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ENERGY SAVING POTENTIAL OF RESIDENTIAL HVAC OPTIONS AT FORT IRWIN, CALIFORNIA

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MASTER

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ABSTRACT

The Pacific Northwest Laboratory (PNL) evaluated heating and cooling system options for existing family housing at Fort Irwin, California. The purpose of this work was to quantify the energy conservation potential of alternative system types and to identify the most cost-effective technology available. The conventional residential heating/cooling systems at Fort Irwin are separate propane forced-air furnaces and central air conditioners. The options examined included air- and ground-source heat pumps, a natural gas furnace with central air conditioning, and a natural-gas-fired heat pump. The most cost-effective technology applicable to Fort Irwin was found to be the high-efficiency ground-source heat pumps. If all conventional units were replaced immediately, the net energy savings would be 76,660 MBtu (80.9 TJ) per year and a reduction in electrical demand of approximately 15,000 kW-month. The initial investment for implementing this technology would be approximately $7.1 million, with a savings-to-investment ratio of 1.74.

NOMENCLATURE

Btu	British thermal unit
TJ	terajoule
GJ	gigajoule
kW	kilowatt
kWh	kilowatthour
gal	gallon
l	liter
h	hour
MWh	megawatthour
mo	month
y	year
°C	degree Celsius
°F	degree Fahrenheit

INTRODUCTION

The U.S. Army Forces Command (FORSCOM) has tasked the U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP), supported by the Pacific Northwest Laboratory (PNL), to identify, evaluate, and assist in acquiring all cost-effective energy projects at Fort Irwin, California. To meet its federally mandated target of reducing overall energy consumption by 30% from 1985 levels by the year 2005, Fort Irwin has been aggressively pursuing all feasible base-wide energy conservation projects.

At Fort Irwin, one major energy end-use sector targeted for improved energy efficiency is the on-post family housing heating/cooling systems. Family housing at Fort Irwin consists of 1,637 units, which, with 2.9 million square feet of floor space, makes up the single largest building category by square footage. The conventional residential heating/cooling system is a propane (LPG) forced-air furnace and central air conditioner. Operation of these systems accounts for approximately 12% (8,612 MWh) of the total electric energy and 35% (78,109 MBtu [82 TJ]) of the propane consumed at Fort Irwin annually. Obviously, this end-use sector represents a significant energy conservation resource if the maximum savings is fully captured.

The number of conceivable energy conservation measures, fuel-switching opportunities, and renewable energy projects at a federal facility is very large. The Pacific Northwest Laboratory uses two methods to select, evaluate, and prioritize these energy resource opportunities (EROs). The first is the Facility Energy Decision Screening (FEDS) model for most building-related end uses. The second is a manual process to evaluate all the remaining end uses.

This paper presents a detailed description of the FEDS methodology used by PNL to identify and evaluate nine alternative residential heating/cooling systems applicable to Fort Irwin. The potential energy savings results from full implementation of the most life-cycle-cost-effective technology are also presented.

FACILITY ENERGY DECISION SCREENING PROCESS

The FEDS model is a multilevel software tool designed to provide a comprehensive approach to fuel-neutral, technology-independent, integrated (energy) resource planning and acquisition. It was developed becasue no tool existed that would meet the requirements of the FEDS process. FEDS currently has two levels--Level-1 and Level-2. Level-1 is a menu-driven DOS-based software program designed for facility energy managers as a screening tool. Level-1 assesses the likelihood of cost-effective energy projects based on high-level facility inputs and numerous assumptions. The output of Level-1 is used to assess a facility's overall energy conservation potential from the perspectives of potential energy savings, potential cost savings, and estimated investment requirement.

Level-2 is also a DOS-based software program that can be used by facility energy managers to identify, characterize, and assess individual energy projects. However, Level-2 goes into far greater detail, providing specific information on energy and cost savings, as well as the estimated investment requirement for specific technology retrofits. Level-2 is the appropriate analysis to follow positive Level-1 results; typically, a Level-2 input file can be initiated from a Level-1 input file. Level-2 allows the user to enter facility-specific data inputs to replace the inferred default values from Level-1. These inputs form "building sets," which are groups of buildings similar in use, age, construction type, fuel use, fuel availability, or other definable characteristics. By developing building sets based on detailed facility data, Level-2 tailors the analysis to the facility and provides more accurate and detailed economic findings.

