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Energy Optimization for Fort Carson Combat Aviation Brigade Complex

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ABSTRACT

The Fort Carson, CO, Combat Aviation Brigade (CAB) complex is a proposed 60-building development originally planned as a grouping of individual structures, each with its own boilers and chillers. None were to be engineered to share energy resources with neighboring structures. After the initial planning for the CAB, the US Army named Fort Carson as one of eight pilot net zero installations for energy use as a part of the Army's overall effort to conserve resources. Fort Carson's goal for the CAB complex at Butts Army Airfield consequently became the construction of a "net zero ready" community of buildings designed to optimize energy performance, water conservation, and waste diversion.

The US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) conducted a study to assess the potential for synergy between CAB facilities energy needs and the feasibility of building a Central Energy Plant (CEP) that would produce hot and chilled water to be used for heating and cooling throughout the CAB complex, and that could also generate electricity through cogeneration. This paper describes the results of the study and different alternatives considered, as well as energy requirements and specific technologies that have been applied to this new generation of buildings.

INTRODUCTION

The Fort Carson, CO, Combat Aviation Brigade (CAB) complex is a proposed 60-building development in Fort Carson's Butts Army Airfield area. It is one of the largest ($700M+) complexes planned for development by the Army in the near future. Though it is an integral part of Fort Carson, the CAB complex is located four miles from the main cantonment. Demonstration of the "net zero energy" (NZE) concept on a smaller scale of the CAB area will help test different concepts that will help to develop a "roadmap" to NZE for the whole installation. Also, lessons learned can be applicable to other Army installations.

The CAB complex was originally planned as a grouping of individual structures that each had its own boilers and chillers. All buildings were planned to obtain electricity from the commercial supply grid; emergency electrical generators would be authorized only at life-safety and some mission critical facilities. In the original plan, dozens of buildings planned for construction at the CAB area were to have been designed to meet only the Energy Policy Act of 2005 (EPAct 2005) site energy requirements of 30% better than ANSI/ASHRAE/IESNA Standard 90.1-2004. None were to be engineered to potentially share energy resources with neighboring structures. Several buildings at the CAB area have been already constructed using this approach.

Subsequent to the initial planning for the CAB, the US Army named Fort Carson, CO, as one of eight pilot net zero installations for energy use as a part of the Army's overall effort to conserve resources. After being named an Army Pilot Net Zero Energy Installation, Fort Carson's goal for the CAB complex at Butts Army Airfield became the construction of a "net zero ready" community of buildings. Net zero ready buildings optimize energy performance, water conservation, and waste diversion. These buildings are able to achieve net zero performance with minimal, subsequent modification to include the addition of one or more renewable energy sources. Use of a Central Energy Plant (CEP) is also a key concept for this net zero ready community.

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Before moving ahead with the remainder of the new construction for the CAB during the period of 2012–2017, the Installation Management Command West Division (IMCOM-West) tasked the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) to conduct a study to assess the potential for synergy between CAB facilities energy needs and the feasibility of building a Central Energy Plant (CEP) that would produce hot and chilled water to be used for heating and cooling throughout the CAB complex, which includes the Wilderness Road Complex (WRC) and the Butts Army Air Field (BAAF) areas at Fort Carson. The CEP would also generate electricity through cogeneration. The study was to be conducted in parallel with design and contracting of buildings planned for construction in 2012. Therefore, ERDC-CERL, the Fort Carson Directorate of Public Works (DPW), and US Army Corps of Engineers (USACE) Omaha District researchers and engineers worked together to reach a consensus and to implement the study results in the ongoing design.

The objective of this study was to increase energy efficiency in the CAB area by reducing the building energy demands, replacing individual heating and cooling units at every structure with a centrally controlled and balanced CEP, and reducing energy waste with generation of electricity, potentially making it an NZE area by eliminating the need for fossil fuels. Electricity generated by the CEP through cogeneration has to meet or exceed uninterrupted energy security needs for the CAB complex's mission critical facilities. An optimized CEP will initially use natural gas for fuel, and will significantly reduce total source energy (fossil fuel) consumption for the CAB area. Eventually, the CEP could be transitioned to run on biomass or biogas generated through the on-site gasification of biomass such as woodchips.

This paper describes the results of the study and different alternatives considered, as well as energy requirements and specific technologies that have been applied to a new generation of buildings that were designed and some of which have already been built after conception of this study.

BASELINE CASE

The 60-building complex comprising the CAB area includes eight existing buildings built before 2005, 18 recently constructed facilities built between 2005 and 2010, and 34 new facilities to be constructed between 2012 and 2017.

The baseline case for the study was the 60 building complex, including boilers and chillers in each facility. The baseline case assumed that all 26 existing buildings were either constructed to meet or will be eventually upgraded so that their electrical and thermal energy needs will meet EPAct 2005 requirements. For the baseline case, it was also assumed that the 34 new facilities would be constructed to meet EPAct 2005 requirements. (Note that this was Fort Carson's initial plan for the CAB new construction.)

In the baseline case, individual building heating systems are connected, for redundancy, to two heating boilers, each with the heating generation capacity of ~65% of the peak heating load for the building. Each building had an additional domestic hot-water (DHW) boiler. Individual building air-cooled electric chillers provide chilled water to building cooling systems designed to meet peak cooling load.

The complex was originally designed as a grouping of individual structures without regard for possible efficiencies to be gained by sharing heating and cooling capacity or by trading off the diurnal nature of many power requirements (e.g., early morning ablutions, dining cycles, evening cooling, and administrative facility lighting requirements).

Table 1 shows the time breakdowns of floor area and cluster energy consumption of these 60 buildings. Figure 1 shows the general layout of the CAB facilities.

To determine the peak energy values and energy use schedules for the eight existing buildings built before 2005 at the Butts Army Airfield site, it was assumed that these buildings performed similarly in energy performance and schedule to facilities more recently constructed to meet the Energy

Table 1. Overview of Site Development

Stage	Description	No. of Buildings	Area sq ft	(m^2)
Stage 1	Wilderness Road existing buildings	18	735,851	(68,434)
	Butts Airfield existing buildings	8	179,599	(16,685)
Stage 2	Buildings to be constructed in FY12	6	550,138	(51,163)
Stage 3	Buildings to be constructed in FY14	6	479,902	(44,631)
Stage 4	Buildings to be constructed in FY15	6	666,067	(61,944)
Stage 5	Buildings to be constructed in future	16	900,928	(83,786)
	Total	60	3,512,485	(326,661)

