, \$
				MMBtu/h	MW		
Decentralized heating and cooling	2,344,200	130,788,604	100	57	16.8	18	358,866,115
Baseline	2,455,446	—	0	47	13.8	18	NA
Base case	1,872,823	86,350,800	100	57	16.8	18	306,942,547

and essentially eliminate water makeup as compared to the steam distribution system.

The existing boilers will be used to provide hot water for the system by converting steam to hot water via heat exchangers. The hot water will then be pumped through the central hot-water distribution piping system by circulation pumps to be located within the existing CEP building.

Air-cooled chillers will be provided for all buildings that do not currently have cooling, and they will be added as part of future building upgrades.

This option will provide 61 MMBtu/h (18 MW) of natural-gas-fired emergency electrical generation to serve as emergency backup for the entire West Point campus. Electrical energy will be generated from three new 20 MMBtu/h (6 MW) natural-gas-fired engine generators, which will be installed near the laundry/hospital area.

Operation and maintenance activities at the CEP will be slightly more than those of the existing steam system due to the added heat exchanger and pumps. Maintenance for the hot-water piping system will be considerably less than that for the steam piping, primarily due to the elimination of the steam traps and the reduction in corrosion and expansion/contraction within the piping system. (The steam system is down once a year for maintenance.) Operational and maintenance activities of the hot-water systems at each building will be less than those of the current steam system. Additional maintenance and operational costs will occur for the added chillers and for the emergency generation equipment. The central steam-to-hot-water-system conversion alternative can be summarized by the following list of measures:

- Base-case renovation and new construction projects will be completed.
- Buildings will be converted from steam to hot-water systems.
- Buildings requiring new hot-water radiators and/or unit heaters will also receive improved building envelope, including:
 - Increased wall and roof insulation
 - New or added high-efficiency windows
- Emergency natural gas engines will cover critical electric loads of 61 MMBtu/h (18 MW) installed.
- Steam piping distribution system will be replaced with (200°F to 160°F [93°C to 71°C], depending on the season) hot-water piping system¹
- New electrical chillers will be installed.

The breakdown of the total 310,344 MMBtu (90,953 MWh) of energy to be purchased by USMA for the NZE area within the conversion to hot water alternative is as follows:

- A. Thermal energy used by buildings (127,782 MMBtu [37,449 MWh]: 41.17%):
 - 104,972 MMBtu (30,764 MWh): 33.82% is losses in buildings
 - 22,637 MMBtu (6,634 MWh): 7.29% is used for DHW within buildings

¹ The hot water will operate in the 160°F to 230°F (71°C to 110°C) temperature range depending on the season. There are two system pressures. Low pressure is distributed at 12 psig (83 kPa) (~240°F [116°C]) and serves buildings near the CEP. High pressure, which serves the entire NZE, is at 160 psig (1103 kPa) (~370°F [188°C]).

- 173 MMBtu (51 MWh): 0.06% is used for cooking heat
- B. Thermal energy distribution losses on-site (8,565 MMBtu [2,510 MWh]: 2.76%):
- 6710 MMBtu (1967 MWh): 2.16% is pipe conduction losses in the distributions lines
 - 1240 MMBtu (363 MWh): 0.4% is energy losses with condensate in condensate lines
 - 615 MMBtu (180 MWh): 0.2% is steam losses in distribution piping
- C. Thermal energy conversion losses in boilers and turbines at the CEP (36,163 MMBtu [10,598 MWh]: 11.65%)
- D. Thermal energy for on-site electricity generation (8479 MMBtu [2,485 MWh]: 2.73%)
- E. Electricity purchased from the grid (129,355 MMBtu [37,910 MWh]: 41.68%)

The conversion to hot water scenario electrical consumption for NZE buildings totals 11,097,412 Btu/yr (37,901 MWh/yr), which is the general demand by buildings and electrical chillers at the NZE area. The electrical utility purchase from the grid is reduced by 8476 MMBtu/h (2484 MW) of electricity that is produced by cogeneration. The natural gas used to cogenerate this electricity totals 8479 MMBtu (2485 MWh), which already includes conversion losses that were calculated within the inefficiencies at the CEP. The existing system has a steam turbine that steps the pressure down from 160 to 15 psig (1103 to 103 kPa). Less steam demand from the energy improvements results in less electricity being generated. Since it is not known how much the emergency generation will have to run, no fuel was included in any option for the emergency electrical generation. The 61.4 MMBtu/h (18 MW) is emergency backup only. The energy associated with emergency electrical generation (natural gas consumption and electricity produced) were not incorporated within the calculated energy use for this alternative.