Currently, FEDS Level-1 and Level-2 analyze most major building end uses (heating, cooling, lighting, ventilation, and service hot water) including their interactive effects (e.g., the effect of a lighting technology on heating and cooling loads). The resultant output provides specific cost, energy (and demand changes), and life-cycle cost (LCC) information, by cost-effective technology.

The second method PNL uses addresses those end uses not analyzed by the FEDS software. This analytical approach is a three-step manual-calculation (hereafter referred to as "Manual") process developed by PNL to make ERO selection, evaluation, and prioritization manageable. It was this manual process that PNL used to evaluate the residential heating/cooling systems options at Fort Irwin. The steps in this process are:

- Preliminary Screening. Select promising EROs from a master list, considering the site's mission, building stock, end-use equipment characteristics, utility characteristics, climate, energy costs, other local conditions that affect ERO viability, and recommendations from site staff.
- Cost and Performance Analysis. Establish, with a reasonable degree of accuracy, the technical and economic feasibility of each ERO that passed the preliminary screening. Perform an analysis comparing the operating and economic performance of the existing equipment and the ERO. Where applicable, include impacts on energy security and the environment in the analysis.
- Life-Cycle Cost Analysis and Prioritization. Perform an LCC analysis and rank EROs by net savings, so that a package with the optimal return on investment can be defined. If any utility cost-sharing or rebate programs exist, they can be included within this evaluation step.

All federal agencies are required to evaluate the LCC of alternative technologies when making energy investments. An LCC evaluation computes the total long-run costs of alternative actions and identifies the action that maximizes the net savings of the energy investment. The LCC analysis and prioritization step used in both the Level-2 and manual methods is required by, and complies with, federal law (10 CFR 436).

MANUAL ERO SELECTION PROCESS

According to 10 CFR 436, federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs. Life-cycle costing methods and procedures for evaluating federal energy projects are provided by the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards [NBS]). The *Life-Cycle Costing Manual for the Federal Energy Management Program* (NBS, 1987) provides the methodologies, procedures, and equations to be used in a life-cycle cost analysis. Its annual supplement, the *Energy Prices and Discount Factors for Life-Cycle Cost Analysis* (NIST, 1993), provides the discount rate and energy escalation rates to be used in the analysis. The analysis at Fort Irwin was performed in "real" terms; that is, the analysis assumed that prices for all goods and services would vary at the same rate as the inflation rate. Consequently, the "real" rate of inflation is zero. A life-cycle cost evaluation computes the total long-run costs of a number of potential actions and selects the action that minimizes the long-run costs. The LCC of a potential investment is the present value of all of the costs associated with the investment over time. The first step in calculating the LCC is to identify the relevant costs: these are listed in Table 1.

Life-Cycle Cost Calculation

The LCC of an alternative is calculated by summing the present values of the installed cost, the annual energy cost, the annual operations and maintenance (O&M) cost, and the replacement cost, as shown in Equation (1):

$$LCC = PV_{IC} + PV_{EC} + PV_{OM} + PV_{REP} \quad (1)$$

where

LCC = life-cycle cost
PV_{IC} = present value of installed cost
PV_{EC} = present value of annual energy cost
PV_{OM} = present value of annual O&M cost
PV_{REP} = present value of future replacement cost.

TABLE 1: COST ELEMENTS IN THE LIFE-CYCLE-COST ANALYSIS

Cost Element	Description	Example
Installed Cost	Cost of materials purchased and the labor required to install them	Price of an energy-efficient HVAC system, plus cost of labor to install
Energy Cost	Annual expenditures on energy to operate equipment; includes both energy and demand charges	A lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.
Nonfuel Operations and Maintenance	Annual expenditures on parts and activities required to operate equipment	Replacing air-conditioner filters
Replacement Costs	Expenditures to replace equipment upon failure	Replacing an oil furnace when it is no longer usable

Installed Cost

The installed cost is the one-time, first cost of an ERO. Replacement of existing equipment in the baseline case is covered by the replacement cost category. The present value of installed cost is used because not all EROs are "Replace Immediately" (RI) actions. In those cases where the ERO is to be implemented immediately, the present value of the installed cost is equal to the installed cost. When implementation of an ERO is scheduled for some future time, however, as in the case of "Replace on Failure" (ROF) EROs, the installed cost paid at that time must be discounted back to the present.