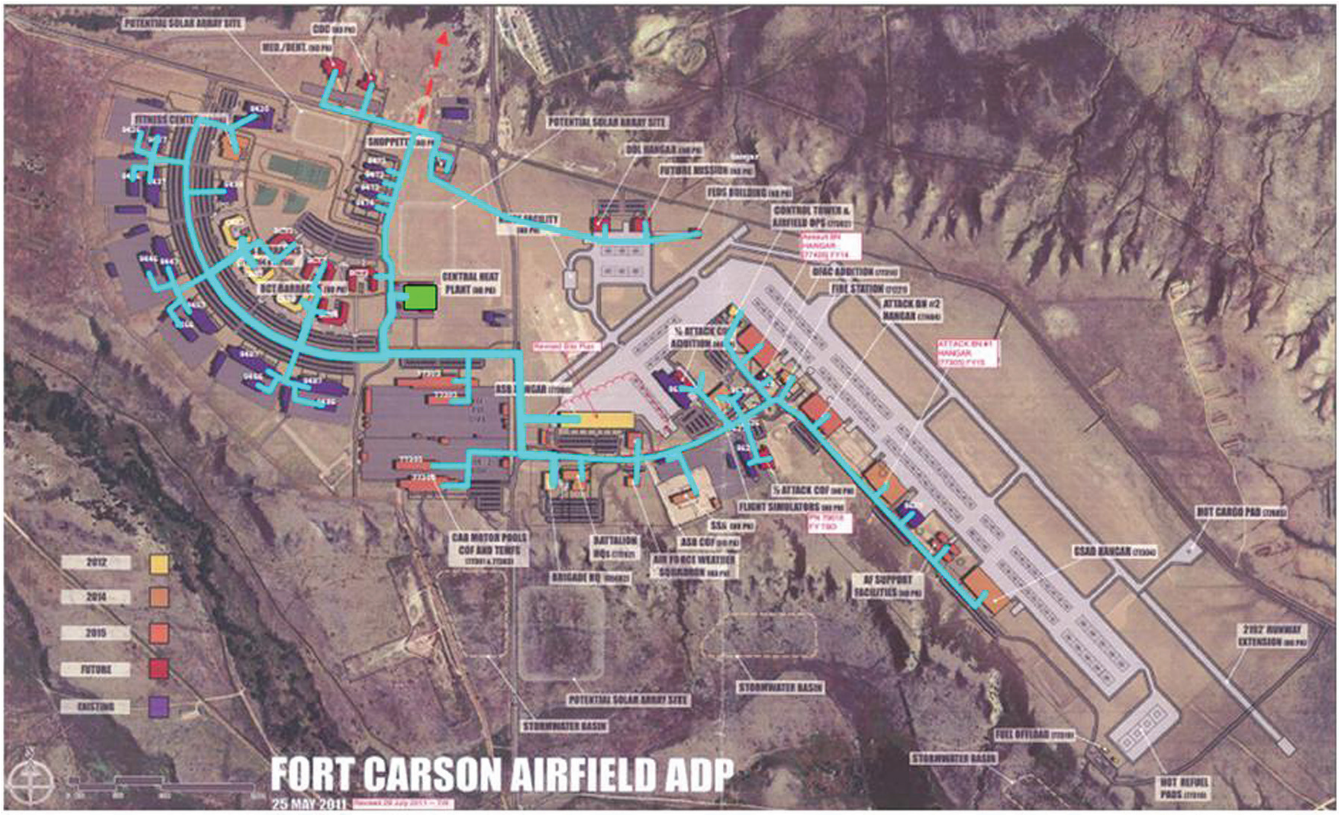

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Figure 1 *Fort Carson airfield site plan.*

Policy Act of 2005 (EPACT 2005) site energy reduction requirements. Peak energy values and annual energy use schedules for typical Army facilities that meet EPACT 2005 energy requirements were determined in a previous USACE EPACT study (Zhivov et al. 2009a; Herron et al. 2009; Deru et al. 2009).

The Wilderness Road area buildings, which were built from 2006 to 2010, were assumed to be EPAct 2005 compliant, and the Energy Use Intensities (EUIs) for these buildings were obtained directly from the USACE EPACT study.

The buildings to be built after 2012 were originally planned to be constructed to the EPACT 2005 standard. For the baseline case analysis, the EUIs for these buildings were also obtained directly from the USACE EPACT study.

DEVELOPMENT OF ALTERNATIVE CASES

Alternative cases were developed and technically and economically analyzed in this study with the following major objectives:

1. Increased the CAB area site energy use efficiency by reducing energy demands in newly constructed buildings to the levels required by the US Energy Independence and Security Act of 2007 (EISA). Energy usage of typical Army facilities built to comply with EISA energy reduction requirements was determined in a previous USACE EISA study (MILCON Energy Efficiency and Sustainability Study of Five Types of Army Buildings, June 2011.)
2. Provide thermal and electrical energy security (continuity of operations and leveling of future utility expense escalations) for the CAB area that meets all the mission critical electric loads at a higher reliability level. Based on discussions with Fort Carson personnel, the mission critical electricity demand for Fort Carson Airfield (CAB) area was determined to be 1 MW.
3. Provide primary heating and cooling for all the CAB buildings from a central heating and cooling plant. The CEP shall be optimized to consider a diversity factor of the combined coincident loads compared to the individual building non-coincident loads and to reduce energy waste with the generation of electricity. The CEP will initially use natural gas for fuel, but could eventually be transitioned to run on biomass or biogas generated through the on-site gasification of biomass such as woodchips, which potentially will result in an NZE CAB area by eliminating the need for fossil fuels.

Table 2. Building Energy Usage for CAB Facilities

Building Type	Typical Building Area, ft^2	Typical Building Area, m^2	EPACT 2005 EUI*, $kBtu/ft^2$	EPACT 2005 EUI, kW/m^2	EISA 2007-Ready EUI, $kBtu/ft^2$	EISA 2007-Ready EUI, kW/m^2
Dining facility	26,000	2415	415	1309	285	899
Barracks	39,890	3706	75	237	37	117
Admin/brigade headquarters (BdeHQ)/ battalion headquarters (BnHQ)	40,902	3800	66	208	49	155
Vehicle maintenance/ hangar maintenance	36,241	3367	55	174	25	79
Company operations facility (COF)	48,000	4459	49	155	20	63

Table 3. Peak Loads and Diversity Factor for the Alternative Building Case

	Heating & DHW (kBtu/h)	Heating & DHW (kW)	Cooling Electric (kBtu/h)	Cooling Electric (kW)	Electric (kBtu/h)	Electric (kW)
Coincident peak loads	38,234	11,205	4153	1217	25,495	7472
Non-coincident peak loads	50,382	14,765	4742	1388	29,833	8743
Diversity factor % (coincident/non-coincident)	76%		88%		85%	

4. Provide maintenance for all alternatives (and the base case scenario) at the levels prescribed by manufacturers, not based on current practices to eliminate or dramatically reduce the need for emergency repairs.
5. All alternatives considered for implementation must be life-cycle cost (LCC) positive.

BASELINE CASE AND ALTERNATIVE CASE BUILDING ENERGY USAGE AND LOAD PROFILES

For this study, all baseline case buildings were assumed to be EPACT 2005 compliant. The energy consumption of all buildings was determined by the USACE EPACT study. The energy consumption of alternative case buildings was determined by assuming that all existing buildings on the CAB site would perform as EPACT 2005 compliant buildings and that all newly constructed buildings were assumed to be constructed to EISA-ready standard as determined by the USACE EISA study. Table 2 lists the building energy usage for typical Army facilities at the CAB site.

Building design concepts for the CAB area new construction (barracks, hangars, administrative buildings, dining facility, etc.) were developed based on results of the two previous USACE studies (EPACT and EISA). The EUIs for these designs were estimated using EnergyPlus simulations on an hourly basis. The load profiles from the modeled facility types were then scaled and allocated to the facilities being constructed at the CAB. The base case with decentralized energy generation and alternatives with CEP options have been established using the same conceptual models of buildings: EPAct 2005 compliant for the base case, and a combination of EPAct 2005 compliant and EISA-ready for alternatives. The simulated energy use requirements of individual facilities have been used to develop architecture and size the equipment for the base case and energy generation alternatives for the CAB complex.

