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January 3, 2012

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Thank you for your time and contribution to ASHRAE literature.

CH-12-007

Net Zero Building Cluster Energy Systems Analysis for U.S. Army Installations

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ABSTRACT

The Army is required by law (EPACT 2005, EISA 2007) to eliminate fossil fuel use in new and renovated facilities by 2030 and to reduce overall facility energy usage by 30% by 2015. Army policy is to achieve eight net zero energy pilot installations by 2020, 25 net zero energy installations by 2031, and for all installations to achieve net zero energy status by 2058.

Achieving Net Zero Energy (NZE) will only be possible if an optimum mix of demand reduction and renewable sources are put in place at a community (installation) or building cluster scale. The Army operates what are essentially small campuses, or clusters of buildings on its installations. The US Department of Energy (DOE) is focused on the national grid scale or on individual buildings, while the commercial focus is on retrofits to individual buildings. There are only few case studies worldwide that address dynamics of energy systems at the community scale, and to date, there is a lack of tools to perform that task. The building stock at most US Army installations is complex and includes a mix of high and low energy use buildings. Energy use in these buildings varies due to the different military mission and requirements for each building, installation growth and expansion, and soldier deployment. Achieving net zero energy economically at such installations will require a seamless blend of energy conservation in individual buildings and building systems automation, utility management and control, and power delivery systems that have the capability to offer integration of on-site power generation (including renewable energy sources).

This paper describes the Net Zero fossil fuel based energy optimization process and illustrates it with an example based on the results of study conducted for a cluster of buildings at Fort Irwin, CA. The integrated optimization process is being developed under the Army research and development project "Modeling Net Zero Installations - Energy (NZI-E)" and the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) Annex 51. The process is stepped, beginning with the optimization of each building to achieve the most cost effective energy efficient optimization of building envelope and energy using systems. Then energy saving measures affecting the total building cluster are optimized taking advantages of the diversification between energy intensities, scheduling, and waste energy streams utilization. The energy demands of the resulting energy-use optimized cluster will require the minimum sized renewable energy system needed to make the building cluster Net Zero fossil fuel energy.

ARMY ENERGY POLICY OVERVIEW

Buildings contribute to a large fraction of energy usage worldwide. In the United States alone, buildings consume about 40% of total energy, including 71% of electricity and 54% of natural gas.[1] The Army alone spends more than $1 billion for building-related energy expenses. The Army Energy Security Implementation Strategy [2] sets the general direction for the Army including elimination of energy waste in existing facilities, increase in energy efficiency in new construction and renovations, and reduced dependence on

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fossil fuels. The 2005 Energy Policy Act [3] requires that Federal facilities be built to achieve at least a 30% energy savings over the 2004 International Energy Code or ASHRAE Standard 90.1-2004, as appropriate, and that energy efficient designs must be life-cycle cost effective. According to the Energy Independence and Security Act (EISA 2007) [4], new buildings and buildings undergoing major renovations shall be designed to reduce consumption of energy generated off-site or on-site using fossil fuels, as compared with such energy consumption by a similar building in fiscal year 2003 (FY03) as measured by Commercial Buildings Energy Consumption Survey (CBECS) or Residential Energy Consumption Survey (RECS) data from the Energy Information Agency, by 55% in 2010, 80% by 2020, and 100% by 2030.

Currently most research efforts in the United States are made in the area of renewable energy sources with some attention being paid to energy efficiency for single buildings. The building stock at most Army installations is complex and includes a mix of buildings with low and high energy use; energy use in these is diverse due to nature of building usage and to the dynamic growth of buildings and installations through BRAC and MILCON Transformation Programs, soldier deployment, and mission change. Researchers have paid little attention to integration and minimization of energy use in building communities, i.e., Army installations and university campuses.

In an increasingly energy constrained world, the Army and its logistic support envisions a future where its energy needs are designed and fulfilled by a suite of ultra-low-energy solution options that can be tailored for adaptation at any Army installation depending on climatic zone, mission needs, mix of building types, availability of different sources of renewable energy, etc. Presently, there is no over arching "power delivery/energy storage/demand" architecture and methodology to accomplish this. Commanders must also have the capability to meet their energy use reduction goals alongside a host of other high priority requirements such as energy security, affordability, environmental footprint, occupant well-being and productivity, and building sustainability (as appropriate), depending on the threat conditions, mission needs, utility market prices, etc.

INTEGRATED OPTIMIZATION PROCESS

Introduction

The Army is rapidly changing its views on energy usage to reconsider energy conservation and efficiency [15]. Army installations are essentially small campuses, comprised of clusters of buildings. Energy efficiency requires serious tracking of all waste energy flows, their use, and their storage within the "installation boundaries," with consideration of realistic thermodynamic constraints for all rejected energy (e.g., recovery and reuse of heat in cogeneration processes). Accomplishing these ends is neither straightforward nor inexpensive. The implementation of improved standards and increased energy efficiency in individual buildings can help those buildings become more energy-efficient, but it is difficult to achieve Net Zero Energy (NZE) goals by improving individual buildings in isolation. Net Zero Energy cannot be met with efficiency increases alone; there must be efficiency gains on the conversion, supply, and distribution side as well. Achieving NZE cost effectively will be possible if an optimum mix of demand reduction, energy distribution, energy supply, and renewable sources are put in place at a community (installation) or building cluster scale.

The knowledge base needed to build, renovate, and maintain Army installations with the highest levels of energy efficiency do not penetrate far enough into the market. Many technologies [6,7] are available to improve building energy efficiency related to the building envelope, ventilation, advanced "low exergy" heating and cooling systems, central energy plants with co- and tri-generation, hybrid, and high efficient lighting systems designs and technologies, integrated solar thermal and electrical systems, etc. Economies of scale can make many technologies (e.g., cogeneration or combined heat and power, waste heat recovery, biomass, geothermal energy, solar heating and cooling, etc.) more efficient — in both technical and economic terms — when used in large rather than small or individual building systems. Taking advantage of these technologies will enable optimized systems to reduce primary (both demand and supply) energy consumption to the best available standards, and to lower costs.

Community energy planning and central system's optimization does not require new tools. In the past central energy system designers used hydraulic and thermal optimization tools to design the components of the energy supply system for a combined heating and power plant using an "optimization strategy." This strategy can be used for both heating and cooling systems. These tools and this approach are rarely used by community energy planners, but is an important feature necessary in community-wide energy planning to integrate supply and demand to achieve an optimized solution. The objective in applying the principles of such a holistic approach to community energy is to provide such necessary methods and instruments to master planners, decision makers, and stakeholders.

Thermal Energy Systems consist of three major elements: energy generation, energy distribution, and energy demand (Figure 1).

The goal is to find the optimum balance for the entire energy system where each element requires consideration. This process can be outlined in a several step analysis:

- **Site Setup and Analysis.** Determine building locations, geography, utility locations, etc.
    - *Gather Building Energy Data for Benchmarking*. Gather utility bills, available energy demand data, etc., for all new and existing buildings.
    - *Characterize All Buildings in Inventory.* Determine the building type and use characteristics

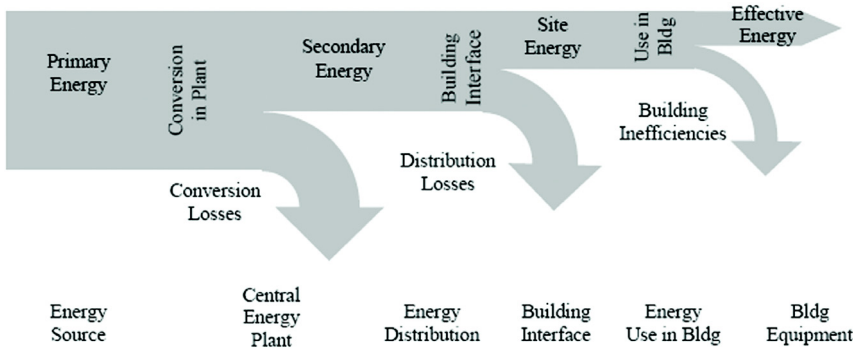


Figure 1 *Energy supply chain from primary energy to its use inside a building.*

and determine appropriate building model to simulate for demands.