The data in Table 9 summarize the central steam-to-hot-water-system conversion alternative for the NZE area.

In spite of additional loads due to new construction and to the new requirement for barracks cooling, energy efficiency measures applied to new construction and renovation projects will reduce energy by site (50.8%) and by source (37%) compared to the baseline. The conversion from steam to a hot-water system will reduce energy costs by 37%. Energy security issues will be resolved by installing an emergency generator providing 61 MMBtu/h (18 MW) power capacity. Peak load remains close to the grid capacity.

Compared to the base case, this scenario will have the following benefits:

- Lower installed cost due to lower-cost hot-water pipe that experiences less expansion and has no steam traps to maintain
- Reduced heat loss because 200°F (93°C) hot water has a lower temperature than 160 psig (1103 kPa) steam

- Reduced heat loss because a lower supply temperature allows more efficient insulation to be used
- Lower maintenance costs for hot water because steam traps are not used and there will be less corrosion due to a closed pipe system
- A closed hot-water system with a longer life than a steam system
- Improved efficiency of temperature control in buildings and thus reduced heating load

This scenario will require additional investments compared to the base case but will have a lower life-cycle cost with a simple payback of 17 years. To meet the NZE requirement for this area, 621,541 MMBtu (182,156 MWh) must be produced using renewable energy sources.

CENTRAL STEAM-TO-TRIGENERATION-SYSTEM CONVERSION SCENARIOS (ALTERNATIVES 3 AND 4)

The trigeneration scenario includes Alternative 3 (with reciprocal engines) and Alternative 4 (with gas turbines).

Similar to the conversion to hot water alternative, in Alternatives 3 and 4 the following measures will be implemented:

- Base-case renovation and new construction projects will be completed.
- Buildings will be converted from steam to hot-water heating systems.
- Buildings requiring new hot-water radiators and/or unit heaters will also receive improved building envelope.
- Wall and roof insulation will be increased.
- New high-efficiency windows will be installed.
- Steam piping distribution system will be replaced with hot-water piping system.

In this scenario, thermal piping losses are significantly reduced compared to the base case. The steam piping in the tunnels would be replaced with a pre-insulated steel hot-water piping system that would greatly reduce the piping heat losses and essentially eliminate heating-medium losses.

Alternatives 3 and 4 differ from Alternative 2 in that both trigeneration scenarios generate heat and electricity at the CEP location and all cooling needs are provided from one of three central chilled-water plants. The trigeneration options require central chiller plants to take advantage of the hot water for generating chilled water with absorption chillers. It was decided that it was more economical to provide three plants to minimize the piping distribution costs.

The campus demand for space heating and DHW heating is the controlling factor for operation of the trigeneration system. The hot-water requirements during summer and winter push the trigeneration electrical generation past what is required for the NZE campus. During these times, excess electricity can be sold back to the grid. During peak heating periods, which can occur during the months of December, January, and February, the heating load is beyond what combined heat

Table 9. Summary of the Central Steam-to-Hot-Water-System Conversion Alternative

Alternative	Site Energy, MMBtu (kWh)	Source Energy, MMBtu (kWh)	Energy Cost, \$	On-Site Power Generation, Btu (MWh)	Maintenance Costs, \$/yr	Capital Costs, \$	Mission-Critical Power Generated On-Site	Peak Power, MMBtu/h (MW)	Grid Capability to Meet Peak Power	Life-Cycle Cost, \$	SPB/DPV*
Central steam-to-hot-water conversion	310,344 (908,687,232)	621,541 (1,819,872,048)	4,509,399	727,315 (2484)	1,466,000	104,772,604	100	61 (18)	18	299,154,506	17/24
Baseline	630,602 (1,846,402,656)	988,165 (2,893,347,120)	7,151,497	750,446 (2563)	2,455,446	NA	0	47 (13.8)	18	NA	NA
Base case	406,129 (1,189,145,712)	716,339 (2,097,440,592)	5,190,838	506,251 (1729)	1,872,823	86,350,800	100	57 (16.8)	18	306,942,547	NA