When buildings are interconnected, the peak loads will be smaller due to a diversity factor of the combined loads compared to the non-coincident loads. Therefore, the design size of the equipment to meet the highest peak load will be smaller than the sum of design sizes for a decentralized system approach.

The hourly simulation gives the load profile for the cluster and identifies the diversity factor to properly size the equipment for the cluster. Table 3 lists the sum of the individual building peak loads (the non-coincident peak load), the building cluster simultaneous peak loads (the coincident peak load), and the diversity factor for heating and DHW, cooling, and electric loads for the cluster for the load profiles used for the alternative cases (combination of EPAct 2005 compliant and EISA-ready). The decentralized heating loads would require the total installed primary heating equipment capacity

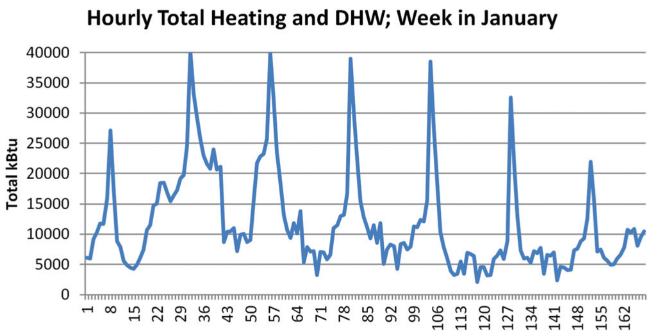

Figure 2 *Total heating—for 60 CAB buildings in alternative case.*

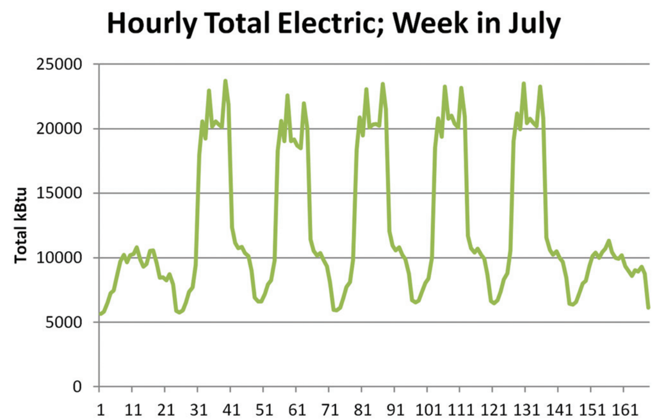

Figure 4 *Total electric—for 60 CAB buildings in alternative case.*

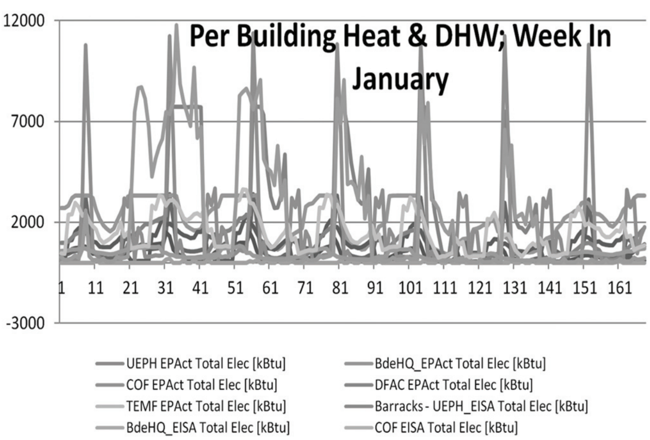

Figure 3 *Example individual building heating—alternative building case.*

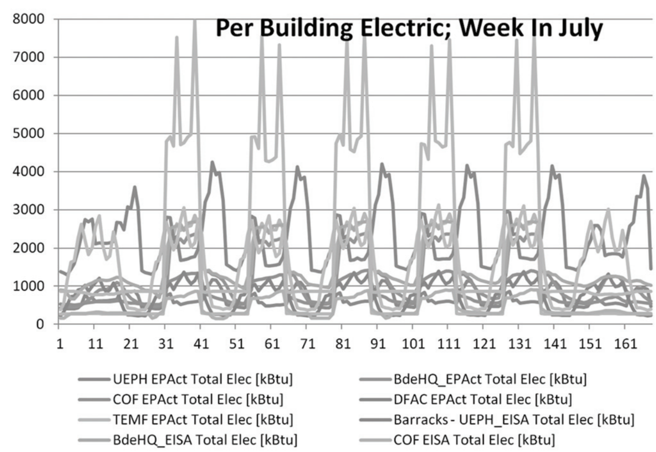

Figure 5 *Example individual building electric—alternative building case.*

to be approximately 32% larger to meet the minimum heating loads for all of the buildings served individually. Similarly, individual building cooling equipment would have a total installed primary cooling equipment capacity approximately 14% larger than the cooling equipment capacity sized for the peak cooling capacity of the building cluster. Applying typical design safety factors to these peak loads would make these differences even larger.

Figures 2 and 3 show a typical total heating demand profile for the 60 total buildings and for example individual buildings for the CAB Alternative Case for a week in January.

Figures 4 and 5 show a typical total electrical demand profile for the 60 total buildings and for example individual buildings for the CAB Alternative Case for a week in July.

Table 4 lists loads for the alternative case buildings connected to a CEP. Again, these loads are based on simulation results from the USACE EPACT study for all existing buildings, and from the USACE EISA study for all new buildings to be constructed starting FY12. Figure 6 shows 8760 hourly load curves derived from this demand data for the annual distribution of loads.

DERIVING AREA LOAD PROFILES

A system relying on cogeneration was examined as a general approach towards NZE supply. Heat for DHW and space heating is generated in a high efficiency combined heat and power (CHP) plant, so that a certain share of the required electrical power can also be generated on site. The centrally produced heat is distributed via a district heating (DH) system to individual buildings. The generation of cooling from heat (tri-generation) was also considered to enable the cogeneration plant to be operated at full capacity almost year round (not only in winter). In an additional district cooling (DC) system, absorption chillers can use heat to generate chilled water, to be distributed by the DC network. The use of heat to generate cooling has the double advantage of:

- increasing the share of on-site-produced electricity by allowing the CHP equipment to be operated at higher equivalent full load hours;
- reducing electricity demand for cooling because absorption chillers can replace a certain share of the electrical chillers.

Table 4. Loads on CEP for 60 Alternative Case Buildings

Load	Peak Load		Total Demand	
Electricity w/o Cooling	21,496,406.4 Btu/h_{el}	(6.3 MW_{el})	84,347,804,160 Btu_{el}	(24,720 MWh_{el})
Cooling Load	15,013,363.2 Btu/h_{cool}	(4.4 MW_{cool})	42,651,600,000 Btu_{cool}	(12,500 MWh_{cool})
Heating	34,121,280.0 Btu/h_{th}	(10.0 MW_{th})	35,554,373,760 Btu_{th}	(10,420 MWh_{th})
DHW	13,307,299.2 Btu/h_{th}	(3.9 MW_{th})	13,580,269,440 Btu_{th}	(3,980 MWh_{th})
Heating and Cooling	38,234,112.3 Btu/h_{th}	(11.2 MW_{th})	48,728,833,499 Btu_{th}	14,281 MWh_{th}

Both of these factors will help to increase the energy efficiency of the Fort Carson Airfield energy system significantly—more than a decentralized heating and cooling system could. The CHP plant can generate electricity at a much higher efficiency than would a conventional utility power plant that feeds into a transmission grid. The use of co-gen heat (rather than conventionally produced electricity) to produce cooling increases the overall system's efficiency.