- *Pre-Planning and Data Gathering*. Gather all building and site data from stakeholders and partners. Gather all of the data with no pre-conceived answers.

- **Building Simulation.** Simulate base and efficient cases for each building type selected in the site inventory: (1) *Determine Baseline Model*. Simulate each building classification type identified in the building characterization step from the inventory; (2) *Energy Efficiency Measures (EEM)*. Determine the appropriate building energy efficiency measures for each simulated building type; (3) *Simulate the Energy Efficiency Cases*. Simulate the energy efficiency scenarios and produce the optimization curve for each building type; (4) *Generate the EEM Project List*. During the optimization process, generate the project list to bring the building to net zero ready status; (5) *Produce Building Energy Use Profiles with Peaks*. Develop hourly, monthly, and annual use profiles for all demand energy.
- **Distribution and Supply Optimization.** Take data from the building efficient cases to set up the load and network design to determine the optimal distribution and supply network: (1) *Integrate All Building Energy Demands*. Use the efficient case for the building cluster to be analyzed; (2) *Develop Load Duration Curves*. Integrate all energy demands for the building cluster to be optimized and produce curves; (3) *Use Hydraulic Simulation.* Develop the hydraulic parameters for integrated heating and/or cooling systems; (4) *Determine the Supply Equipment Inventory.* Determine all of the existing and planned boilers, chillers, solar thermal, generators, renewables, etc. locations, sizes, age, etc.; (5) *Use Electric Distribution Simulation*. Do a grid analysis and determine the optimized distribution of the electrical system and electric renewable energy supplies; (6) *Use Supply and Distribution Optimization Simulation*. Use a model like "POLIS" to determine the optimal distribution and supply systems for both the thermal and electrical and the integrated loads to calculate primary energy demands with the included distribution losses; (7) *Determine Centralized and De-Centralized Options*. Optimization must consider both sets of scenarios.
- **Cost and Emission Analysis.** Integrate energy and fuel use. Using the efficient buildings, optimized distribution systems, and supply scenarios, calculate the fuel costs and associated emissions.
- **Financial Analysis.** Use energy, fuel, distribution, and supply costs to calculate the initial costs, investment costs, annual income, yearly cash flows, and cumulative cash flows, for the project life for each scenario.
- **Sensitivity and Risk Analysis.** Estimate the sensitivity of important financial indicators in relation to technical and financial input assumptions and develop final results for each of the scenarios investigated.
- **Overall Scenario Results and Project Recommendations** Display overall scenario results showing risk and reward for the project and make scenario/project recommendations with the development of the project business plan.

The primary goal is to calculate the amount of energy delivered, in various forms, by the energy systems. The challenges of the model are to assess the system's energy needs in terms of heating, cooling, and power generation, and then to estimate how those needs can be met by the various energy systems that are ultimately chosen. The model is devoted to calculating the system's load and energy use and to evaluate how they can be optimally met.

Building Level Optimization

The Army's present and future building stock is comprised of a variety of building types. Energy requirements in some of them (i.e., barracks, office buildings, child development centers, maintenance facilities, and hangars) are dominated by climate control (heating, cooling, and humidity), with smaller

effects from plug-in loads. Other buildings (e.g., command and control facilities, hospitals, training facilities with simulators, dining facilities, laboratories, etc.) have high energy loads dominated by internal processes and/or high ventilation requirements.

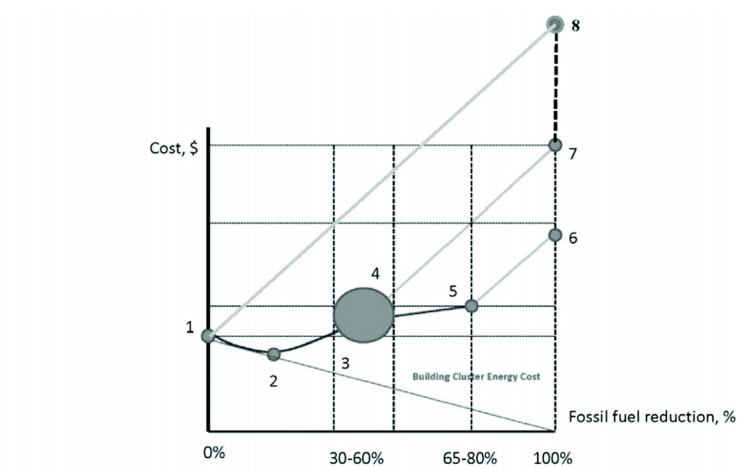
In most of these facilities, some energy use reduction methods are similar and well understood (e.g., building envelope improvement, better lighting systems designs and technologies, etc.). In buildings with high internal loads, however, energy use can be reduced only by altering the way specific processes use energy efficient appliances and significant waste streams [2,3]; currently, this is rarely addressed. However, in buildings with high internal loads, energy use can only be reduced by intervention into specific processes by using energy efficient appliances and significant waste streams [7].

Energy demand determines the amount of energy that the distribution and supply generation side must provide. Models such as EnergyPlus, ESPr, TRANSYS, or other accurate hourly energy analysis programs can simulate and optimize building level energy use. Evaluation of a community or a cluster of buildings will reveal opportunities for energy savings and challenges for analysis and optimization. Addressing buildings as a cluster does not require a deep evaluation of each building, but it does require that individual analyses be applied to the building cluster, and that consideration be given to the possibility of integrated supply services.

The building optimization process starts with (1) identifying typical buildings and energy systems on Army installations and existing energy wastes and inefficiencies related to these buildings and systems [7]; (2) developing load profiles for typical base-case buildings; and (3) analysis of suites of technologies for an ultra-low energy installation to include waste recovery and energy conserving (ultra-low energy), and energy generation and storage technologies that could be applied to buildings and the energy systems that support those buildings to minimize traditional electrical and fossil energy use.

There is a debate over whether to conserve energy first or just generate energy with renewable alternatives. Figure 2 shows several theoretical paths that a designer or master energy planner can choose and the process for each individual building and building cluster optimization. Point 1 represents the base case building, which is either an existing building, or a new building that must be built to local code requirements with a given total annual cost, which is the annual mortgage or financed first cost plus the annual energy operating costs. If renewables are added at this point, the total annual cost of the net zero energy building will be as shown in point 8, using a constant cost for a unit of photovoltaic system ($/ft^2 [$/m^2] of a PV panels or $/kWh electricity produced). Point 8 has the largest annual cost, created by adding expensive renewable technologies without reducing buildings demands first.

Another alternative from Point 1 is to add energy efficiency technologies at the building level, which will require investing in these technologies (additional first cost); eventually, you reach Point 2 with the lowest total annual cost. Typically you would not add renewables at point 2 since adding many conventional energy efficiency technologies at this point may be more cost effective than adding renewable generation. When Point 3 is reached, you have achieved the same total



1 – Building prior to retrofit
2 - Building after retrofit with Business As Usual (BAU)
3 - Building after retrofit option to maintain the same annualized cost
4 - Building after maximum building site energy reduction retrofit
4-5 Building fossil fuel reduction due to Central Energy Plant (CEP) with co-generation
6 - NZE building connected to CEP with co-generation and a renewable energy source
7 - NZE building connected to a renewable energy source
8 - Building prior to retrofit connected to a renewable energy source

Figure 2 *Building fossil fuel reduction optimization process.*

annual cost as your existing building or base case building built to code (Point1), but the building at point 3 is now much more energy efficient and often much more comfortable. As one continues to add energy efficiency improvements, the building will eventually reach Point 4, where adding more energy efficiency measures will either result in diminishing returns, or where they will cost more than adding renewable generation.