* SPB = simple payback; DPV = discounted present value

and power generation equipment can provide. During these periods, the existing boilers are used to supplement the hot-water load to the campus. In the spring and fall, the heating and cooling loads, and the corresponding electrical generation, fall. During these times, additional electricity from the grid will be required to meet the campus needs. The waste heat available from combined heat and power generation provides considerably more cooling with absorption chilling in these options than in the base case or the decentralized option.

Alternative 3

The conversion of the CEP to the trigeneration engine system will require considerable modification of the CEP to accommodate the needed space and structural improvements for the new equipment (Figure 7). The CEP (building 604) will undergo demolition and complete refurbishment at an estimated cost of \$4,500,000. The existing steam turbine generators will be removed. Leadership in Energy and Environmental Design® (LEED®) costs were not considered in the cost estimate. Demolition costs considered the recycling value of the steel.

According to manufacturer cost information, the development of the cogeneration plant within the CEP has a total cost of \$29,000,000. This includes three 14 MMBtu/h (4 MW) generators with corresponding hot-water heat exchangers, which have the capacity to meet the mission-critical 41 MMBtu/h (12 MW) demand. An area north of the existing steam boilers will be cleared and prepared for locating the steam-to-hot-water heat exchangers. The conversion of the CEP heat exchangers and pumps will cost a total of \$2,000,000. The low-pressure steam from the steam turbine generators in the CEP will be converted to hot water to be distributed to the campus. The redundant pumps and heat exchangers will be located in the CEP on the north side of the existing steam boilers. One less heat exchanger will be required as compared to the hot-water conversion option because the heat exchangers with the generator will provide redundancy.

New centrifugal electric chillers at the New Cadet Barracks and the CEP (building 604) are to replace existing electric chillers with increased capacity at a cost of \$8,450,000. The existing electric and absorption chillers would be removed and replaced with larger-capacity absorption chillers and electric chillers. A chilled-water storage tank is provided to generate the chilled water at night for use during the day. This reduces the chiller plant capacity requirements, matches the heating load with the cooling load, and reduces the electrical demand of the NZE campus. The absorption chillers will be sized to take full advantage of the generator waste heat. The electric chillers with chilled-water storage tanks will be sized to pick up the remaining chilled-water capacity requirement. (Capacity is increased because the study assumes that the dorm air conditioner is on during the day.) A chilled-water storage tank is provided to allow the electric chiller capacity to be reduced by 50%, which reduces

the chiller electrical demand correspondingly. The chillers are sized to take advantage of the chilled-water storage tank, which will double the chiller cooling capacity by storing chilled water at night. This cost is based on budget costs provided by the equipment manufacturer and on CERL contractor TKDA's experience associated with replacement of these systems. A centrifugal electric chilled-water plant with a cooling tower will be provided on the north campus (located at Building 655, Eisenhower Hall,) to reduce the required district energy chilled-water piping cost for a cost of \$3,549,000.

New absorption chillers with increased capacity will replace existing absorption chillers at a cost of \$11,830,000. The absorption chillers are sized to use the full amount of waste heat from the generators in the summer and take advantage of the chilled-water storage tank, which will double the chiller cooling capacity by storing chilled water at night. The electric chillers are sized to fill the gap between the absorbers and the total cooling load. This cost is based on manufacturer budget costs and architect/engineer firm experience associated with replacement of these systems.

In addition to the improvements at the CEP and conversion to hot water, both a hot-water storage tank and a chilled-water storage tank will be constructed on the campus, as well as a chilled-water distribution system. A 400,000 gal (1,514,000 L) hot-water storage tank is to be constructed to match the heating load with the electrical load. With the added electrical generation capacity of the combined heat and power system, the CEP (building 604) will require an electrical upgrade to improve service and capacity. The trigeneration system generation efficiency in Alternative 3 is approximately 80%–43% for electrical generation and 37% for heat recovery. Compared to the base case, thermal losses are lower in the hot-water loop due to its lower operating temperature and the use of more efficient thermal insulation. The waste heat from the reciprocating gas engines is used primarily for domestic water heating, building heating in the winter, and absorption chiller cooling in the summer.