As a first step in the study, load curves were derived for the six different demand types: (1) heating, (2) hot water, (3) electrical chillers, (4) heating, ventilating, and air-conditioning (HVAC) fans, (5) electrical equipment, and (6) lighting, based on the demand at the final stage of installation development (60 buildings = 100% of building area). Each of the six load curves is then scaled down for the five stages of development. This results in 30 sets of load data. Downscaling is based on the data of square footage for each building type in the different stages. Sorted load duration curves are derived from the 30 sets of load data to show the increase in the different demand types as the number of buildings grows.

Figure 6 shows example load profiles derived from the cluster of the buildings and an overview of important information that may be used to size different scenarios and to size a central plant.

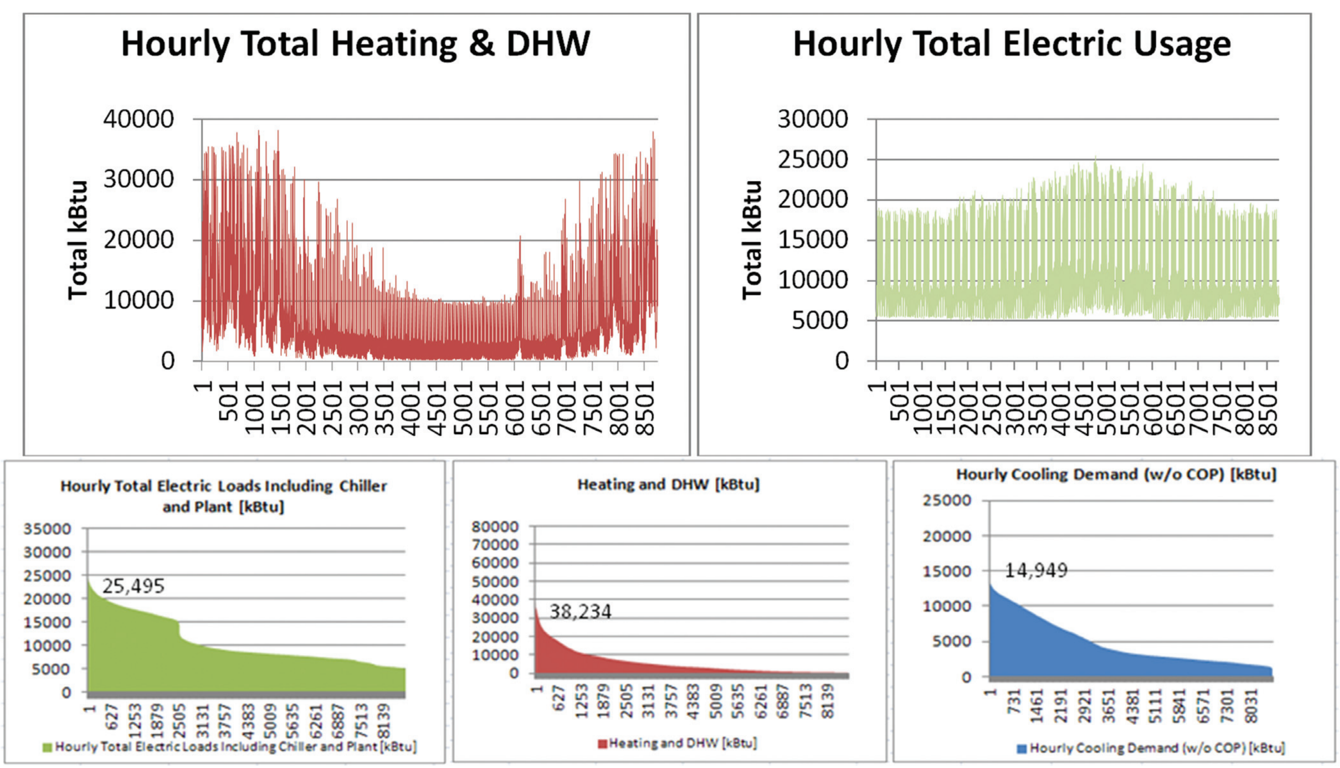

Figure 6 Load profiles—new buildings built to EISA-ready specifications; all other buildings to Epact specifications.

ALTERNATIVES FOR ENERGY GENERATION EQUIPMENT AND DH NETWORK

Four alternatives for generation equipment were considered:

- **Alternative 1.** One gas turbine plus natural gas boiler(s) for peak load and redundancy.
- **Alternative 2.** Two internal combustion engines plus natural gas boiler(s) for peak load and redundancy.
- **Alternative 3.** One large woodchip boiler with steam turbine sized to meet the entire CAB area load plus additional capacity that could provide power to elsewhere on Fort Carson. Natural gas boilers would be provided for redundancy.
- **Alternative 4.** One woodchip boiler feeding a steam turbine sized to exceed the average annual CAB electrical loads and pulling extraction steam to meet the peak heating loads plus a back up bio-diesel generator, with heat recovery, sized to meet the critical electrical load of 1MW plus a natural gas boiler for heating redundancy.

Alternative 1 uses a small gas turbine (Figure 7) with a thermal capacity of 8800 kBtu/h (2579 kW), and an electrical capacity of 1160 kW (in which the ratio of heat production to electricity production is about 2:1). The gas turbine was sized to fit the total heating duration curve. The heat is mainly used for heating and DHW production. Part of the high temperature heat is also used in absorption chillers to generate a share of the cooling demand.

The main advantage of using a gas turbine is that it can produce higher temperatures, which make it possible to operate absorption refrigeration equipment to be operated at a higher efficiency. The main disadvantage of gas turbines is that they are currently not able to use fuels other than natural gas or bio synthetic natural gas (bio-SNG) because they require gases of high purity and calorific value as a fuel. If, in the future, syngas from woody biomass can also be purified to natural gas grid standards, syngas will also be a fuel option.

Bio synthetic natural gas, also called bio methane, is biogas obtained by fermentation from liquid manure, sewage, grain, or corn. The raw biogas is then cleaned and concentrated to achieve the same characteristics as natural gas (calorific value, content of sulfur, CO_2, artificial odor, etc.). The quality characteristics of the refined biogas allow it to be fed into the natural gas grid for transportation to the site of intended use.

Alternative 2 uses two internal combustion engines plus natural gas boiler(s) for peak load and redundancy (Figure 8). The size of the CHP engines was chosen to fit the total heating load duration curve. Each CHP engine has a thermal capacity of 6125×10^3 Btu/h and an electrical capacity of 1505 kW (heat to electricity ratio of 1.2:1). One CHP engine alone can cover the mission critical electrical demand of 1 MW at Fort Carson Airfield, so Alternative 2 has the advantage of additional supply security. Another advantage is the possible modularity of Alternative 2; one engine can be installed in an early phase of Airfield development and the second one added as the installation grows.