For an individual building analysis, this building at Point 4 would be "Net Zero Ready." For different types of buildings and climate locations, fossil fuel based energy reduction will vary [18]. In buildings with low internal energy loads, reduction of fossil fuel can be significant (50 to 75%), but in buildings with high internal loads, reductions of only 20 to 30% may be achieved. This is true even for buildings built or retrofitted to "passive house" requirements, and that use advanced "low exergy" systems to satisfy remaining heating and cooling needs. The remaining energy requirements will be dominated by electrical power needs for lighting, appliances, and internal processes and by domestic hot water needs i.e., for showers. Adding renewables from Point 4 will result in the total annual cost shown by Point 7. The process from Point 4 to 7 is approximately at the same slope, or cost, as the process from Point 1 to 8, but it is shown to be more cost effective to purchase less expensive renewable energy technology for a building with reduced energy demands.

Alternatively, the building characterized by point 4 can be connected to co-generation plant serving either this individual building or cluster of buildings. This will require a smaller investment compared to the cost of decentralized boilers and chillers for single buildings, and the cost of larger renewable generation equipment [16], but will result in a significant fossil fuel reduction due to use of waste heat accompanying electricity generation. This heat can be used either to satisfy heating, cooling, and domestic hot water needs of the building cluster, or be exported to another building cluster. The use of co-generation for individual buildings and building clusters affects the optimal location of Point 4 for each individual building. When the subject of interest is a single building, the waste heat produced by co-generation process can be only used for heating, cooling, and domestic hot water needs of this building. The amount of waste heat generated will determine the optimal level of the building insulation and its loads. Typically, the level of insulation used in new construction and retrofit project results in small heating and cooling loads and the waste heat from co-generation process will compete with the heat that can be generated using solar thermal systems. When the boundaries of the analysis go beyond a single building, the waste heat can be used for the building clusters under consideration, and the decision on the level of building insulation must be made based on a mix of buildings (new and old) and on other potential uses of waste heat.

Connecting to a Combined Heat and Power (CHP) plant, fossil fuel usage by the building cluster (Point 5) can be further reduced by another 20-25%. When a CHP uses biomass or biogas as a fuel, the connected building(s) become "Net Zero" fossil fuel. When CHP uses biomass or biogas as a fuel, the connected building(s) become "Net Zero" fossil fuel. Typically, at point 5, buildings do not require additional thermal energy from renewable energy source, but may require additional electrical power. After point 5, adding solar- or wind-generated electrical power becomes a cost-effective supply option. At this point, by definition, the building cluster is "Net Zero Ready." Path 1-2-3-4-5-6 is the lowest cost path for building improvement leading toward net-zero fossil fuel based energy strategy.

When this process has been completed for each building, the results from all of the individual buildings are integrated and summed into annual load duration curves. The load duration curve shows the cumulative duration for different loads in the system over a full year. These curves are derived from hourly load data to show all possible variations to the system and are generated from the hourly building energy simulation program. Due to the diversity of energy use in buildings comprising the cluster (community), the peak of the resulting load curve is much smaller than the sum of peaks of individual buildings so that the needed generation and back-up capacity is much smaller.

Building Cluster or Installation Analysis

Energy models that optimize distribution of energy from central generation/production to the energy usage by the buildings and systems can be used to develop the community energy concept. The building simulation gives results for demand curves for domestic hot water consumption, electricity consumption, heating, and cooling for those buildings at existing climatic conditions; these are passed to the next step.

These models will minimize energy waste and losses and optimize first and operating costs, (First Cost + Operating Cost = Total Cost). Based on this concept, a Master Planning process can be developed that will provide an orderly approach to changing the typical Army installation to an ultra low energy consuming community.

Distribution and Supply Optimization

An energy system optimization model like POLIS [8] can simulate supply systems. Between energy generation and energy demand points (at each building level), a distribution system transports the energy via hot or chilled water system. These systems can be simulated using a hydraulic flow model. While "energy balancing" means just calculating the correct energy flows (and perhaps also carbon emissions) in a system, to estimate energy costs and to benchmark with other similar systems, simulation and optimization is necessary for system planning. A simpler simulation approach is preferable to generally compare available alternatives, to model a whole-system energy balance and compare the effects of different demand or supply side measures in terms of energy efficiency, capital and energy costs, and greenhouse gas

(GHG) emissions with the simulated demand curves from the building simulation optimization step.

Energy system models developed in the past for the optimization of large systems might be applied for this purpose. However, if such a model is to be used as a regular planning tool, the model should be run by skilled planners who are familiar with them. With POLIS models an energy system as a closed system that includes the entire chain from demand, through the distribution system, to the supply systems. Every element (e.g., buildings, boilers, generators, grids, etc.) are described as "knots" of energy and cost related parameters linked together in an interconnected system in which different usages are interlinked. Power supply, heating, and air-conditioning are modeled in a common system. This offers the opportunity to compare efficient technologies like co-generation (power + heat) and tri-generation (power + heat + cooling). The model requires at least an hourly time resolution. The results of such a modeling offer the best suited solution to reduce the energy usage of a building cluster and leads the way to least-cost, net-zero installations. Furthermore, the approach of optimizing building clusters will offer new and/or additional options to cost efficiently reduce the fossil energy footprint of community systems. The results can be directly applied to detailed design planning to implement the solution found in the model.

POLIS can model an energy system by using prototype generation equipment, distribution systems, and load profiles. Cost, emissions, and technical parameters are used to describe existing or future elements of the system. Simulation is performed using hourly load profiles for thermal and electrical energy demand throughout a year (8760 hours) generated from the summation of the building cluster energy simulations. POLIS allows calculation of the best suited combination of paths to meet the load, with the objective to minimize total system costs, or to minimize total GHG-emissions. Since distribution systems play a significant role in an overall thermal energy system, a hydraulic flow model should be used to analyze critical capacities and flows in the system. Through an iterative process, these two models will determine whether an optimization of the energy system (POLIS results) will lead to a feasible optimized supply and generation system.

FORT IRWIN, CA BUILDING CLUSTER CASE STUDY RESULTS

The integrated energy optimization process described to this point includes the analysis of building energy efficiency improvements and the optimization of energy generation and distribution. The tools required to optimize individual buildings were applied for the analysis of eight types of Army buildings. The goal was to meet or exceed EPACT 2005 requirements for new construction [9,10,11,12] and for the "Integration of Energy/Sustainable Practices into Standard Army MILCON Designs" study [18] of five common types of Army buildings with aggressive goals to achieve 60 to 80% energy use reduction against CBECS 2003. The implications of the first cost analysis are currently being completed. [13] This section illustrates the proposed approach using the example of the building cluster to be renovated at Fort Irwin [16].

Fort Irwin, the home of the National Training Center, is a U.S. Army installation located 37 miles northeast of Barstow, CA in the High Mojave Desert midway between Las Vegas, NV and Los Angeles, CA. The energy required to serve the needs of more than 1600 buildings located on the installation is not generated on site; it must be conveyed over long distances. Electric power is transmitted from distant generators through the power grid; LPG for heating and domestic hot water (DHW) is trucked to Fort Irwin in bulk. The costs associated with fuel transport raise the already high energy costs for the installation.

The Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) with a support from a group of industry experts conducted an energy study at Fort Irwin with a focus on a representative group (cluster) of buildings (Figure 3), which included five barracks buildings, a dining facility, and a central energy plan to which all these buildings were connected.

The integrated optimization process used in this analysis includes optimization of each building in the cluster to meet its economic energy efficient optimum. The building cluster is then energy optimized taking advantage of the diversification between energy intensities, scheduling, and waste energy streams use between the buildings. The optimized cluster minimizes the amount of energy from renewable sources needed to make the building cluster net zero. In the future, it may be possible to connect other buildings, e.g., Bldg 272 (the club) and three administrative buildings (276, 278, and 280) to the same central plant.

Figure 3 *Buildings comprising the cluster used for the analysis: barracks (1), central energy plant (2), and dining facility (3).*

Barracks Bldg 264

Barracks Bldg 264 was selected as representative for the analysis of barracks. Bldg 264 has a total area of 28,959 ft^2, has three stories, and can house 136 people. Two people share a room; two rooms share a bathroom. The walls are 8-in. concrete masonry unit (CMU) with 1-in. exterior continuous insulating board plus stucco. The floor is 6-in. concrete. The windows have double-panes, and aluminum frames without a thermal break. There is external horizontal sun shading above the windows, approximately 1 ft shade depth. The roof has a pitched metal surface with 4 in. of above deck insulation.

Heating and cooling is provided by 300 cfm (8 m^3/min), two-pipe, fan coil units that serve the two-person living areas. Two Makeup Air Units (MAUs) are located above the third floor ceiling. Supply air ducts run from these MAUs to provide ventilation air that enters the fan coil's return air plenum located above the false ceiling in the hallway of each living quarter. Since the fan coils are located inside the soldiers' living areas (which are kept locked), access for maintenance can be difficult. Thus, fan coil maintenance is time consuming and not always done at specified intervals. Filters get dirty quickly and need to be replaced regularly to maintain nominal air flow through the fan coil units. Dirty air filters are also a potential breeding ground for biological growth, which typically goes undetected. The ability to maintain the units without entering an occupied space is desirable and should be incorporated into the design solution.

The building has three MAUs, two of which are for the living quarters (1320 and 1120 cfm [31 and 37 m^3/min]), and one for the main areas and the corridors (2700 cfm [76 m^3/min]). The field survey found that none of the MAUs for the living quarters in any of the barracks in the cluster that was studied were running. This means that currently there is no fresh air coming into the soldiers' rooms. The MAUs for the living quarters total a supply capacity of 2440 cfm (68 m^3/min), which is equivalent to 18 cfm (0.5 m^3/min) per person.

The exhaust from the bathrooms in Bldg 264 is provided by an individual exhaust fan in every bathroom, ducted to exhaust ducts vented at the roof. The exhaust fans only run when the lights are on in the bathroom, not continuously. These exhaust fans are difficult to maintain and are very dirty. In some of the other barracks in the cluster, the bathroom exhaust had been changed to use roof-mounted central exhaust fans so that the bathroom exhaust runs continuously.

Heating and cooling is supplied from the central plant in Bldg 263. For the fan coils, there are manual switch-over valves in the mechanical room. Every spring and fall, as the seasons change, flow is switched from the heating source to cooling and vice versa. This manual switchover creates comfort problems during the change of seasons when the weather variation between night, morning, and afternoon is dramatic, and heating is required overnight and cooling in the afternoon. Since this manual switchover only occurs twice a year, comfort conditions may be compromised through several months of the year.

DHW is generated within the building with heat from the central plant that passes through a heat exchanger that is controlled to keep a certain DHW temperature in the DHW storage tank.

Analysis of Dining Facility 271

Dining Facility 271 (Figure 3) has a total area of 12,040 ft^2, is one story high, and serves an average of 1000 meals per day. The dining area occupies approximately 40 percent of the building area. Serving, kitchen, and utility rooms occupy the remainder of the building. The original building construction was supplemented with an addition to the dining room.

The Dining Facility walls are 8-in. CMU block with 1 in. insulating board plus drywall. The floor is 6 in. concrete. The windows in the original building are single pane, and the windows in the addition are double-pane. Both window types have aluminum frames with no thermal breaks. The roof is a flat metal deck with 4 in. of rigid insulation under a black single ply roof.

Heating and cooling is provided by an air handling unit, three make-up air units, and two evaporative cooling units. All units have hot water heating coils and chilled water cooling coils. The cooling coils are downstream of the evaporative coolers in the evaporative cooling units. The air handling unit has a capacity of 12,000 cfm (336 m^3/min) and serves the dining and serving areas of the building. A 3600 cfm (101 m^3/min) make-up air unit also provides air for the exhaust hoods in the serving area. One evaporative cooling unit in the kitchen and one makeup air unit (MAU) provide 5500 cfm (154 m^3/min) to the general area. The MAU has a capacity of 4400 cfm (123 m^3/min); both supply air units together support the exhaust of two large hoods and several smaller exhaust systems. The other evaporative cooling unit (2000 cfm [56 m^3/min]) and MAU (4000 cfm [112 m^3/min]) are located in the dishwashing area. These units provide air for the exhaust from the dishwasher machine and general dining room exhaust. All these units are located on the roof except for the air handling unit (AHU), which is located in the first floor mechanical room.

The ventilation rate for the dining room is over 2 cfm/ft^2 (1 m^3/min/m^2). The amount of outside air is adjustable. The evaporative cooling units and MAUs use 100% outdoor air. The mode of the current operation is that "all supply and exhaust air systems run all the time."

Heating and cooling is supplied from the central plant, Bldg 263. The supply air units have both heating and cooling coils, and thus can easily handle changing weather conditions that require heating and shortly thereafter cooling, which is often experienced in the spring and autumn.

DHW is generated within the building with heat from the central plant that passes through a heat exchanger, controlled to keep a certain DHW temperature in the DHW storage tank at all times.

Analysis of Central Energy Plant 263

The central energy plant in Bldg 263 is operated to supply heating and cooling to five barracks buildings within the cluster plus the dining facility, Bldg 271. The dining facility also has its own mechanical systems such as a steam boiler, direct expansion (DX) cooling, and evaporative cooling units in addition to the heating and cooling supply from 263.

The central plant has one area for heating with three fairly new Patterson Kelley boilers, which burn a combustible gas (LPG from the central LPG farm, expanded and distributed as gas around Fort Irwin). The heating capacity is 2000 MBH/boiler. The Hot Water (HW) supply temperature is set at 180°F [82°C]). The HW circulation pump is driven by a 30 hp motor connected to a variable frequency drive (VFD) that is set at 33 percent constant load.

In the central plant, all boilers were on. Boiler B was the lead, and all boilers were on standby. HW supply temperature was 180°F (82°C) and the HW return temperature was also 180°F (82°C). Substantial savings could obviously be generated by modifying the system's mode of operation. Note that, since the energy waste of the existing system operating strategy was not captured in the computer models, the savings potential is greater than shown.

The central plant also has a centrifugal chiller (a Trane CVHE 036G, with a nominal capacity is 360 tons, installed in 1987). An external open cooling tower removes the excess condenser heat. The chilled water (CHW) pump is 25 hp, constant speed unit. The condenser pump is also a 25 hp, constant speed unit. The CHW supply temperature setpoint is fixed at 45°F (7°C), and the condenser water supply temperature setpoint is fixed at 85°F (29°C). In the chiller plant, the CHW supply and return temperatures were 47°F (8°C) and 53°F (12°C), respectively.