Alternative 4

The combined-cycle gas turbine generator alternative uses two 15 MMBtu/h (4.5 MW) natural gas turbine engine generators to provide the bulk of the electrical generation requirement. The natural gas turbine generator will generate electricity at an efficiency of 30% to 35%. The hot combustion exhaust gases from the turbine are sent to a heat recovery steam generator to generate about 1200 psig (8273 kPa) steam. Duct burners can be included in the heat recovery steam generator to increase the steam output to meet peak heating demands, to increase the steam turbine output, or with the inclusion of a fresh air fan to create steam without the combustion turbine in operation. The steam from the generator is then used in a steam turbine generator to create up to an additional 10 MMBtu/h (3 MW) of electrical power.

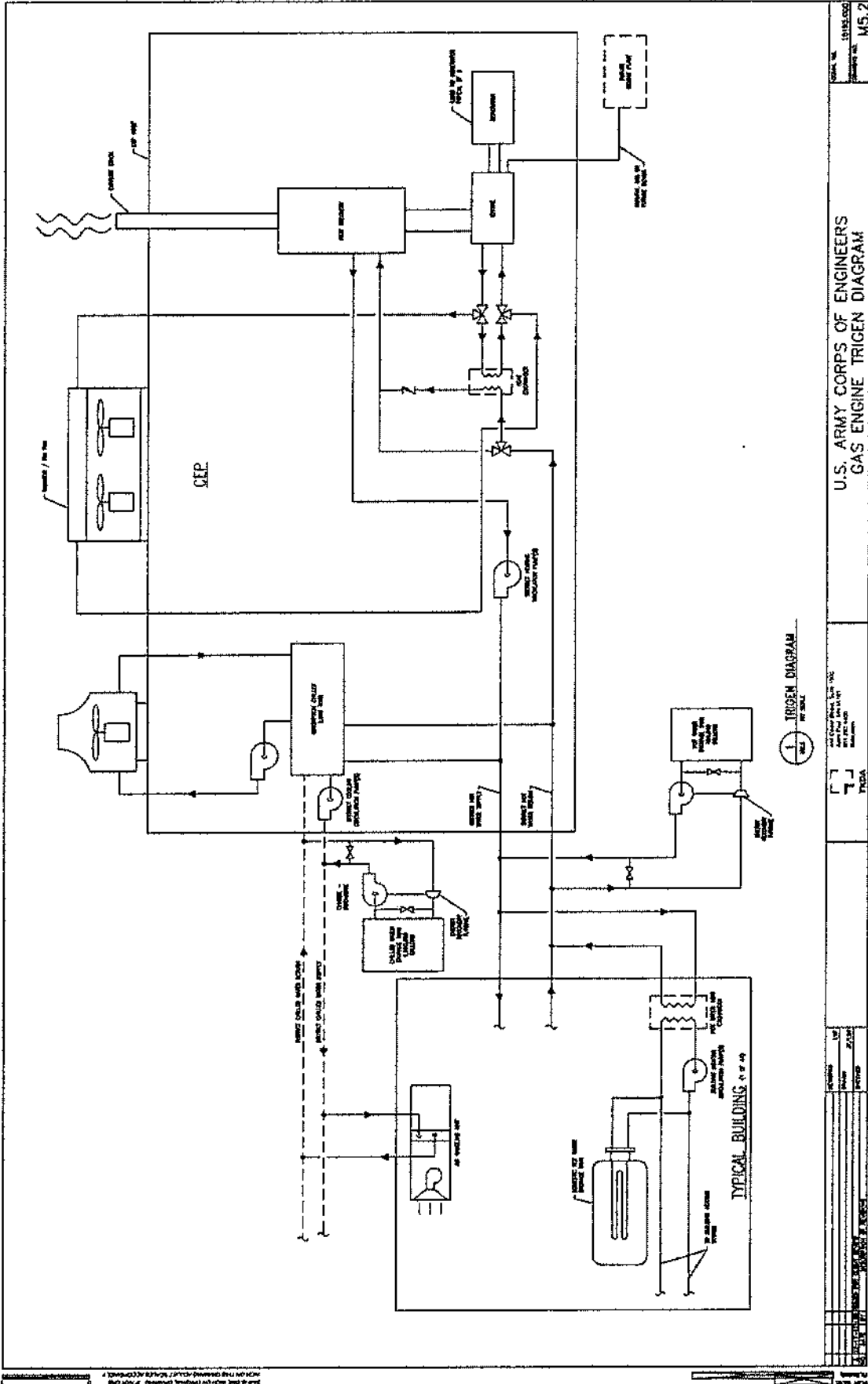


Figure 7 Layout of trigeneration system at the CEP with reciprocating engines.

The steam generator will boost the overall system electrical efficiency to about 45%. The steam exits the steam turbine at about 10 psig (69 kPa) and is converted to hot water. The heat from the hot water is then used throughout the campus for building heat, domestic water heating, and absorption cooling.

A combined-cycle electrical generation system could be fit into the existing CEP by installing two 15 MMBtu/h (4.5 MW) gas turbine generators with associated heat recovery steam generation in the existing turbine generator room. However, there would not be room available for supplementary burners in this arrangement, so it would be necessary to maintain two of the existing boilers for peak heating and backup. Boiler #3 would need to be removed to provide space for the steam turbine generator. The steam-to-hot-water heat exchangers and corresponding pumps will be located in the northeast corner of the boiler plant as is proposed for the engine generator option.

The main benefit of a natural gas turbine combined-cycle electrical generation system is the lower maintenance requirement as compared to a reciprocating engine generator. A turbine generator needs regular inspection of the turbine blades but replacement only when worn (which can exceed 100,000 operating hours). This directly explains why the maintenance costs of a turbine generator are so much less than those of a reciprocating engine generator.