Energy Cost

The present value of the annual energy cost is composed of both energy and demand costs. Energy costs represent the recurring annual expenditures for energy to operate equipment. These costs include both the fuel costs for consumption and the demand charges. The estimated stream of annual energy and demand costs over the analysis period is adjusted to account for increasing real energy price and is discounted to determine the present value of the future cost stream. This adjustment for price escalation and discounting is accomplished through the use of a modified uniform present value factor (UPV*), which is provided annually by NIST (1993). The UPV* incorporates the discount rate and the projected energy price rates of change. For ROF measures, the existing stream of costs is assumed to continue until failure of the existing equipment, at which time the ERO cost stream replaces it.

Operations and Maintenance Cost

The present value of the annual O&M cost is the discounted stream of annual nonfuel expenditures on parts and activities required to operate the equipment. The present value of the stream of expenditures is calculated using the uniform present value factor (UPV). As with energy costs, the existing stream of costs for ROF measures is assumed to continue until failure of the existing equipment, at which time the ERO cost stream replaces it.

Replacement Cost

Although the installed cost category covers the first cost of implementing an ERO, subsequent equipment installations fall into the replacement cost category, as do all equipment costs associated with the baseline case. Unlike energy and O&M expenditures, replacement costs are not regular, annual expenses. The present value of the replacement cost is the discounted stream of expenditures to replace equipment upon failure. Although the cost to replace a piece of equipment is actually borne in the year in which the equipment is bought, the replacement costs are annualized for this analysis. Any part of the annualized cost that would be borne after the analysis period is then subtracted from the total, in effect adding a salvage value. If the remaining time in the analysis period is less than the life of equipment installed for the ERO, the installed cost will overstate the true cost. The replacement cost calculation corrects for this overstatement. In this situation, the PV_{REP} is negative, corresponding to negative replacement costs (salvage value).

Existing equipment is assumed to have no salvage value or disposal cost. Although these assumptions may not be entirely accurate, they partially offset each other. If salvage value is to be included for existing equipment, a few requirements must be met. First, it must be likely that the base will actually carry out a salvage process rather than dispose of the equipment. Regardless of value, if the base does not carry out this process, no savings will be accrued. Second, the salvage value should be the actual value of the equipment in its existing condition, less all costs associated with preparing it for sale and selling it. If this resulting net value is not greater than the disposal cost, then it should be ignored for analysis purposes.

Net Savings Calculation

Energy resource opportunities are selected for implementation on the basis of their net savings. The net savings of an ERO is the life-cycle savings of the ERO, as compared to not implementing the ERO, as shown in Equation (2):

$$NS = LCC - LCC' \qquad (2)$$

where

NS = the net savings of the ERO
LCC = the life-cycle cost of the existing situation
LCC' = the life-cycle cost if the ERO is implemented.

Most EROs are selected according to a very simple rule: if the net savings is positive, then the project should be undertaken. If the net savings is zero or negative, then the ERO should not be implemented. A positive net savings means the long-run costs of the ERO are less than the long-run costs of the existing situation.

The selection criteria can be complicated by a number of factors. If the ERO is part of a set of mutually exclusive options, then only the option with the highest net savings is selected. This is the case with the residential HVAC system, as there are a number of options (e.g., heat pumps, furnace plus air conditioner), and only one heating and cooling system can be installed. Any of the EROs might be chosen, or it may be optimal to do nothing. If the net savings of two or more EROs considered is positive, then the ERO with the highest net savings would produce the greatest benefits and should be selected.