This chiller runs at partial load for most of the summer and mid-seasons. Partial load efficiency of chillers of this era is notoriously poor and can exceed 3 kW/ton during very light loads. The chillers do not typically unload much below 30 to 40 percent of their design capacity, so loads below this level are served very inefficiently.

In addition, the constant speed pumps are designed to deliver 360 Tons of capacity at all times. At full load, the pumping energy penalty is approximately 0.10 kW/ton. At a 10 percent load, the pumps contribute approximately 1.0 kW/ton to the energy consumption equation. A properly controlled variable speed pumping scheme will use less than 0.1 kW/ton at nearly all loads and will operate at less than 0.05 kW/ton across most of the load range. Cooling plant efficiency could be improved by more than 50 percent by replacing old constant speed technology for the compressor, chilled water, and condenser water pumps with new technology and automatic reset control systems.

The designs anticipated in this document can improve the energy efficiency of the new cooling plant by more than 50 percent by using variable speed drives on all of the equipment, higher chilled water supply temperatures, lower condenser water supply temperatures, and load based optimization system reset strategies that reset the chilled water supply temperature and differential pressure, the condenser water temperature, and the supply air temperature and static pressure setpoint based on the needs of the end use cooling loads. Additionally, the new insulation level requirements will substantially reduce cooling loads, and reduce chiller plant energy consumption by nearly 70 percent overall in comparison with the base case.

After the initial assessment of the sample buildings, including detailed studies of drawings, data was available for input into the eQuest Energy simulation model. These data formed the base case (present situation) with the goal to establish the annual energy use per building, and ultimately for the entire cluster.

Modeling of Buildings and Systems

The modeling of the buildings, the systems within the buildings, and the systems supporting the buildings was done by using eQuest, an hourly annual building energy analysis tool that provides professional-level results with an affordable level of effort. In addition to the observations listed above, the following input data was used in the base case simulation of the buildings:

Barracks Bldg 264

- The infiltration is estimated to be equivalent to 1 Air Change per Hour (ACH).
- The total window area is 20 percent of the gross wall area on the north and south walls. No windows are on the east or west walls.
- There is a laundry on the ground floor; it is estimated that each soldier washes three loads of laundry per week.
- Lighting is estimated to be at a level of 1.10 W/ft^2 in the living quarters and 0.8 W/ft^2 in the corridors and storage areas. For the laundry, common areas, and the administrative spaces, the lighting levels modeled are 1.6 W/ft^2.
- Miscellaneous electric loads (plug loads) are estimated to be 1 W/ft^2.
- DHW use is estimated to be 12 gal/day/person, supplied at 140°F (60°C). Inlet water temperature is assumed to equal the ground temperature.

Dining Facility 271

Additional input data for the computer model for the dining facility is:

- The infiltration is estimated to be equivalent to 0.3 ACH.
- All the windows are fixed with an area of 23 percent of the gross wall area on the southwest side, 14 percent on the southeast side, and 4 percent on the northwest side of the building.

- Lighting is estimated to be at a level of 1.85 W/ft^2 in the dining area, 0.92 W/ft^2 in the serving area, 1.19 W/ft^2 in the kitchen, and 0.81 W/ft^2 in the mechanical room.
- The cooking energy use is estimated to be 11.6 W/ft^2 in the kitchen and 5.0 W/ft^2 in the serving area. There is also a natural gas cooking energy use of 198 Btu/ft^2 in the kitchen and 50 Btu/ft^2 in the serving area.
- The refrigeration load used for the kitchen is the default value of 3.6 W/ft^2.
- The miscellaneous load inputs are 1.0 W/ft^2 in the dining area, 0.2 W/ft^2 in the kitchen and 0.1 W/ft^2 in both the serving and mechanical room areas.
- The office equipment energy use estimate is 0.2 W/ft^2 for all spaces except the mechanical room.
- The DHW use is the default value in the program for a full service restaurant.

Central Energy Plant 263

Additional input data for the computer model for the Central Energy Plant is as follows:

- Heating:
  - There are three gas-fired boilers, 80% efficient.
  - There is constant flow in the hot water loop.
  - The hot water temperature is set at a fixed value of 180°F.
  - The boilers are on all year, 24 hrs/day, as a standby measure for whenever heat is requested.[1]
- Cooling:
  - There is one chiller (360 tons) for the entire cluster. Efficiency is estimated to be 0.8 kW/ton.
  - The chiller is electric centrifugal hermetic type, constant speed, and water-cooled by a cooling tower. The cooling tower is an open tower, and the temperature setpoint is fixed at 85°F.
  - The CHW loop flow is constant.
  - The CHW temperature is a constant 45°F.
  - The chiller is in standby mode all year, 24 hrs/day.

Results of Simulation, Annual Energy Use

Table 1 lists the present use of electric energy and fuels in one barracks building according to the annual building energy simulations.

Note: the energy use by building area is 5012 million Btu/12,040 ft^2, or 416,236 Btu/yr/ft^2 The cooking equipment use is 216,360 Btu/yr/ft^2, leaving 199,877 Btu/yr/ft^2 for HVAC, DHW, and lighting. Much of the HVAC and DHW energy use is related to cooking operations.

Building Upgrade Improvements for Typical Renovation Projects.

Barracks buildings in the Army inventory typically get a major renovation at approximately 25 yrs of service under the Building Upgrade Program (BUP). This work attempts to reduce the building's energy use to the energy usage level of a newly constructed building. The building envelope should be improved by adding insulation to the walls and roof, by installing tight-fitting, well insulated doors, and by upgrading to

Table 1. Present Use (Base Case) of Electric Energy and Fuels in One Barracks Building

Usage	Consumption
Electric Consumption (kWh)	
Space cool	124,401
Space heat	0
Vent. Fans	58,120
Pumps and aux.	69,223
Laundry	69,300
Plug loads	85,190
Area lights	74,885
Total	***486,507***
Gas Consumption (kBtu)	
Space heat	665,131
Hot water	628,307
Total	***1,293,438***

Table 2. Base Case Electrical Energy Use for Dining Facility

Electrical	kWh/yr	MMBtu/yr
Cooling	82,500	281.6
Heat rejection	7,260	24.8
Ventilation fans	270,130	922.0
Pumps	40,800	139.3
Cooking equipment	201,950	689.3
Lights	66,940	228.5
Subtotal	*669,580*	*2,285.3*

1. Note that the negative effects of the current design and operational strategy, which are associated with substantial energy waste are not included. With the current operational strategy, it is likely that the boilers are less than 40 percent efficient overall, as they are running when there is no need for them to be operated. Tables 2 and 3 and 3 list the results of the base case simulation for Dining Facility.

windows with a low heat transfer and a minimum solar heat gain. The lighting, HVAC, and domestic water energy systems need to use high efficient equipment and effective controls. Appliances and equipment used in the barracks should be Energy Star rated to minimize their energy use.

Our analysis for cost effectiveness of achieving Net-Zero energy use of the building cluster assumes that the major building upgrade has been accomplished under the BUP. The subject barracks buildings in this cluster would therefore already have had a major improvement in their efficiency of energy use and a significant investment would have been made in the buildings. Recommendations would build on these improvements to achieve buildings that would be ready for renewable energy systems to achieve Net-Zero energy use. To minimize the cost of these additional improvements, it is expected that they would be accomplished during the BUP building upgrade.