This system requires more space than is required for a comparable engine-generator system because the combustion turbine and heat recovery generator layouts include a steam turbine generator. The additional stage along with the extra sophistication of the equipment results in the combined-cycle system being more expensive than the natural gas engine generators. The other important limitation of the natural gas turbine is that it cannot use syngas (as the alternative renewable fuel) without considerable cleaning of the gas. A high-speed turbine wheel will simply not tolerate impurities in the supply gas, which will either wear the turbine blades or deposit impurities on the blades. Syngas scrubbing equipment is expensive and requires substantial space (and open space is scarce at the CEP).

The conversion of the CEP to the trigeneration gas turbine system will require considerable modification of the CEP to accommodate the needed space and structural improvements for the new equipment (Figure 8). The CEP (building 604) will undergo demolition and complete refurbishment at a cost of \$5,500,000. The existing steam turbine generators will be removed.

According to manufacturer cost information, the development of the cogeneration plant within the CEP has a total cost of \$56,000,000. This includes two natural gas turbine generators at 15 MMBtu/h (4.5 MW), each with corresponding high-pressure steam boilers, and one steam turbine generator at 10 MMBtu/h (3 MW); pollution controls; steam-to-hot-water heat exchangers; pumps; and other auxiliary equipment. These turbines produce 41 MMBtu/h (12 MW) to meet

the mission-critical 41 MMBtu/h (12 MW) demand. An area north of the existing steam boilers will be cleared and prepared for locating the steam-to-hot-water heat exchangers. The conversion of the CEP heat exchangers and pumps will cost a total of \$2,000,000. The low-pressure steam from the steam turbine generators in the CEP will be converted to hot water to be distributed to the campus. The redundant pumps and heat exchangers will be located in the CEP near the existing steam boilers. One less heat exchanger will be required as compared to the hot-water conversion option because the heat exchangers with the generator will provide redundancy.

Summary

In spite of additional loads due to new construction and to the new requirement for barracks cooling, energy efficiency measures applied to new construction and renovation projects will reduce energy by site (31.1%) and by source (81.6%) compared to the baseline. Alternative 3 will reduce energy costs by 82.2% (\$5,879,607). Alternative 4 will reduce energy costs by 84% (\$6,008,850). On-site electricity generation will resolve energy security issues in the amount required for mission-critical facilities (41 MMBtu/h [12 MW]). Peak load remains close to the grid capacity.