FORT IRWIN CHARACTERISTICS

Fort Irwin is a roughly 1,000-mi^2 (2500-km^2) U.S. Army Forces Command (FORSCOM) facility situated in the Mojave Desert approximately 37 mi (60 km) northeast of Barstow, California, and south of Death Valley. The main cantonment area is located near the southeastern portion of Fort Irwin. Irwins's primary mission is to operate the National Training Center (NTC). The NTC is a support facility for training troops normally stationed at other posts throughout the United States. A total of twelve 28-day training rotations are scheduled each year. This mission results in erratic energy consumption because a large portion of its population is transient, moving on- and off-site as dictated by the training schedules.

The climate at Fort Irwin is classified as "high desert," with an average annual rainfall of 2.5 in. (6 cm), most of which falls between December and February. Summer maximum temperatures are around 104°F (40°C), and winter minimum temperatures are around 29°F (-2°C). Annual heating and cooling degree-days (base 65°F) are 2,547 and 2,272, respectively.

RESIDENTIAL HVAC OPTIONS

There are 1,637 "older" family housing units at Fort Irwin. Approximately one-third were built in the early 1960s, one-third in the early 1980s, and the remainder in the late 1980s. The structures are primarily wood frame construction with varying levels of insulation in the walls and ceilings. All are equipped with basically the same inefficient propane forced-air furnace and central air conditioning systems.

The equipment options evaluated in this assessment were

1 - air-source heat pump
    1a) minimum compliance
    1b) high-efficiency
2- ground-source heat pump
    2a) average efficiency
    2b) high-efficiency
3 - LPG furnace and central air
    3a) minimum compliance
    3b) high-efficiency
4 - natural gas furnace and central air
    4a) minimum compliance
    4b) high-efficiency
5 - gas-fired heat pump.

Although natural gas is not currently available at Fort Irwin, the natural gas options were included to compare the operating cost of natural gas and propane. The natural gas rate used in the analysis was an estimate based on information provided by Fort personnel and representatives of possible natural gas providers. In addition, each equipment option was evaluated on both replacement bases--RI and ROF.

The technical assumptions used in this analysis are as follows:

- The existing LPG furnaces have an average size of 50 kBtu/h (0.5 GJ/h) input and an annual fuel utilization efficiency (AFUE) of 70.5%.
- The existing air conditioners have an average size of 2.5 tons and a seasonal energy efficiency ratio (SEER) of 8.0.
- The replacement equipment efficiencies and sizes are shown in Table 2.
- Retrofit energy consumption is based on the actual equipment size and estimated run hours of each replacement unit to meet the same load as the existing equipment. The replacement equipment sizes are different from the existing equipment size in almost all cases because actual equipment was chosen for the retrofit options.
- Existing energy consumption was calculated using previously developed energy use intensities (EUIs): 2.91 kWh/ft^2-yr (0.1 GJ/(m^2-y))for cooling and 26.37 kBtu/(f^2-y) (0.3 GJ/(m^2-y)) for heating (Richman et al., 1994).
- Operating hours for the existing equipment are based on the EUIs and equipment capacities as described above. Operating hours for the retrofit equipment are calculated from the existing equipment hours modified by the replacement equipment efficiencies and capacities.

TABLE 2: EFFICIENCY RATINGS AND SIZES OF REPLACEMENT HVAC EQUIPMENT

Option	Replacement Equipment	Cooling Efficiency	Heating Efficiency	Cooling Capacity kBtu/h (MJ/h)	Heating Capacity kBtu/h (MJ/h)
1a	Min. Compliance Air-Source Heat Pump	10.0 SEER	7.0 HSPF	28.2 (29.8)	27.4 (28.9)
1b	High-Eff. Air-Source Heat Pump	15.4 SEER	8.3 HSPF	29.0 (30.6)	29.0 (30.6)
2a	Avg. Eff. Ground-Source Heat Pump	13.3 EER	2.8 COP	30.2 (31.9)	20.8 (21.9)
2b	High-Eff. Ground-Source Heat Pump	16.0 EER	3.5 COP	31.2 (32.9)	21.2 (22.4)
3a & 4a	Min. Compliance Furnace and A/C	10.0 SEER	78.0% AFUE	28.6 (30.2)	40.0 (42.2)
3b & 4b	High-Eff. Furnace and A/C	15.7 SEER	92.6% AFUE	30.8 (32.5)	37.0 (39.0)
5	Gas-Fired Heat Pump	1.1 COP	1.3 COP	36.0 (38.0)	53.5 (56.4)