To define the cost effectiveness of these Net-Zero energy use improvements, a prediction of the building energy use with the BUP improvements must be made. (Note that, since most of the dining facility energy use depends on the type and operation of the cooking equipment, the Net-Zero energy use is assumed to be the same as the base case.) This will be done by simulating the building energy use with the following building characteristics:

- Roof insulation = R-30, light colored reflectance = 0.27.
- Wall insulation = R-18.
- Infiltration same as base case (approximately 0.4 cfm/ft^2 (0.21 m^3/min/m^2) @75 Pa.
- Windows = double pane, U=0.45, Low E.
- Lighting = 3.07 Btu/hr/ft^2 0.9 W/0.09 m^2 in living quarters and 3.41 Btu/hr/ft^2 (1 Watt/0.09 m^2) in the laundry area.
- HVAC = fan coil units with central heating and cooling system. Add DOAS unit (DX coil and HW heating) if model can handle this type system.
- DHW heater = Gas heater 90 percent efficient with storage tank.

Table 4 lists the building energy use results of the annual building energy simulation computer program run for a building typical of the barracks buildings.

Proposed Energy Conservation Measures

The following possible improvements were identified for the Barracks:

- Upgrade the external insulation of the walls to R-42.
- Install a new roof using a cool roof surface and R-39 insulation.
- Install triple-pane, Low-E, operable windows.
- Install window and door monitoring switches that turn heating or cooling off when the switch is activated (i.e., then the door or window is open). This measure was initially deleted to reduce the first cost of the project, but it is a desirable option that should be considered.
- Install more efficient lighting to reduce the load to 1.71 Btu/hr/ft^2 (5.6 W/m^2).
- Assume Army influence on plug loads to get down to 2.05 Btu/hr/ft^2 (6.5 W/m^2).
- Install efficient laundry equipment (EnergyStar) to reduce the electric load by 50 percent.
- Duct all bathroom exhausts to common roof-mounted exhaust fans with continuous operation, mainly to prevent mold growth in the bathrooms. Install a heat recovery unit

Table 3. Base Case Natural Gas Energy Use for Dining Facility

Natural Gas Use	MMBtu/yr
Space Heating	678.6
DHW	131.9
Cooking Equipment	1,915.7
Subtotal	2,726.2
Total	***5,011.5***
Btu/yr/ft^2	***416,236***
Btu/yr/ft^2 – Cooking Equip.	***199,877***

Table 4. Energy Use After Typical Barracks Building Upgrade

Element	Consumption
Electric Consumption	
Space cool	383 MBtu (112134 kWh)
Space heat	0 MBtu (0 kWh)
Ventilation Fans	179 MBtu (52560 kWh)
Pumps and aux.	218 MBtu (63907 kWh)
Laundry	237 MBtu (69300 kWh)
Plug loads	2901 MBtu (85190 kWh)
Area lights	218 MBtu (63874 kWh)
Total	***1,525 MBtu (446965 kWh)***
Gas Consumption	
Space Heat	626 MBtu (1,833,414.03 MWh)
Hot Water	580 MBtu (1,699,616.14 MWh)
Total	***1207 MBtu (3,533,030.18 MWh)***

to recover heat from exhaust air to outside air entering the DOAS AHU. This is considered for all systems mentioned below except the DOAS-VAV system.

- Replace the existing two-pipe fan coil units with these system types:
    - DOAS-VAV System with Direct Evaporative Cooling
    - DOAS System with Radiant Heating and Cooling (direct and indirect evaporative cooling)
    - DOAS System with Fan Coils (direct and indirect evaporative cooling)
    - DOAS-VAV System with Direct and Indirect Evaporative Cooling

The modifications to the Dining Facility to reduce energy use are:

- Add external insulation to walls (R-12) for a total of R-20.
- Install a new roof with a cool roof surface and R-42 insulation.
- Install triple-pane, Low-E, fixed windows with aluminum frames having thermal breaks.
- Install new doors with double pane glass.
- Reduce infiltration to 0.1 ACH by sealing unwanted openings in the building.
- Install more efficient lighting to reduce the load to 3.41 Btu/hr/ft^2 (10.8 W/m2) in the dining area, and install controls to reduce lighting by 50 percent when unoccupied.
- Install skylights in dining and serving areas and controls so lights may be switched off when natural light is adequate.
- Change cooking equipment to electric, which is three times more efficient than gas or steam-heated appliances.
- Improve kitchen hood performance by adding wings to the hoods and air flow control.
- Install a heat recovery unit in the kitchen exhaust system.
- Reduce DHW energy use by 50 percent by improving the dish washing machine and drain water heat recovery as well as refrigeration equipment heat recovery.
- Readjust the dining and serving area space temperatures to 75 °F (24 °C) when occupied and cooling and to 70 °F (21 °C) when occupied and heating. When unoccupied, the temperature setpoint would be 78 °F (26 °C) cooling and 68 °F (20 °C) heating.
- Replace existing MAUs and AHU with units having evaporative coolers followed by cooling coils that reduce the cooling energy use.
- Reduce the dining area miscellaneous load by turning off the TV when the space is unoccupied.

The total estimated cost for these improvements is $2,441,000.

The modifications to the Central Energy Plant to reduce energy use are:

- Replace the boilers with (92 percent) more efficient boilers.
- Control hot water supply temperature vs. outdoor temperature with a maximum of 160°F (71°C) and a minimum of 100°F (38°C).
- Install VFDs for variable hot water loop flow.

Chiller Plant Upgrade Project

- Install a downsized, high efficiency VSD centrifugal chiller designed to operate properly at high lift conditions (for Thermal Energy Storage system charge cycles).
- There is currently a project being considered separately that may add a chilled water Thermal Energy Storage system to cool the complex.
- The chiller shall be designed for variable flow evaporator and condenser systems.
- Convert the chilled water piping/pumping system to be a primary-only, variable flow design.
- Install a new variable speed condenser water pump.
- Install a new high surface area, low fan horsepower (hp), variable speed, high wet bulb rated, cooling tower system. The cooling tower (CT) should be rated at 78°F wet bulb temperature, with a maximum of 0.05 brake horsepower (bhp) (0.04 kW) per rated ton of heat rejection (15,000 Btu/hr).
- The CT should be designed to operate with flow down to 30 percent of the design flow.
- Install a cooling tower condenser water filtration system. A sub-1 micron sand filter system is recommended to reduce the volume of fine solids while minimizing the impact to labor.
- Install a chilled water filtration system. A sub-1 micron sand filter system is recommended to reduce the volume of fine solids while minimizing the impact to labor.
- Install a heating hot water filtration system. A sub-1 micron sand filter system is recommended to reduce the volume of fine solids while minimizing the impact to labor.
- Install a refrigerant monitor and refrigerant exhaust system for the new chiller for code compliance.
- Modify the chilled water piping for the new design/chiller.
- Modify the condenser water piping for the new design/chiller.
- Install a 20 tons (300 KBtu/hr) heat recovery chiller (set up for 135 °F [57 °C] water) and a storage tank for domestic hot water needs. This measure was initially deleted from the project, as it is expected that there will be a solar thermal heating system, or a waste heat recovery system that would be implemented along with the system upgrades. If no form of “free” heating is available for the project, this would be a viable option.
- Integrate the heat recovery system into the existing heating system. This measure was initially deleted from the project, as it is expected that there will be a solar thermal

heating system, or a waste heat recovery system that would be implemented along with the system upgrades. If no form of "free" heating is available for the project, this would be a viable option.

- Interface the proposed new chilled water Thermal Energy Storage Tank with the appropriate TES piping/ pumping systems.
- Install Load Based Optimization System (LOBOS) controls for the heating and cooling central plant systems.
- Upgrade the DDC Controls in the plant.
- Install an Energy Monitoring/evaluation System.