Compared to the base case, both trigeneration alternatives of this scenario will have the following benefits (Table 10):

- Reduced heat losses because hot water has a lower temperature than steam
- Reduced heat loss because a lower supply temperature allows more efficient insulation to be used
- Lower maintenance costs for hot water because steam traps are not used
- A hot water system that has a longer life than a steam system because it is a closed system
- Improved efficiency of temperature control in buildings and thus reduced heating load (due to a 10% savings resulting from the use of improved controls)

Both alternatives will require additional investments compared to the base case but will have lower life-cycle cost (simple paybacks of 10 years with Alternative 3 and 16 years with Alternative 4). To meet the NZE requirement for this area, 181,457 MMBtu/yr (53,180 MWh/yr) must be produced using renewable energy sources with Alternative 3 and 162,624 MMBtu/yr (47,660 MWh/yr) with Alternative 4.

As a substitute for some portion of natural gas in Alternative 3, syngas could bring USMA's central area to source NZE when it becomes economically feasible. If used, syngas would be produced on-site at USMA. Alternative 3 will sometimes generate surplus electrical power, which can be shared with the rest of the USMA cantonment area or sold to the grid.

Alternative 4 cannot use syngas (as the alternative renewable fuel) without considerable cleaning of the gas. A high-

Table 10. Summary of Trigeneration Alternatives

Alternative	Site Energy, MMBtu (kW/h)	Source Energy, MMBtu (kW/h)	Energy Cost, \$	On-Site Power Generation, Btu (MWh)	Maintenance Costs, \$/yr	Capital Costs, \$	% of Mission-Critical Power Generated On-Site	Peak Power, MMBtu/h (MW)	Grid Capability to Meet Peak Power	Life-Cycle Cost, \$	SPB/DPV
Trigeneration with engines	434,378 (1,271,858,784)	181,457 (531,306,096)	1,271,890	20,238,921 (69,122)	2,198,667	130,430,694	100	41 (12)	18	232,125,392	10/13
Trigeneration with turbines	367,992 (1,077,480,576)	162,624 (476,163,072)	1,142,647	18,371,442 (62,744)	1,968,089	158,430,694	100	41 (12)	18	255,470,743	16/20
Baseline	630,602 (1,846,402,656)	988,165 (2,893,347,120)	7,151,497	750,446 (2,563)	2,455,446	—	0	47.1 (13.8)	18	NA	NA
Base case	406,129 (1,189,145,712)	716,339 (2,097,440,592)	5,190,838	506,251 (1,729)	1,872,823	86,350,800	100	57.3 (16.8)	18	306,942,547	NA

* SPB = simple payback; DPV = discounted present value

speed turbine wheel will simply not tolerate impurities in the supply gas, which will either wear the turbine blades or deposit impurities on the blades. Syngas scrubbing equipment is expensive and requires substantial space (and open space is scarce at the CEP).

CONCLUSION

In spite of additional loads due to new construction and new requirements for cooling in barracks, all scenarios—the base case and four alternatives—significantly reduce energy use. Compared to the baseline, the alternatives reduce energy use from 31% to 51% for site energy and from 27% to 84% for source energy. They reduce energy costs from 27% to 84% (Figure 9).

The greatest site energy reduction (~50%) can be achieved with the conversion to hot-water system and decentralized system alternatives, followed by the trigeneration using turbines scenario (42% site energy reduction). However, only the trigeneration alternatives allow for a significant source energy reduction (82% to 84%) with a significant (>80%) energy cost reduction.

All scenarios excluding the base case will resolve energy security issues. However, the decentralized and conversion-to-hot-water alternatives will require purchase of additional generators, while both trigeneration alternatives will reduce the total power demand for mission-critical facilities from 61 to 41 MMBtu/h (18 to 12 MW) (due to use of higher-efficiency central chillers and chilled-water storage) and will provide 100% demand with on-site power generation.