Notes:
(1) Efficiencies for the LPG and natural gas furnace and central air conditioner options are assumed the same; the only difference for these two options is the price of fuel.
(2) Regarding ground-source heat pumps 1) There are no efficiency standards for ground-source heat pumps, so an average efficiency unit was chosen to represent the minimum-compliance case. 2) Because the ground temperature remains fairly constant, the given efficiencies are assumed to represent seasonal values (EER = SEER).

Table 3 defines the assumptions common to all of the residential HVAC EROs analyzed. Other cost assumptions are as follows:

- Prices for all goods and services (e.g., installed cost of a technology) will vary at the same rate as the inflation rate; therefore the "real" rate of inflation is zero.
- Energy or fuel prices vary at a rate different from that of the inflation rate. NIST (1993) reports the value by which the energy prices vary from the real rate of inflation (the escalation rate).
- The discount rate was 3.1% real (NIST, 1993), and the analysis period was 25 years.
- The replacement equipment installed costs are shown in Table 4.
- O&M costs were $75/yr for all air- and ground-source heat pump options, $85/yr for all furnace and air-conditioner options (including the existing), and $105/yr for the gas-fired heat pump option.
- The cost of natural gas was assumed to be $0.35/therm ($3.32/GJ).

RESULTS

The FEDS manual process described above was used to evaluate the various residential HVAC EROs at Fort Irwin. The results are shown in Table 5. Of all EROs considered, only one was determined to not be cost-effective—the high-efficiency air-source heat pump (Option 1b-RI). The other EROs were cost-effective and had net savings ranging from $0.9 to $6.9 million and savings-to-investment ratios (SIRs) ranging from 1.16 to 2.48. Energy savings ranged from 2,470 MBtu (2.6 TJ) to 76,680 MBtu (80.9 TJ), and electricity demand savings ranged from 6,290 kW-month to 34,380 kW-month.

The gas-fired heat pump (Option 5) was the winning ERO (i.e., the highest net savings). However, because natural gas was not available at Fort Irwin (and it was unknown if the unit can be converted to LPG), this option was considered "not implementable" at Fort Irwin. In addition, present or future air quality laws may limit the use of individual natural gas engines at each housing unit.

The runner-up HVAC ERO was the immediate replacement of the existing equipment with high-efficiency ground-source heat pumps (Option 2b). This ERO

TABLE 3: FUEL PRICES USED IN LCC ANALYSIS

	Current Fuel Price
Natural Gas	$0.35/therm ($3.32/GJ)
Electricity	
Summer On-Peak	$0.13752/kWh
Summer Mid-Peak	$0.06517/kWh
Summer Off-Peak	$0.04077/kWh
Winter Mid-Peak	$0.07688/kWh
Winter Off-Peak	$0.04335/kWh
Electricity Demand	
Summer On-Peak	$18.90/kW
Summer Mid-Peak	$2.35/kW
Winter Mid-Peak	$3.15/kW
Propane (LPG)	$0.473/gal ($0.125/l)

TABLE 4: INSTALLED COST OF REPLACEMENT EQUIPMENT

Option	Replacement Equipment	Material (1994 $)	Labor (1994 $)
1a	Minimum Compliance Air-Source Heat Pump	2,180	559
1b	High-Efficiency Air-Source Heat Pump	5,175	559
2a	Average-Efficiency Ground-Source Heat Pump	3,000	559
2b	High-Efficiency Ground-Source Heat Pump	3,770	559
3a & 4a	Minimum Compliance Furnace and A/C	1,483	468
3b & 4b	High-Efficiency Furnace and A/C	4,725	468
5	Gas-Fired Heat Pump	5,000	750

Note: Material costs are from manufacturers' catalogs and sales representatives. Labor costs are from R. S. Means (1992). All costs include 15% overhead and profit. Material and labor costs for the ground-source heat pump excavation and piping are included in the material cost column above.