Figure 9 shows the annual load duration curve for the generation of heat in Alternative 2. One CHP module will be able to operate more than 8000 full equivalent hours, and the second module will operate about 6000 full equivalent hours. The heat from the CHP engines will be used to supply heating and DHW as well as heat for cooling via absorption chillers. Heat for cooling will only be supplied by the CHP engines, not from boilers. The gas boilers will used to cover peak demand

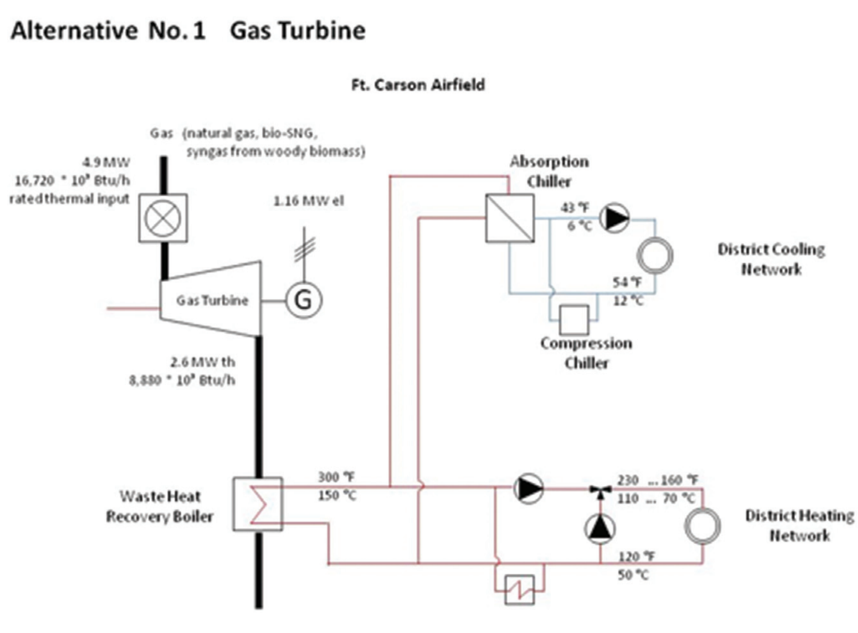

Figure 7 *Schematic alternative no. 1—gas turbine.*

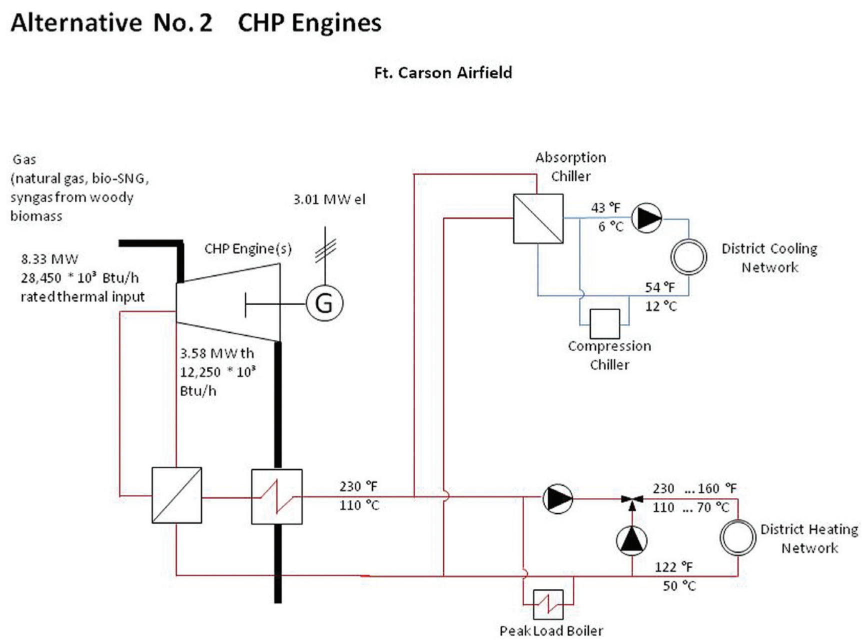

Figure 8 *Schematic alternative no. 2—CHP engines.*

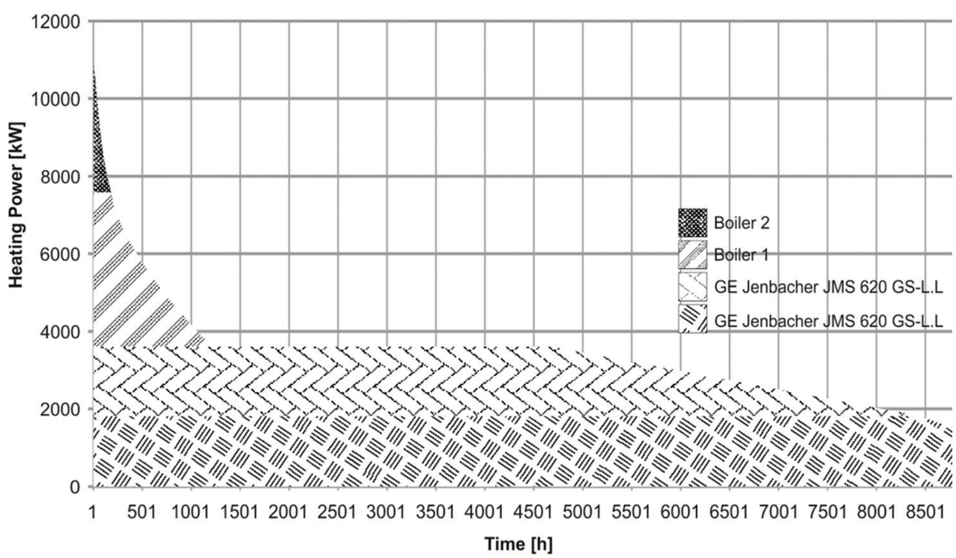

Figure 9 *Distribution of heating generation for alternative no. 2.*

for heating and DHW. The economic performance of a system that uses engines for CHP generation can generally be improved by including a heat store for short-term storage (i.e., several hours or days). The integration of a heat store enables CHP engines to operate at a favorable working point for longer periods. Therefore, the first cost estimate for Alternative 2 includes a pressurized heat store.

Alternative 3 includes the use of a large woodchip boiler and steam turbine (Figure 10). The main advantage of this alternative is that wood can be used as a renewable fuel. The steam turbine was sized ($52{,}000 \times 10^3$ Btu/h thermal capacity, 5.2 MW el) to accommodate the critical electricity load at Fort Carson Airfield plus the main cantonment (~5 MWel). The main disadvantage of Alternative 3 is that the ratio of heat to electricity production is only 3:1. This means that heat production is much higher than heat demand at the CAB, especially during the summer months. However, the excess heat from the woodchip boiler