Typical Upgrade Project Financial Summary, Envelope, and HVAC Rehabilitation Costs for the 263 Building Cluster

The data in Table 5 summarize the cost of a typical Army building upgrade of the subject building complex at Fort Irwin. This would include barracks upgrades of five buildings, an upgrade of the nearby dining facility, and an upgrade of the hot and chilled water system that services these buildings. The total estimated cost is 29.4 million dollars to accomplish this work. To obtain a Net-Zero energy ready status for this six-building cluster would cost an estimated $31.7 million dollars, which is an increase of 2.3 million over the upgrade cost.

Energy Savings Estimates

The estimated energy use of the five barracks and dining facility as operating during the site visit was 10,580 MBtu/yr (3.1 million kWh/yr) and 9193 million Btu (26,917 million kWh) of LPG gas. The data generated by computer analysis indicate that a typical upgrade of a barracks building only saves 8 percent of the electricity use and 7 percent of the heating energy as compared to the barracks "as found." In other words, a typical barracks upgrade is not very energy efficient.

The results of further analysis (Table 6) show that upgrades to Net Zero energy ready buildings allow a reduction in the energy consumed to heat, cool, and ventilate the cluster facilities by 44 to 49 percent of electrical use and 30 to 59 percent of heating use with paybacks of 2 to 10 yrs depending on the alternative chosen. Since the proposed energy efficiency work includes the implementation of DOAS and high efficiency dehumidification systems that would dramatically reduce the potential for biological growth, in climates where

Table 5. Cost Summary for Typical Upgrade of Barracks and DFAC in the Cluster

Upgrade	Cost
Typical barracks upgrade project envelope rehabilitation costs for five barracks	$3,225,250
Typical barracks upgrade project HVAC rehabilitation costs for five barracks	$22,015,684
Typical upgrade project envelope and HVAC rehabilitation costs for DFAC	$1,614,932
Typical upgrade project chiller plant rehabilitation costs for 265 complex	$2,522,790
Typical upgrade project HVAC, envelope, and chiller plant rehabilitation costs for barracks and DFAC complex	$29,378,656

Table 6. Modeled Savings of Five Alternatives

Alternative	Total Cost $ Millions	Incremental Cost $ Millions	% Electrical Savings	% LPG Savings	$K Savings /yr	Simple Payback (yrs)
Typical renovation	29.4	29.4	6%	5%	$27	
1	31.7	2.4	48%	59%	$242	10.0
2	30.9	1.6	48%	58%	$240	6.7
3	30.7	1.3	49%	58%	$242	5.4
4	29.9	0.48	45%	30%	$171	2.8
5	30.7	1.4	44%	30%	$168	8.3

mold is an issue, the avoided costs of mold mitigation can decrease the payback to 1.2 yrs.

Renewable Energy Use Analysis

To achieve "Net- Zero" energy status, a building cluster needs to provide the remaining energy amount using renewable energy sources. These sources could include energy generated by solar, wind, hydro power, biomass, waste products, and/or geothermal energy sources. For the Fort Irwin location, the most attractive renewable energy sources are solar and waste products. The basic energy and labor cost data in Table 7 were used to develop the renewable energy concepts.

BASIC DATA USED FOR CALCULATIONS.

The following renewable energy options were considered:

Option 1. The Barracks and the Dining Facility are connected to the Central Heating Plant (Bldg 263) by a district heating grid. Three LPG boilers, 2060 MBtu/hr each, generate heat for domestic hot water DHW needs and space heating (SPH). No water storage tanks are installed in the Central Heating Plant. DHW storage tanks with a capacity of approximately 1500 gal are installed in each building. The LPG and electricity prices are the actual values given during the energy assessment. While the assumption of the price increases per year for LPG, electricity, and other issues (labor, etc.) are lower than energy price increases of the past, the calculations are based on a conservative approach. This, combined with measures already discussed, would result in a zero net energy heating use and 4,848 MBtu/yr (1420414 kWh/yr) electrical usage. The electrical use may be further offset with waste-to-energy cogeneration, or the use of a tri-generation plant.

Table 7. Basic Energy and Labor Cost Data for a Building Cluster

Basic Data	Value
LPG	0.084 $/kWh
Electricity	0.083$/kWh
Price increase LPG/yr	5%
Price increase power/yr	3%
Price increase others/yr	2%
Estimated maintenance LPG labor/yr	250 hr
Labor cost	65 $/hr
Maintenance / cost LPG/yr	$13,000
Estimated repair cost LPG/yr	$15,000
Total maintenance LPG/yr	$28,000

Option 2. Solar Thermal Systems are installed on barracks roofs to cover most of the DHW demand of these buildings. Due to a small DHW demand in the Dining Facility, the heat for DHW supply of the Dining Facility would be produced by the central heating system. The DHW demand is met with 35 solar thermal collectors placed on top of each barracks. The Solar Thermal System is connected to the water storage tank located in the mechanical room of each barracks. Use of solar thermal system allows removal of one LPG boiler from the Central Heating Plant (Figure 4).

The coverage of the DHW demand with the Solar Thermal System using evacuated tube collectors is approximately 90 percent. In the summer period, the Solar Thermal System is designed to cover 100 percent of the DHW demand.

Option 3. Solar thermal systems supply domestic hot water heating and biomass boilers supply space heating of barracks buildings and dining facility (Figure 5). Solar Thermal Systems installed on the barracks roofs cover most of the DHW demand of these buildings. The heat produced by the central heating plant would use wood waste as the fuel source for approximately 95 percent of the heating requirement. The LPG boilers would be used only as peak load boilers and for redundancy during Biomass System maintenance.

Currently, the wood waste (pallets, packaging, trees, etc., see Figure 6) at Fort Irwin is shredded and dumped in the landfill. This is a waste of energy because approximately 50 percent of the wood waste is untreated wood, which can be used as fuel.

FY08 data from Fort Irwin show that approximately 900 tons (816,462 kg) of wood waste is availability on the installation. It is expected that the available volume of wood waste will remain at this level in the coming years. The required volume of wood waste is approximately 180 tons/yr (163,292.40 kg/yr).

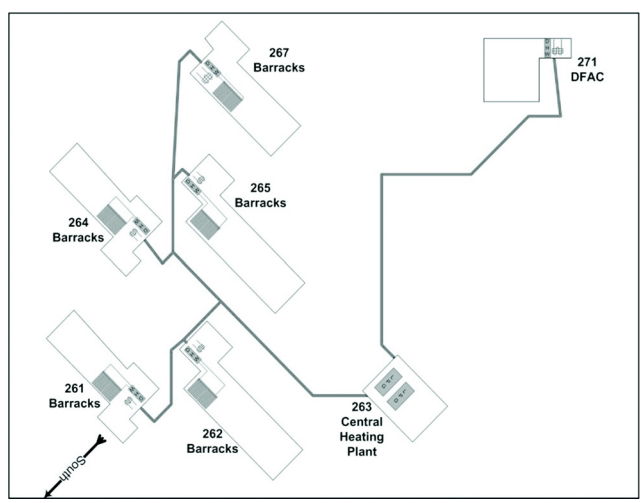


Figure 4 *Schematic of heat supply for domestic hot water (DHW) and space heating to a building cluster under Option 2.*

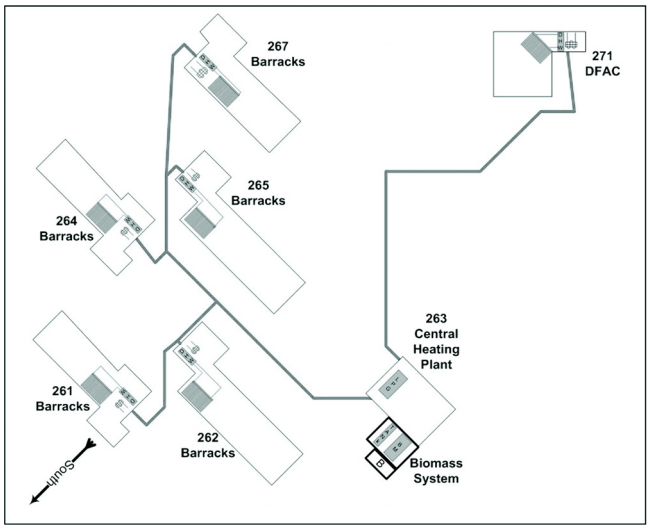


Figure 5 *Schematic of heat supply for domestic hot water (DHW) and space heating to a building cluster under Option 3.*

The expected volume of wood waste will cover the requirements if half of the wood waste is untreated wood. Treated wood should not be used as a fuel source because of emission problems (dioxine or other harmful substances).