TABLE 5: SUMMARY OF FEDS RESULTS FOR RESIDENTIAL HEATING/COOLING OPTIONS.

Equip. Option	RI or ROF	First Cost ($000)	Existing O&M ($000/y)	Retrofit O&M ($000/y)	LPG (MBtu/y) (TJ/y)	Electric (MWh/y)	Demand (MW-mo)	Energy ($000/y)	Demand ($000/y)	Total ($000/y)	Net Savings ($000)	SIR
1a	ROF	4,483	139	123	77,702 (82)	-6,111	6.8	94	75	170	1,905	1.53
1b	ROF	9,387	139	123	77,702 (82)	-2,480	15.9	244	156	400	1,316	1.17
2a	RI	5,287	139	123	77,702 (82)	-2,317	12.1	357	191	549	4,234	1.73
2b	RI	7,087	139	123	77,702 (82)	-300	15.2	479	234	714	5,244	1.74
3a	RI	3,194	139	139	7,471 (8)	1,714	6.3	238	112	350	4,351	2.36
3b	ROF	8,501	139	139	18,544 (20)	4,205	15.1	295	150	444	2,717	1.40
4a	ROF	3,194	139	139	7,471 (8)	1,714	6.3	104	72	175	3,030	2.17
4b	ROF	8,501	139	139	18,544 (20)	4,205	15.1	256	150	405	2,051	1.30
5	RI	9,413	139	172	-26,797 (-28)	8,574	34.4	561	497	1,058	6,944	1.74

would require an investment of $7.1 million and had net savings equal to $5.2 million, a SIR of 1.74, annual energy savings of 76,680 MBtu (80.9 TJ), and demand savings of 15,230 kW-mo. Although the high-efficiency ground-source heat pump increases electricity consumption by 299,850 kWh (1.1 TJ), it would result in a decrease of 77,700 MBtu (80.2 TJ) of propane. The energy and demand savings result in an annualized energy cost savings of $479,320 and annualized electric demand savings of $234,470.

Typical annual energy consumption at Fort Irwin is approximately 1,100,000 MBtu (1160 TJ), which includes fuel use by vehicles. If vehicle fuel use is excluded, then total estimated energy consumption at Fort Irwin is approximately 500,000 MBtu (528 TJ). The ground-source heat pump savings represent approximately 7% of annual energy consumption and 15% of energy consumption, excluding vehicles.

The gas-fired heat pump was the only option that would require significant additional maintenance; the oil, oil filter, and spark plug must be replaced yearly at an estimated cost (materials and labor) of $105 per unit. Replacing the furnace and air conditioner with a heat pump should result in minor O&M savings of approximately $16,370/yr.

CONCLUSION

Fort Irwin faces a monumental task in its efforts to reduce its overall energy consumption by the mandated 30%. Key to accomplishing this is a systematic methodology to identify and prioritize the most life-cycle-cost-effective conservation measures from the many and sometimes conflicting choices. In some instances, even the order in which a series of conservation measures is applied to a building can significantly affect the final energy savings realized. The FEDS model is a tool the energy manager can use to assess a facility's energy conservation potential in a comprehensive, fuel-neutral, and technology-neutral manner. Once the initial assessment has been completed, specific energy projects for a selected building, building types, or energy end use can be readily identified.

Within this context, the FEDS manual process was used to successfully evaluate 18 residential HVAC EROs applicable to Fort Irwin. Those that were not LCC-effective were eliminated from further consideration. The remaining options were ranked by net savings. The most LCC-effective ERO was found to be the gas heat pump, with the high-efficiency ground source heat pump second. Energy savings (and energy cost savings) that could be realized from an immediate replacement of all of the conventional furnace and air-conditioning equipment were found to be significant.

In addition, fuel-switching from LPG to electricity associated with the winning ERO is an attractive feature to Fort Irwin, as the local air quality could be improved from the reduction in on-site burning of fossil fuel.

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