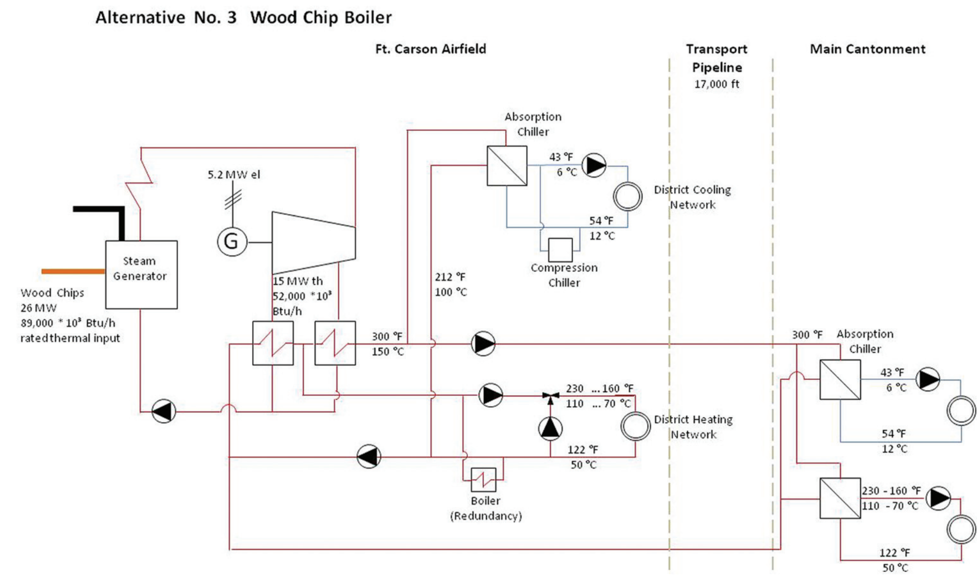

Figure 10 *Schematic alternative no. 3—wood chip boiler.*

can be exported to another heat sink. The idea is to transport the heat to the main cantonment at a high temperature level so that it can be used for chilled water production or can be fed into the local heating network.

Alternative 3 does not include a seasonal heat store.

Alternative 4 includes the use of a smaller woodchip boiler that feeds a steam turbine with extractions for heating (Figure 11). The boiler will include burners that can use natural gas heating, as a backup to woodchips, to achieve the rated output. A bio-diesel fueled CHP reciprocating engine/generator will provide critical load redundancy (1MW and 4060 × 10^3 Btu/h thermal capacities). Alternative 4 also includes a redundant boiler sized for the average annual heating load. The advantage of Alternative 4, like Alternative 3, is that wood (biomass) and bio-diesel are renewable fuels that allow Alternative 4 to operate at "100% NZE."

The size of the steam turbine (36,203 × 10^3 Btu/h thermal capacity, 3.0 MWel) exceeds the average annual electrical load at the CAB. The excess electricity can be transported through Fort Carson's electrical distribution system to offset the approximately 10% annual natural gas usage required to maintain the standing pilot and for startup and shutdown of the unit. The main disadvantage of Alternative 4 is that the heat production is much higher than the heat demand at the CAB, especially during the summer months. Waste heat will need to be expelled though finned fan coolers, or could be used for other process uses.

Distribution piping. A rough draft network layout was developed for the centralized generating equipment based on the site (green on the map shown in Figure 1). The envisaged network consists of two separate piping systems, one for heating and one for cooling. Temperatures for the DH network are assumed at 230°F/110°C for the supply temperature and at 122°F/50°C for the return temperature. The DC network temperatures are assumed at 43°F/6°C for supply and at 54°F/12°C for return. Maximum pipe size and average pipe size were estimated based on maximum loads for heating and cooling and on temperature differences between supply and return pipes (60 K for heating, 6 K for cooling). A temperature difference of 40 K was assumed for the export pipeline, the supply temperature being 300°F/150°C and the return temperature 230°F/110°C.

Alternative 3 differs from the other alternatives in that its heat generation equipment is not sized to the heat demand of the 60 buildings within the spatial boundary of the Fort Carson Airfield energy system, but to the electricity load at the Airfield plus the main cantonment. The woodchip plant produces excess heat that will be exported beyond the system boundary. The primary energy of the export will be evaluated with a Primary Energy Fluence (PEF) of the energy it replaces outside the system boundary. Exported energy that replaces decentralized natural gas heating will be evaluated with a PEF of 1.05; exported energy that replaces electrically driven compression chillers by absorption chillers will be evaluated with a PEF of 3.34.

In Alternative 3, excess heat is exported to the main cantonment outside the Fort Carson Airfield site. The export pipeline marked red on the map in Figure 1. The length of the network in the CAB area is estimated at 28,500 ft (8687 m). The length of a transportation pipeline (as necessary for Alternative 3) is assumed to be 17,000 ft (5182 m).

FIRST COST OF ALTERNATIVES

An estimate of first costs was prepared for all four alternatives based on the assumptions outlined above. Euros were converted to US dollars at an assumed exchange rate of 1.4.

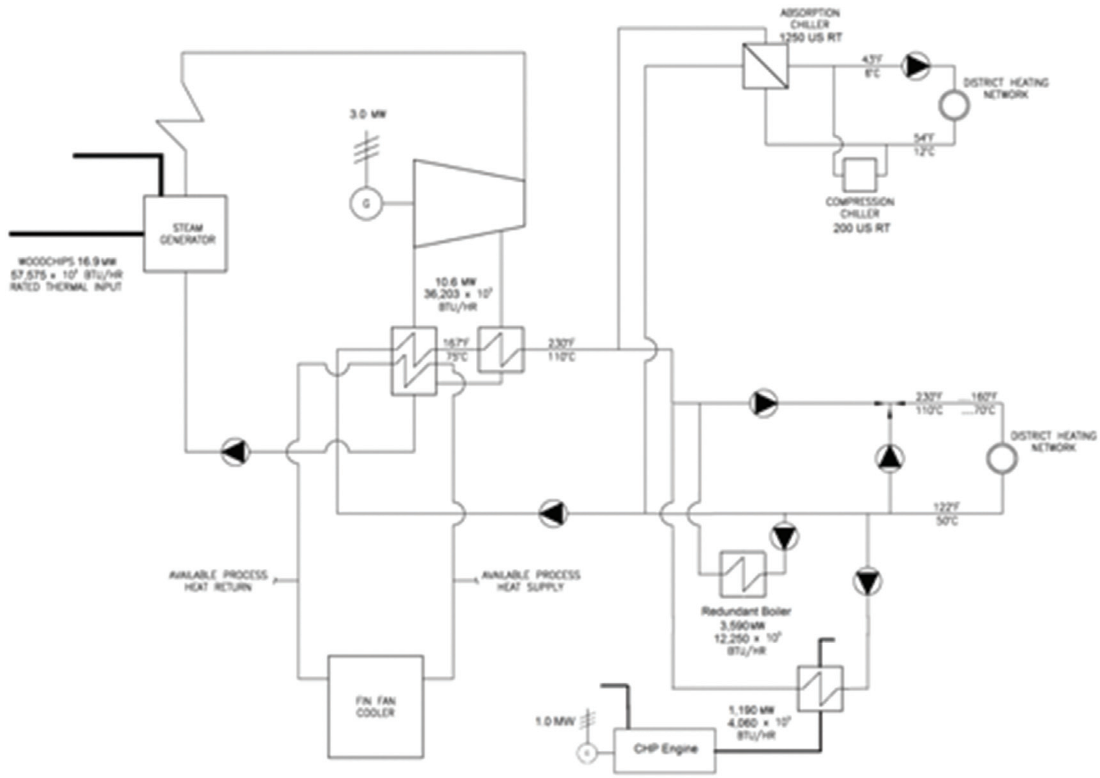

Figure 11 *Schematic alternative no. 4—wood chip boiler.*

First costs are listed separately for heating equipment, cooling equipment, and construction of DH/DC networks. Total first costs are roughly equal for Alternatives 1 and 2, while Alternative 3 has more than double the first costs due to the need for a heat export pipeline and the surplus of renewable electricity generation capacity:

1. Alternative 1—Gas Turbine $25.5 million US
2. Alternative 2—CHP Engines $25.4 million US
3. Alternative 3—Large Woodchip Boiler $77.4 million US
4. Alternative 4—Small Woodchip Boiler $43.9 million US.