The trigeneration option using a combination of gas and steam turbines has the highest investment costs. The decentralized and trigeneration using reciprocal engines alternatives have the second-highest investment costs. The trigeneration engine alternative has the lowest life-cycle cost with a simple

payback of 10 years and a discounted payback of 13 years, followed by the trigeneration with gas and steam turbines alternative. To meet the NZE requirement, the base case and the decentralized and hot-water system alternatives will require on-site power generation using photovoltaic energy generation in an amount that will vary between 621,541 and 716,339 MMBtu/yr (182,156 and 209,938 MWh/yr).

Both trigeneration alternatives will provide on-site power generation for mission-critical facilities. They will result in a significant site energy reduction (31% with Alternative 3 and 42% with Alternative 4) and an outstanding fossil-fuel-based energy use reduction (82% and 84%, respectively).

Among trigeneration scenarios, an important benefit of Alternative 4, which combines a natural gas turbine with a cycle electrical generation system, is its lower maintenance requirement as compared to a reciprocating engine generator. However, Alternative 4 has a significantly higher investment cost and requires more area than the engine generators.

The substitution of syngas for natural gas (produced locally from imported biomass) as a fuel in Alternative 3 makes the selected area an NZE area and also a net positive energy area. Alternative 3 will sometimes generate surplus electrical power, which can be shared with the rest of the USMA cantonment area or sold to the grid. Alternative 4 cannot use syngas (as the alternative renewable fuel) without considerable cleaning of the gas. As previously mentioned, a high-speed turbine wheel will not tolerate impurities and syngas scrubbing equipment is costly and requires substantial space.

Based on technical and economical merits, Alternative 3 is the most fitting selection, as it meets all energy goals (including the potential for NZE) and has the lowest life-cycle cost and an attractive return on investment with a simple payback of 10 years.

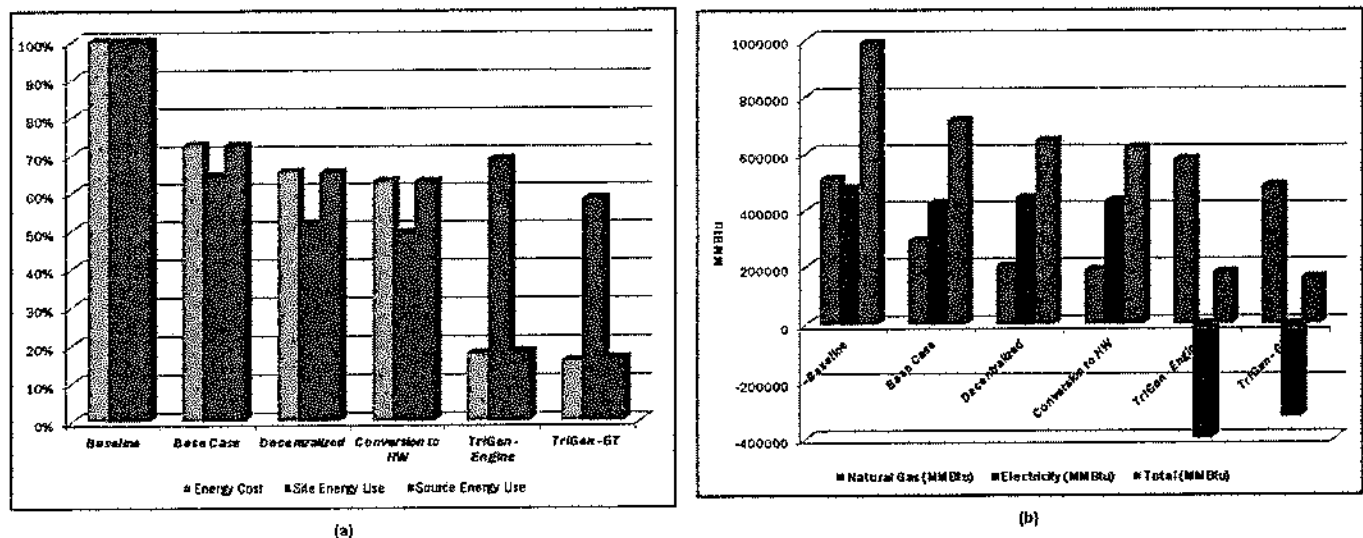


Figure 9 Comparison of all alternatives to the baseline: a) site, source, and costs as a percentage and b) types of energy used.

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