Option 4. The DHW and SPH demand of the Barracks and the Dining Facility could be met with a Biomass System using wood waste as the fuel source. The LPG boilers would be reduced to peak load boilers and for redundancy in case of maintenance of the Biomass System. No Solar Thermal Systems would be installed.

Standalone Photovoltaic Systems for Barracks

The barracks have a significant amount of roof space at a 30-degree tilt on which PV panels could be installed to feed into the grid. The 2600 ft^2 (242 m^2) of roof area left after installation of solar thermal system will provide enough room for 125 photovoltaic panels flush to the roof. This yields a total capacity of 1.2 kBtu/min (21.9 kW_{DC}).

Standalone Photovoltaic System for the Dining Facility

The dining facility roof has approximately 1,313 ft^2 (122 m^2) of flat available roof area with a 20-degree tilt. Considering 7 ft (2.25 m) of spacing between each row of panels 18 photovoltaic panels can be installed on roof and yields a total capacity of 182 Btu/min (3.2 kW_{DC}).

Summary of Renewable Energy Opportunities for the Building Cluster

Installing Solar Thermal, Biomass (wood chip), and PV electrical generation systems can save 4,832 million Btu/yr (14,148 million kWh/yr) and generate 142,083,190 Btu/yr (41,630 kWh/yr) (Table 8). Renewable thermal energy generation is cost effective and has a payback period of les than 10 years. Using photovoltaic panels to generate renewable electrical energy is not cost effective solution since it has a significant payback period of 47 years.

Figure 6 *Wood waste at Fort Irwin.*

CONCLUSIONS

Application of the energy optimization process described in this paper to new construction and major retrofit project shows [18] that utilization of high performance building envelope (improved insulation package and air tightness specifications), advanced lighting strategies, and efficient HVAC systems results in significant energy savings (site and source) in Army buildings in all climates. 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 (starting 2015) cannot be achieved by any type of building except for maintenance facilities in some climate zones.

Well insulated and air tight building envelope significantly reduces heating and cooling loads on the HVAC systems, and minimizes the impact of different system types selected. For example, the HVAC system type can be selected using multiple criteria (e.g., greater energy efficiency, ease of operation and maintenance, and ease of installation). Some heating and cooling technologies that can reduce building site energy use will result in increased use of source fuel. For example, while the use of ground-source heat pumps (GSHPs) may appear to be an attractive choice to reduce building site energy consumption, calculations made back to the source fuels negate many of the gains related to the use of GSHPs, and in some locations, show that GSHPs use more source fuel than alternative technologies.

When buildings built or retrofitted with a high performance building envelope, using advanced lighting systems and highly efficient "low exergy" HVAC systems reach a theoretical energy use minimum, the largest percentage of the remaining energy use in the building will be related to its "mission": lighting, plug loads, and domestic hot water usage. It is important to understand these loads, to improve their efficiency, and to reduce their use. Additional savings may be

Table 8. Renewable Energy Options for the Building Center

Central Heating Systems	Compared Retrofit Options	Total Heat/ Electricity Production MBtu/kWh$_e$ (MJ/ kWh$_e$)	Heat Production LPG – MBtu (MJ)	Heat Production Solar MBtu (MJ)	Heat Production Biomass – MBtu (MJ)	Investment Heating ($)	Payback Time Heating (years)
LPG boilers for heating Option 1	Base Case vs. Cluster Upgrade with Radiant Cooling, DOAS & IDEC	158,211 (166,912,605)	158,211 (166,912,605)	0 (0)	0 (0)	0	See Table 6
		64,726 (68,285,930)	64,726 (68,285,930)	0 (0)	0 (0)	0	
LPG boilers with SWH (DHW – Barracks) Option 2	Base Case LPG vs. Base Case LPG + Solar Thermal Systems	158,211 (166,912,605)	158,211 (166,912,605)	0 (0)	0 (0)	0	0
		153,522 (161,965,710)	102,833 (108,488,815)	50,378 (53,148,790)	0 (0)	646,282	7
Biomass boilers + SWH (DHW – Barracks) + LPG boilers Option 3	Base Case LPG vs. Base Case Biomass + Solar Thermal + LPG	158,211 (166,912,605)	158,211 (166,912,605)	0 (0)	0 (0)	0	0
		153,393 (161,829,615)	738 (778,590)	55,378 (58,423,790)	97,277 (102,627,235)	1,313,280	6
Biomass boilers + SWH (DHW – Barracks) + LPG boilers (peak load) Option 4	Bldg Upgrade with Radiant cooling, DOAS & IDEC +LPG boilers vs. Bldg Upgrade with Radiant cooling, DOAS & IDEC(LPG + biomass+ SWH)	64,726 (68,285,930)	64,726 (68,285,930)	0 (0)	0 (0)	0	0
		60,041 (63,343,255)	447 (471,585)	39,544 (41,718,920)	20,050 (21,152,750)	923,200	10
PV Barracks		36,390 (38,391,450)				$143,562	47.5
PV Dining Facilities		5,240 (5,528,200)				20,673	47.5

achieved with measures related to improved efficiency of power generation supplied to the building (co- and tri-generation) and use of energy supplied from renewable energy sources. Connecting a building to a Combined Heat and Power (CHP) plant, can further reduce the building's fossil fuel usage by 15–25% depending on the thermal-to-electric load ratio.

The analysis applied to the existing building cluster that will be undergoing major retrofit shows that it is possible, with only a slight additional cost, to fund energy saving projects that will reduce the energy consumed to heat, cool, and ventilate facilities by 44–49 percent of electrical use and 30–59 percent of heating use. Using the incremental cost of these projects over the retrofit costs, the additional savings will provide a payback of less than 10 yrs. Also, it is possible to achieve net zero fossil fuel energy used for heating and cooling using solar thermal and biomass based generation technologies. Standalone solar photovoltaic power generation is not a cost-effective technology, but when used in combination with other demand-based and thermal generation technologies, may result in a cost-effective NZE solution.

Under a future US climate regulatory regime, the credits associated with greenhouse gas emissions may have significant value and should be included in the financial evaluation of all projects. The costs of natural gas, alternative energy

technology, alternative fuels and the impact of greenhouse gas regulation are significant uncertainties in the future. For this reason, implementing construction and retrofit projects by connecting buildings to centralized systems is an approach that minimizes the potential future risks. The integrated energy solution recommended here demonstrates that vastly improved energy efficiency and greenhouse gas reduction are feasible in the context of a normal scale development using proven approaches from the United States and elsewhere.

A "business as usual" approach employs individual boilers and chillers for each building, and normally results in a significant overcapacity and over time excessive energy use by this equipment. Alternatively, district heating and cooling systems link buildings in common networks that eliminate inefficient over-capacity of boilers and chillers and allow the integrated system to meet the integrated peak loads instead of the sum of individual peak loads. This way, efficient machines can be added now so that, in the future, new technologies may more easily added at one common location instead of in each individual building.

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