Tables 5 to 8 list the details for the first cost estimates.

Building the heating and cooling network will require the largest part of the investment ($14 million US) as compared with the heat generation ($9.6 million US) and the cooling equipment ($1.9 million US) for the CEP. Yet building these networks and using tri-generation will make it possible to achieve large savings in electrical costs by Cooling/DN 150 6 in.reducing electrical chilling capacity and generating a considerable share of electricity on site.

ENERGY BALANCE AND COST COMPARISON OF ALTERNATIVES

As a first step to achieve a net zero primary energy balance, a general energy balance at the CAB area was analyzed for each alternative to determine how much fuel of which type will be needed to satisfy the respective demands for heating, cooling, and electricity. To increase overall system efficiency, it is imperative to use all (or almost all) heat that is generated when producing electricity. In winter, the heat is primarily used for heating; in summer, it can be used for cooling with absorption chillers (heat for cooling). Depending on the size and type of the electricity generation equipment in the alternative scenarios, the share of cooling that will be generated from heat (absorption chillers) or from electricity (compression chillers) will differ. The more co-generated heat is available, the more cooling can be generated by absorption chillers.

In Alternatives 1 and 2, the cogeneration equipment for heat production was sized to meet the heat demand at the Fort Carson CAB (for absorption chillers in summer and heating in winter), and to achieve at least 6000 equivalent full load hours to improve the economic feasibility of the alternatives. However, there is not enough heat to cover the total cooling demand with absorption chillers. Therefore a certain share of cooling demand will have to be covered with electrical compression chillers. In Alternative 1, about half the cooling demand still must be provided from electrical chillers; in Alternative 2, compression delivers about one third of cooling demand. In Alternative 1, on-site generation can provide only 36% of the Airfield's electricity demand, while Alternative 2's on-site share is 88%. Alternative 3 requires hardly any elec-

Table 5. Overview First Costs of Alternative No. 1 Gas Turbine

	P_{el} (kW)	P_{th} (kW	P_{th} (kBtu)	Spec Costs (€)	Spec Costs ($)	First Costs ($)
Gas turbine Solar Saturn 20	1160	2600	8900	2800 €/kW$_{el}$	3920 $/kW$_{el}$	4,547,000
Peak load boiler		17,600	16,100	60 €/kW$_{th}$	25 $/kW$_{th}$	1,478,000
Buildings						840,000
Elec. measuring and control system						700,000
Pressure threshold system						700,000
Water treatment						210,000
Pumps						560,000
Piping						560,000
Total heat						9,595,000
			P cooling (ton)		Spec Costs ($/ton)	First Costs ($)
Absorption chillers (including pumps, cooling tower)			460		2100	966,000
Electrical chillers (all incl.)			980		1000	980,000
Total cooling						1,946,000
	Distance (m)		Distance (ft)	Spec Costs (€/m)	Spec Costs ($/ft)	First costs ($)
Heating/DN 100 4 in.	8700		28,500	500	213	6,071,000
Cooling/DN 150 6 in.	8700		28,500	650	277	7,895,000
Total network						13,966,000
Total first cost						25,507,000

tricity for compression chillers, but needs more electricity to power pumps to export the excess heat to the main cantonment. The share of on-site generation for Alternative 3 is 153%. Alternative 4 is based on a single wood-fired boiler feeding a steam turbine. The steam boiler is sized to exceed the annual electrical load of the CAB and should provide excess generation to the electrical grid to offset natural gas usage. In Alternative 4, heat production is higher than the average heat demand at the CAB, especially during the summer months. Waste heat will need to be rejected though finned fan coolers, or it could be used for other process uses such as providing for snow melt under the helicopter pads and walkways, or for glycol deicing of planes during the winter and heating for vehicle washing during the summer.

After considering the results of this preliminary analysis above, Alternative 2 was selected for further consideration for implementation at the Fort Carson CAB site. Alternative 2 was the least-first-cost alternative, and it also has a minimal requirement for additional electrical energy generation by photovoltaic (PV) panels or other renewable sources (compared to Alternative 1), it has no additional waste heat that must be transported to the main Fort Carson cantonment (Alternative 3).

Table 9 lists the cost and energy results for the baseline case and Alternative case 2. Table 10 summarizes the net zero primary energy balance for Alternative 2.

As proposed, Alternative 2 reduces the CAB site energy by 4% and reduces source energy (fossil fuel use) by 66% compared to the base case. When economically justified, switching the fuel used for the CHP from natural gas to syngas and adding a small amount of renewable energy electrical generation become the last steps to achieving the area NZE goal.

CONCLUSION

To cost effectively achieve net zero energy in a building complex requires a significant reduction in energy use compared to the current minimum energy performance standard. Newly constructed buildings must be built to meet EISA-

Table 6. Overview First Costs of Alternative No. 2 (CHP Engines)

	P_{el} (kW)	P_{th} (kW	P_{th} (kBtu)	Spec Costs (€)	Spec Costs ($)	First Costs ($)
CHP engines	3010	3580	12,200	930 €/kW$_{el}$	1300 $/kW$_{el}$	3,919,000
Peak load boiler		12,000	41,000	60 €/kW$_{th}$	25 $/kBtu	1,008,000
Buildings						840,000
Elec. measuring and control system,						700,000
Pressure threshold system						700,000
Pressurized heat store (500 m^3/17,650 ft^3)				1000 €/m^3	40 $/cu ft	700,000
Water treatment						210,000
Pumps						560,000
Piping						560,000
Total heat						9,197,000
			P cooling (ton)		Spec Costs ($/ton)	First Costs ($)
Absorption chillers including pumps, cooling tower			650		2100	1,365,000
Electrical chillers (all incl.)			900		1000	900,000
Total cooling						2,265,000
	Distance (M)		**Distance (Ft)**	**Spec Costs (€/m)**	**Spec Costs ($/ft)**	**First Costs ($)**
Heating/DN 100–4 in.	8700		28,500	500	213	6,071,000
Cooling/DN 150 6 in.	8700		28,500	650	277	7,895,000
Total network						13,966,000
Total first cost						25,428,000

ready site energy use intensity (USACE EISA study), and all older buildings be renovated to the achieve at least the EUI specified by EPACT 2005 (USACE EPACT). This can be accomplished by using high-performance building envelopes (improved insulation and airtightness), advanced lighting strategies, and efficient HVAC systems, which together will result in significant (site and source) energy savings in all climate conditions. For example, barracks site energy can be reduced by 50%–70% (depending on climate) compared to the EPACT 2005 baseline; maintenance facilities by 77%–85%, brigade headquarters by 32%–82%, etc. However, source energy use reduction goals of EISA 2007 (beginning in 2015) cannot be achieved by any type of building — except for maintenance facilities in some climate zones.

Furthermore, heating and cooling energy generation systems should be consolidated in CEP(s) serving a cluster of buildings, which will result in: (1) reduced overall energy generation capacity accounting for a diversity of heating and cooling loads in buildings comprising the cluster, (2) equipment redundancy, (3) reduced maintenance costs, (4) reduced waste heat resulting from on-site electrical power generation, and, therefore, (5) reduced use of fossil fuel-based source energy.

In addition to fossil fuel reduction, CHP on-site generation provides required energy security and significant energy cost reduction. Switching fuel for CHP generation from natural gas to syngas, when economically justified, becomes the last step to achieving the area NZE goal. Using a CEP in such a manner avoids the use of more expensive non-dispatchable renewable energy sources such as wind or solar power generation (along with energy storage e.g., batteries).

With the reduced thermal energy needs for buildings, the CEP plant energy generation architecture, which includes two CHP modules with natural gas-fired engines, and peaking boilers combined with absorption chillers and thermal storage, was found to be the preferred alternative to make the new CAB area at Fort Carson "net zero ready."

Table 7. Overview First Costs of Alternative No. 3 Wood Chip Boiler

	P_{el} (kW)	P_{th} (kW	P_{th} (kBtu)	Spec Costs (€)	Spec Costs ($)	First Costs ($)
Biomass boiler including steam turbine and buildings	5200	15,000	52,000	6000 €/kW_{el}	8400 $/$kW_{el}$	43,680,000
Peak load boiler		5000	17,100	60 €/kW_{th}	25 $/kBtu	420,000
Pressure threshold system						700,000
Water treatment						200,000
Pumps for heat transport						600,000
Total heat						45,600,000
			P cooling (ton)		**Spec Costs ($/ton)**	**First Costs ($)**
Absorption chillers at Fort Carson Airfield including pumps, cooling tower			1290		2100	2,709,000
Electrical chillers cooling tower at Fort Carson Airfield (redundancy – all incl.)			150		1000	150,000
Absorption chillers at main Cantonment including pumps, cooling tower			2290		2100	4,809,000
Total cooling						7,668,000
	Distance (m)		**Distance (ft)**	**Spec Costs (€/m)**	**Spec Costs ($/ft)**	**First Costs ($)**
Heating/DN 100–4 in.	8700		28,500	500	213	6,071,000
Cooling/DN 150 6 in.	8700		28,500	650	277	7,895,000
Transport pipeline to main Cantonment	5200		17,100	1400	597	10,209,000
Total network						24,175,000
Total first cost						77,443,000

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Table 8. Overview First Cost of Alternative No. 4 Woodchip Boiler with Diesel CHP

	P_{el} (Btu/min)	P_{el} (kW)	P_{el} (Btu/min)	P_{th} (kW)	P_{th} (kBtu)	Spec Costs ($/Btu/min$_{el}$)	Spec Costs ($/kW$_{el}$)	First Costs ($)
Biomass boiler including turbine, generator, controls, storage bunker, conveyors, air pollution controls, switch gear, and stack	170,760	3000	604,490	10,620	36,240	398,440	7000	21,000,000
CHP engine (bio-diesel)	56,920	1000	67,735	1190	4060	73,996	1300	1,300,000
Redundant boiler			204,343	3590	12,250	1423	25	306,250
Buildings								2,200,000
Pressure threshold system								700,000
Water treatment								200,000
Piping								560,000
Elect. Measuring and control system								700,000
Total heat								26,966,250
				P cooling (kBtu)	P cooling (ton)	Spec Costs (€/kBtu)	Spec Costs ($/ton)	First Costs ($)
Absorption chillers including pumps, cooling tower				15,000	1250	17,728	2100	2,625,000
Electrical chillers (all included)				2400	200	12,663	1500	300,000
Total cooling								2,925,000
				Distance (m)	Distance (ft)	Spec Costs (€/m)	Spec Costs ($/ft)	First costs ($)
Heating/DN 100–4 in.				8687	28,500	492	213	6,070,500
Cooling/DN 150 6 in.				8687	28,500	639	277	7,894,500
Total network								13,965,000
Total first cost								48,856,250

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Table 9. Comparison of Alternative 2 with the Base Case

Option	First Cost ($Mil)	Annual Maint. Cost ($)	Annual Energy Cost ($)	Site Energy (kWh)	Source Energy (kWh)	LCC Present Value ($)	SPB (years)
Base case	2.5	800,000	3,321,114	70,126,355	160,465,154	126,265,893	NA
Alt 2	25.4	300,000	2,399,793	67,222,000	70,381,434	99,215,004	12

Note: the base case included higher loads for new construction than the alternative case

Table 10. Energy Balance for Alternative 2

1. Generation of heat a. 2 X BHKW GE Jenbacher JMS 620 GS-L.L						
Capacity						
Electrical capacity	3010 kW_{el}			Electricity generation	23,176,000 kWh_{el}/a	
Electrical efficiency	36.2%					
Thermal capacity	3580 kW_{th}	12,250 $kBtu_{th}$/h		Heat generation	27,529,000 kWh_{th}/a	94,016,000 $kBtu_{th}$/a
Thermal efficiency	43.0%					
Rated thermal input	8330 kW	28,450 kBtu/h		Fuel use	64,021,000 kWh_{th}/a	218,643,000 $kBtu_{th}$/a
b. 3 x boiler, natural gas						
Capacity				**Energy**		
Thermal capacity	12,000 kW_{th}	40,980 $kBtu_{th}$/h		Heat generation	2,706,000 kWh_{th}/a	9,241,000 $kBtu_{th}$/a
Thermal efficiency	85%					
Rated thermal input	14,120 kW	48,220 kBtu/h		Fuel use	3,183,000 kWh/a	10,871,000 kBtu/a
2. Generation of cooling a. Absorption chiller						
Capacity				**Energy**		
Cooling capacity	2300 kW_{cool}	7800 $kBtu_{cool}$/h	650 $tons_{cool}$/h	Cooling generation	8,739,000 kWh_{cool}/a	28,819,000 $kBtu_{cool}$/a
COP	0.65					
Thermal capacity	3600 kW_{th}	12,000 $kBtu_{th}$/h		Heat use	13,445,000 kWh_{th}/a	
b. Compression chiller						
Capacity				**Energy**		
Cooling capacity	3200 kW_{cool}	10,800 $kBtu_{cool}$/h	900 $tons_{cool}$/h	Cooling generation	3,777,000 kWh_{cool}/a	12,888,000 $kBtu_{cool}$/a
COP	3					
Electrical capacity	1100 kW_{el}	3600 $kBtu_{el}$/h		Electricity use	1,259,000 kWh_{el}/a	

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DISCUSSION

Robert Besant, Professor, University of Saskatchewan, Saskatoon, SK, Canada: How did you select the most accurate air infiltration rate for the buildings you used in your study?

R.J. Liesen: Since the Army Corps has an air sealing requirement of 0.25 cfm/ft^2 at 75 Pa and a leakage test at the end of construction, this requirement is selected as the air infiltration rate once the value has been converted to EnergyPlus inputs. The requirement and the air leakage testing procedure can be found in engineering construction bulletins at the following websites:

- http://www.wbdg.org/ccb/ARMYCOE/COEECB/ecb_2012_16.pdf
- http://www.wbdg.org/ccb/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf