Cost-Effective Energy Efficiency in the Czech Republic

Tom Secrest and Steve A. Shankle, Pacific Northwest Laboratory
Zirka Zemen, SEVEn
Andrew Popelka, Tecogen

Energy efficiency is a particularly important issue in the emerging economies of Eastern Europe. Inefficient energy use is prevalent, placing stress on an already fragile economy, Much of the energy used in the Czech Republic is supplied by lignite, a soft brown form of coal. Its combustion is largely responsible for an extreme acid rain problem and other forms of air pollution and land-use complications.

This paper reports on a project in the mid-sized (250,000 residents) industrial city of Plzen, in the Czech Republic. The Facility Energy Decision Screening process, developed by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy's (DOE's) Federal Energy Management Program, was applied to the city to determine the level of cost-effective energy efficiency potential in the city.

The project found that significant cost-effective energy potential exists in Plzen, primarily in large, cooperatively owned apartment buildings heated by district systems. These results were enthusiastically received by the Plzen city council. Because of its success, this project will be a model for the advancement of energy efficiency throughout Central and Eastern Europe via a network of Energy Efficiency Centers established by AID with support from PNL.

Introduction

The city of Plzen in the Czech Republic is considering options for providing its citizens energy services to lower their energy bills and reduce pollution created by the burning of low quality brown coal. The U.S. Agency for International Development, under the Support for Eastern European Democracy program, funded an assessment of the space and water heat efficiency potential in Plzen. The assessment was funded through the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and was conducted by the Pacific Northwest Laboratory and its subcontractors, Tecogen, a U.S.-based energy research and development firm, and SEVEn, the Czech Center for Energy Efficiency.

This report describes the residential building assessment for Plzen. The project's primary objective was to characterize the city's baseline space and water heat energy use and cost-effective efficiency potential that exists in residential buildings. This effort was not intended to provide a definitive analysis to enable the selection of specific application technologies.

Given the data limitations and assumptions made, it is estimated that a significant cost-effective efficiency resource exists in the space and water heating end-uses in residential buildings. At current fuel prices, the cost-effective resource amounts to 27% of total building sector space and water heat energy consumption and increases to 29% and 34% of building sector consumption in two scenarios in which energy price controls and subsidies are relaxed,

About 84% of the efficiency resource resides in the district heating area at current fuel prices; this number drops to 80% and 67% of the efficiency resource in two higher fuel price scenarios. Space and hot water heat provided by gaseous fuels is the next largest efficiency resource, increasing from 14% of the resource under current prices to 17% and 20% in the higher fuel price scenarios. While coal consumption for local boiler and onsite consumption is expected to increase significantly, it accounts for less than 2% of the total efficiency resource under the high fuel price scenario. Under the highest fuel price scenario, the coal-based efficiency resource increases to about 13% of the total resource. Finally, the electricity-based efficiency resource is the least sensitive to fuel prices and mounts to less than 1% of the total efficiency resource in all price scenarios.

Nearly 80% of the residential sector efficiency resource is in high-rise, multifamily buildings, and, of this, 98% is in the district heating area under current fuel prices. Under the highest fuel price scenario, about 70% of the residential sector efficiency resource is in the high-rise building types, of which 90% is in the district heating area.

The Ievelized energy cost of the total efficiency resource is on the order of 74 Czech Koruna (Kc) per gigajoule (GJ) as compared to the current consumption-weighted average energy price of 103 Kc/GJ.[1] The levelized energy cost of the cost-effective efficiency resource is 75 Kc/GJ and 79 Kc/GJ, respectively, at the consumption-weighted prices used in the higher fuel price scenarios, 152 Kc/GJ and 286 Kc/GJ. Under current prices, the levelized energy cost of the efficiency resource within the district system fuel type is on the order of 79 Kc/GJ as compared to 136 Kc/GJ for district heat. As compared to a levelized energy cost for the district-heat-based efficiency resource of 80 Kc/GJ, district heat is projected to increase to 200 Kc/GJ and 350 Kc/GJ under the higher price scenarios.

The Czech Republic city of Plzen is considering options for providing energy services to its citizens to lower their energy bills and reduce pollution created by the burning of low quality brown coal. In the fall of 1992, the U.S. Agency for International Development (AID), under the Support for Eastern European Democracy (SEED) program, agreed to fund an assessment of the heating options for the buildings sector in Plzen. To obtain needed assistance, AID entered into an inter-agency agreement with the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EE) and Office of Fossil Energy (FE). Both EE and FE were assigned responsibility for the demand- and supply-side assessments, respectively.

Energy Use Baseline

This section describes the energy use baseline for the project. The following sections discuss the energy use sectors, the primary fuel input data for heat production Plzen, the energy consumption data for the baseline.

Energy Use Sectors

Three sectors were defined for allocating the consumption of thermal energy: residential, non-residential, and industrial. Subsectors were then defined within the residential sector. The residential subsectors are described below:

Res-1	houses 300 to 400 years old
Res-2	houses 150 to 180 years old
Res-3	houses from the beginning of the 20th century
Res-4	villa houses from the thirties
Res-5	one-floor detached houses
Res-6	two-floor detached houses
Res-7	cooperative buildings from the fifties to sixties
Res-8	eight-floor pre-fab houses.

The estimated numbers of residential buildings and heated square meters by building type for Plzen are shown in Table 1.

These data indicate that about 50% of residential heated floorspace is found in the pre-fab high-rise multi-family housing types with another 7% in the multi-family cooperative type (Res-7). Detached housing accounts for about 16% of heated floorspace with the remaining 26% accounted for by the four building types dating from the early 1930s and older.

Fuel Input Data

Table 2 provides the primary fuel inputs for the major types of conversion units/processes for heat production in Plzen.

Energy Consumption Data

The 20.9 million GJs of primary energy consumed to produce thermal energy are accounted for by major function in Table 3.

Of the total primary energy consumption used to provide thermal energy, about 38% provides space and water heat, 20% meets process energy requirements, 38% is lost in conversion and transmission/distribution losses, and about 3% is used for electricity generation.

Losses for the production and transmission of district heat amount to about 44% of total energy input to generate district heat. Conversion losses for local consumption and boilers amount to about 25% of their total combined energy input. A discussion of heat and hot water energy and process energy use follows.

Heat and Hot Water Consumption. Energy consumption for heating and hot water use by fuel type and heating equipment type is shown in Table 4 for the three sectors. Nearly 40% of heat and hot water energy use is accounted for by the residential sector with about 22% used by the non-residential building sector, and 40% by the industrial sector.

Table 1. Estimated Number and Heated Area of Residential Buildings by Type

Group	Number of Buildings	Heated Area (m^2)	Percent of Total Heated Area
300- to 400-year-old houses	137	56,370	1%
150- to 180-year-old houses	1,177	392,287	8%
1900 vintage houses	1,120	718,741	14%
1930s villas	377	142,347	3%
Single story, detached house	5,851	464,088	9%
Two story, detached house	2,218	364,716	7%
Cooperatives from the 1950s and 1960s	706	334,522	7%
Prefab, high rise apartment buildings	2,034	2,539,960	51%
Total	13,620	5,013,031	100%

Table 2. Total Primary Fuel Input Data for the Production of Heat Energy, 1989

Site of Consumption	Solid Fuels (GJ)[a]	Liquid Fuels (GJ)	Gaseous Fuels (GJ)	Total (GJ)	Percent of Total
Onsite	857,212	0	1,157,834	2,015,046	10%
Boiler plants	1,450,050	585,247	2,323,767	4,359,064	21%
CHSS sources	14,341,440	149,645	0	14,491,085	69%
Total	16,648,702	734,892	3,481,601	20,865,195	100%
Percent of Total	80%	3%	17%	100%	

(a) One gigajoule equals one million BTUs.

(b) Onsite consumption refers to the conversion of fuel to heat and/or hot water within the individual living space, be it a single- or multi-family dwelling. Boiler plant consumption refers to the 586 distributed boilers in Plzen, each serving a single building or a group of buildings. CHSS consumption refers to either the central or distributed boilers serving the CHSS systems.

Table 3. Primary Heat Energy Fuel Consumption Data by Function, 1989

Function	Sector	Consumption (1000 GJ)[(a)]
Heat and Hot Water	Residential	3,047
	Non-Residential	1,769
	Industrial	3,038
	Subtotal	7,854
Process	Industrial	4,041
	Other	207
	Subtotal	4,248
Electricity Production		675
Losses	CHSS	6,417
	Other	1,565
	Subtotal	7,982
Total		20,865

(a) One gigajoule equals one million BTUs.

Table 4. Space and Water Heat Energy Consumption Data by Fuel Type, Heating Equipment Type and Sector, 1989

Sector	Solid Fuels, On-Site (GJ)	Gaseous Fuels, On-site (GJ)	Solid Fuels, Boiler Plants (GJ)	Liquid Fuels, Boiler Plants (GJ)	Gaseous Fuels, Boiler Plants (GJ)	CHSSS (GJ)	Electricity (GJ)	Total (GJ)	Percent of Total
Residential	318,169	633,912	233,275	0	108,690	1,673,465	79,884	3,047,395	39%
Non-residential	92,987	184,831	238,944	2,653	236,679	994,823	17,739	1,768,655	23%
Industrial	46,493	25,538	176,989	129,475	290,239	2,359,975	8,870	3,037,579	39%
Total	457,649	844,281	649,208	132,128	635,608	5,028,263	106,493	7,853,629	100%
Percent of Total	6%	11%	8%	2%	8%	64%	1%	100%	

(a) One gigajoule equals one million BTU.

District heat is the major energy source for heat and hot water at 64% of the total, followed by building boilers supplying 18% and individual home heating equipment supplying nearly 17%.

Specifically, space heat accounts for nearly 80% of the total energy used for residential heat and hot water energy consumption. The high-rise buildings account for about 55% of space heat energy use and about 51% of the total floorspace, yielding the highest use intensity. These buildings are also predominately served by district heat, which accounts for about 88% of their total estimated heat energy use and 90% of the residential sector space heat consumption. The remainder of the residential building stock is served primarily by home heating equipment fired by solid fuel and gaseous fuels, 13% and 21% of total energy use, respectively. Local boilers account for about 10% of residential space heat energy consumption with solid and gaseous fuels at 7% and 3% of the residential total, respectively. Only three building types are served to any extent by local boilers using solid and gaseous fuels—150- to 180-year-old houses, multifamily houses dating from the beginning of the 20th century, and 1950 to 1960 vintage cooperatives.

Hot Water Energy Consumption. As with heat energy consumption, the high-rise buildings account for the majority of energy use for hot water, accounting for 60% of the total hot water energy use. Of this amount, about 87% is provided by the district heating system and the remainder by natural gas and solid fuels, about 10% and 4%, respectively. Following district heat at 58% of total hot water energy use, natural gas is second accounting for about 25% of total energy use, and solid fuels and electricity are about equal at 8% each.

Efficiency Assessment of Residential Buildings

This section presents the estimated efficiency resource in the residential buildings. The following subsections describe the efficiency measures considered, the technical and economic analysis approach employed to estimate the efficiency resource, and the building sector efficiency resource.

Efficiency Measures

Fifty energy conservation opportunities (ECOs) were considered for evaluation for the residential building stock in Plzen. Of these, 24 ECOs were determined to be applicable to more than one building group and were analyzed with respect to energy efficiency potential, cost, and availability on the Czech market. Table 5 summarizes the 24 efficiency measures considered by application costs per unit and measured lifetime.

Analysis Approach

The 24 measures were analyzed by the six fuel and equipment types identified: onsite gas; onsite coal; boiler house gas; boiler house coal; district heat; and electricity, Measures were not analyzed for electric space heating as this represents only 1.3% of the total heating load. However, measures were considered for application to electric water heat.

A situation that was not analyzed is that base space and water heat use may increase because of increases in living standards. Should base use increase, the efficiency potential will also increase.

Following is a description of the technical analysis method for developing each measure category's estimated per measure efficiency improvement and the economic analysis method.

Technical Analysis Method. The analysis method applied to each category of efficiency measures is described below.

Analyses of Building Envelope Measures. The ASEAM3 (A Simplified Energy Analysis Method, version 3.0) computer program for simulating heat losses in buildings was used for the analysis which is based on procedures recommended by the American Society For Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Fundamentals. The program, provides predictions of maximum heat loads, annual energy consumption levels, and the effects of other factors on building heat loads (occupancy, lighting, appliances usage, insolation, etc.).

Baseline and post-measure installation heat losses were calculated for each measure. The difference between the two heat loss values is the energy savings. The development of the baseline building heating loads for each building type required making several assumptions. The most important assumptions involved infiltration rates, internal temperatures in different locations, and occupancy and equipment schedules. These assumptions were based on recommended values, previous experience, and information gathered by surveys (number of opened windows in apartments in occupied and unoccupied periods).

In the modelling of each ECO, only the pertinent value describing the given ECO was changed. The insulation of walls, ceilings, and floors was modelled by lower U-values; the weatherstripping of windows was modelled by lowering the infiltration coefficient; the installation of triple pane and storm windows was accomplished by lowering the window U-value; the weatherstripping of stairway windows and doors and the installation of entrance double doors were both modelled by increasing the unheated space temperature; and the installation of a heat recovery unit for the bath/kitchen was accomplished by reducing the infiltration rate.

Analyses of Water Heating Measures. Energy saving calculations for low-flow shower heads and faucet flow restrictors are based on statistical information regarding the use of hot water in the Czech Republic, statistical information on hot water use by purpose (dish washing, shower, laundry, etc.), and manufacturers performance information. The calculation of energy savings obtainable by insulating the hot water pipes in unconditioned spaces

Table 5. Efficiency Measures Considered and Estimated Per Unit Cost and Lifetime

Number	Energy saving option description	Unit	Cost [Kč/Unit]	Lifetime [Years]
	Building envelope			
1	**Insulate Building Exterior Side Walls.**	m^2	700 to 800	30
2	**Insulate Top Floor Ceiling.**	m^2	700	30
3	**Insulate Attic.**	m^2	385	30
4	**Insulate Floor Above Basement.**	m^2	650	30
5	**Weatherstrip Elevator Penthouse, Stairway, Doors and Windows.**	m	40	10
6	**Weatherstrip Windows and Doors.**	m	30	10
7	**Install Revolving or Double Door in Building Vestibule.**	unit	24,000	30
8	**Install Triple Pane Windows.**	m^2	5,409	30
9	**Install Storm Windows.**	m^2	600	30
10	**Install Heat Reflectors Behind Each Radiator or Heater.**	m^2	148	5
11	**Remove Draperies from Radiator.**		0	
	Domestic Water Heating			
12	**Install Low-Flow Shower Heads.**	unit	400	10
13	**Install Flow Restrictors in Faucets.**	unit	70	5
14	**Insulate Hot Water Pipes in Unconditioned Spaces.**	m	158	15
15	**Install Hot Water Flow Meters.**	unit	600	30
	Heating system			
16	**Balance Heating System Using Existing Valves.**	flat	400	5
17	**Install Balancing Valves on Each Radiator.**	unit	350	15
18	**a. Install Thermostatic Radiator Valves (TRVs)**	unit	380	15
	b. Install Heat Allocators/Meters	unit	67	1
	c. Install Building Level GJ Meter	unit	24,000 to 46,000	30
19	**a. Install Zone Valves on Each Radiator**	unit	330	15
	b. Install Central Thermostats with On-Time Counter in Each Flat	unit	2,300	15
	c. Install Building Level GJ Meter	unit	24,000 to 46,000	30
20	**a. Install Zone Valves on Each Radiator**	unit	330	15
	b. Install Central Programmable Thermostats with On-Time Counter in Each Flat	unit	6,120	15
	c. Install Building Level GJ Meter	unit	24,000 to 46,000	30
21	**Install Building Energy Management System (EMS).**	unit - radiator	7,000	30
	Ventilation and Heat Recovery			
22	a. Install Heat Recovery Vent System in Basements	unit	7,600	10
	b. Weatherstrip Basement Windows and Doors	m	40	10
23	**Install Waste Water Heat Recovery Heat Exchanger**	unit	10,200 to 126,000	15
24	**a. Install Bath/Kitchen Vent Heat Recovery Heat Exchanger**	unit	9,050	10
	b. Install Back-Flow Damper in Kitchen/Bath Vent Duct	unit	350	15

is based on lowering heat losses by additional pipe insulation with an improved R-value or the replacement of existing insulation with high performance materials. Due to the limited nature of this project, the exact length and sizes of pipes could not be determined, but, rather, were estimated for each building group based on typical plumbing designs.

Analyses of Building Heating Systems. All ECOs analyzed in this category provide improved energy management in a building. The installation of temperature control devices (TRV, TS, EMS) in conjunction with the installation of energy cost allocation equipment provides building occupants with an incentive to reduce energy consumption. The use of a programmable thermostat also improves the use of setback during unoccupied periods. The combination of better energy management and distribution within a building and the ability of motivated occupants to lower the energy consumption results in two effects:

- room temperature is kept at the lowest acceptable level

- windows are opened only to maintain acceptable indoor air quality and not for temperature control.

The computerized calculations used for the building heating system energy saving measures were also derived from the procedures recommended by the (ASHRAE) Fundamentals. For each measure, both the baseline and post-measure installation heat losses were calculated. The difference between the two heat loss values is then the energy use reduction calculation. For each ECO analyzed, the temperatures and infiltration rates were estimated based on the performance of the proposed equipment and expected occupant behavior. In general, more accurate equipment and more motivated occupants will produce lower temperatures and lower infiltration rates. The temperatures were not assumed to drop below accepted comfort limits (for example, 21 “C in living rooms and 18°C in bedrooms).

Analyses of Ventilation and Heat Recovery Measures. The energy saving calculations developed for the heat recovery applications were again derived from procedures recommended by the ASHRAE Fundamentals. Inputs to the calculations include properties and mass flow of media from which the waste heat is recovered and manufactures performance characteristics for the heat recovery equipment.

Economic Analysis. A 2.0% real discount rate and a 30-year analysis period were used. Energy prices are currently subject to some form of regulation and/or subsidy, both of which will be modified in the near future. In order to investigate the impact of likely changes in near-term energy prices on the energy efficiency resource, two fuel price scenarios were developed in conjunction with staff from Plzen, TEZA, and ZCE. The prices for 1993 and the low and high scenarios are shown in Table 6.

The low price scenario corresponds to removal of subsidies, and the high price scenario roughly corresponds to West European absolute and relative fuel prices. In both scenarios, the price increases are assumed to happen instantaneously.

Efficiency Assessment Results

This section provides the energy and economic assessment of the 24 building sector efficiency measures considered for the analysis. The method employed to assess the efficiency potential consisted of four steps. The first step screened the individual measures by net present value (NPV)–measures having a positive NPV were retained for additional analysis. The second step combined the measures to identify interactive effects in order to avoid double counting the efficiency potential and to deselect measures that reduced the NPV of selected bundles for individual building types. Third, the bundles and applicable individual measures were then evaluated for each residential building type to estimate residential sector efficiency potential.

Table 6. Fuel Price Levels Used to Drive Analysis of Efficiency Resource by Fuel and Equipment Type

Fuel and Equipment Type	Current Price (Kc/GJ)[(a)]	Low Price (Kc/GJ)	High Price (Kc/GJ)	Low Scenario	High Scenario
Onsite Gas	67.50	100.00	270.00	48.1%	300.00%
Onsite Coal	54.80	80.00	150.00	46.0%	173.7%
Electricity	94.10	200.00	350.00	112.5%	271.9%
Boiler House Gas	97.40	120.00	160.00	23.2%	64.3%
Boiler House Coal	31.45	50.00	100.00	59.0%	218.0%
District Heat	136.40	200.00	350.00	46.6%	156.6%

(a) One gigajoule equals one million BTUs. Twenty-eight Czech Koruna equals one U.S. dollar.

The following seven measures which had an interactive effect, were selected for application:

- insulate building exterior side walls
- weatherstrip elevator penthouse, stairway, doors, and windows
- weatherstrip windows and doors
- install revolving or double door in vestibule
- install storm windows
- install zone valves on each radiator and install central thermostats with 'on time counter' in each apartment
- install heat recovery vent system in basements.

Depending upon the building type, a subset of these items was selected based upon their combined performance.

The following seven measures that did not exhibit interactive effects were also selected for application depending on their performance:

- install heat reflectors behind each radiator or heater
- remove draperies from radiator
- install low-flow shower heads
- install flow restrictors on faucets
- insulate hot water pipes in unconditioned spaces
- install hot water flow meters
- install waste water heat recovery heat exchanger.

Baseline Efficiency Assesment. This section first presents the efficiency assessment using the base economic assumptions and current fuel prices for the residential buildings.

Table 7 provides the cost-effective space and water heat efficiency resource by residential sector building, fuel, and equipment type for 1993 using the base economic assumptions and fuel prices.

The 797,000 GJ of cost-effective savings represents a 26% reduction in current residential sector energy consumption. Residential district heating energy use can be reduced by 40%, which represents over 84% of all of the cost-effective savings. Residential natural gas consumption can be reduced by 38%, accounting for 13% of the efficiency potential, and coal consumption can be reduced by 5%, which represents about 2% of the efficiency potential, Residential electricity use can be cost-effectively reduced by 13%, although this represents less than 1% of total cost-effective savings.

Table 8 provides the economic analysis for the residential sector efficiency resource presented in Table 7.

Table 7. Residential Sector Cost-Effective Space and Water Heat Efficiency Resource by Fuel and Equipment Type Using Base Assumptions and 1993 Fuel Prices, 1993

Fuel	Baseline Use (GJ)[(a)]	Percent of Total Use	Cost Effective Savings Potential (GJ)	Cost Effective Savings as Percent of Use	Percent of Total Cost Effective Savings	Levelized Energy Cost (Kc/GJ)[(b)]
Onsite Gas	633,911	21%	72,711	11%	9%	40
Onsite Coal	318,169	11%	15,962	5%	2%	35
Electricity	47,690	2%	6,012	13%	1%	55
BH Gas	108,689	4%	29,586	27%	4%	60
BH Coal	233,277	8%	476	0%	0%	4
District	1,673,466	56%	672,034	40%	84%	80
Total	3,015,202	100%	796,781	26%	100%	74

(a) One gigajoule equals one million BTUs.
(b) Twenty-eight Czech Koruna equal one U.S. dollar.

Table 8. Economic Analysis Results of Residential Sector Cost-Effective Energy Efficiency Resource for 1993 Baseline

	All Buildings, All Fuels	**High Rise Apartment Buildings, District Heat**	**High Rise Apartments as % of Total**
Annual Energy Use Reduction (GJ):[a]	796,781	619,412	78%
Value of Annual Savings (Million 1992 Kc):[b]	101	84	84%
Present Value of Energy Savings (Million 1992 Kc):	2,260	1,892	84%
Total Installed Cost (Million 1992 Kc):	1,167	980	84%
PV of Installed Cost (Million 1992 Kc):	1,323	1,100	83%
Simple Payback Period (Years):	12	12	
Net Present Value (Million 1992 Kc):	937	792	85%
Annualized Cost (Million 1992 Kc/Yr):	59	49	83%
Cost of Conserved Energy (1992 Kc/GJ):	74	79	

(a) One gigajoule equals one million BTUs.
(b) Twenty-eight Czech Koruna equal one U.S. dollar.

The residential sector cost-effective efficiency resource of 797,000 GJ annually is expected to cost about 1,167 million Kc and have a net present value of 937 million Kc. The cost of conserved energy (the annualized cost divided by the annual energy use reduction) works out to an average of 74 Kc/GJ for all fuels. While high-rise apartment buildings supplied by district heat account for about 50% of residential sector heat and hot water energy consumption, they account for nearly 80% of the cost-effective efficiency resource. The 79 Kc/GJ estimated cost of this resource appears to be very cost-effective when compared to the current price of 136 Kc/GJ for district heat.

Fuel Price Sensitivities. This section provides the projected efficiency resources for the two fuel price scenarios. These results show the levels of efficiency resources available in the base period using the current fuel prices and the low and high price scenarios.

The effect of the increased fuel prices is to increase the NPV of the measures, thus making more measures cost-effective and increasing the magnitude of the efficiency resource. So, the efficiency resource is made up of all the prior ECOs plus additional measures that become cost effective with the higher fuel prices.

The levelized energy cost of the individual measures remains unchanged from the baseline analysis as this value is simply the annualized installed ECO cost divided by the annual energy efficiency. But, the aggregate levelized energy cost does change because more ECOs are included in the calculation.

For the residential buildings, the fuel prices need to increase significantly to provide modest increases in the available efficiency resource. The low price scenario results in only a 6% increase in the cost-effective energy efficiency resource, although the value of these savings increases by over 50%. The high price scenario results in a 26% increase in the cost-effective resource and a 200% increase in the annual value of these savings. The NPV of the energy efficiency projects rises by nearly 110% for the low price scenario and by over 430% for the high price scenario.

Under the alternate price scenarios, the bulk of the energy savings is still found in the high-rise apartment buildings served by the district heat system. However, these savings represent a smaller fraction than under the base scenario, decreasing to 74% and 62% of the residential sector efficiency for the low and high price scenarios, respectively. This result is because more of the non-district heat related

ECOs in the other building types become cost-effective at the higher fuel prices.

Table 9 provides the cost-effective efficiency resource by fuel price scenario and fuel and heating equipment type. This table shows the level of resource increasing from 26% of baseline energy use to 33% in the high fuel price scenario. The efficiency potential for the district heat, boiler house gas, and electricity fuel types are the least sensitive to fuel price increases. The efficiency potential in the onsite gas category shows sensitivity to both price levels, and the potential in the onsite coal and boiler house coal is very sensitive to the high price scenario.

Conclusions

A major purpose of this study was to assess the energy efficiency potential that exists in the buildings sector space and water heat end-uses. Subject to the data limitations and assumptions made, a significant efficiency resource exists in the space and water heating end-uses in the residential building sector. At current prices, this resource amounts to 12% of total building sector space and water heat energy consumption and increases to 29% and 33% of building sector consumption in two scenarios in which energy price controls and subsidies are relaxed.

About 90% of the efficiency resource resides in the district heating area for the current and low price scenarios; this number drops to 80% of the efficiency resource in the high price scenarios. Space and hot water heat provided by gaseous fuels the next largest resource, increasing from 7% of the resource under current prices to 18% in the high price scenario. While coal consumption for local boiler and onsite consumption is expected to increase significantly, it still accounts for less than 3% of the total efficiency resource under the high fuel price scenario. Electricity consumption is projected to be the least sensitive to fuel prices, but the efficiency resource is 1% of less of the total.

Nearly 90% of the residential sector efficiency resource is in the high-rise, multifamily buildings. Of this, 89% is in the district heating area under current prices and 75% under the high price scenario.

The levelized energy cost of the total efficiency resource is on the order of 105 Kc/GJ as compared to the current consumption weighted average energy price of 103 Kc/GJ. At the low and high consumption weighted prices of 152 Kc/GJ and 286 Kc/GJ in the low and high price scenarios, the levelized energy cost is on the order of

Table 9. Residential Sector Cost-Effective Efficiency Resources by Fuel Price Scenario and Fuel and Heating Equipment Type

	Onsite Gas	Onsite Coal	Electricity	BH Gas	BH Coal	District Heat	Total
Baseline Energy Use (GJ)[(a)]	633,912	318,169	47,690	108,690	233,275	1,673,465	3,015,201
Efficiency Resource (GJ)							
1993 Prices	72,712	15,962	6,012	29,586	476	672,033	796,780
Low Prices	98,478	23,173	7,306	34,922	4,982	678,493	847,353
High Prices	157,962	50,853	7,344	35,711	75,390	678,585	1,005,844
Efficiency Resource, % of Use							
1993 Prices	11%	5%	13%	27%	0%	40%	26%
Low Prices	16%	7%	15%	32%	2%	41%	28%
High Prices	25%	16%	15%	33%	32%	41%	33%

(a) One gigajoule equals one million BTUs.

137 Kc/GJ. Under current prices, the levelized energy cost of the efficiency resource within the district system fuel type is on the order of 112 Kc/GJ in as compared to 136 Kc/GJ for district heat. Under the respective low and high prices scenarios, district heat is projected to increase to 200 Kc/GJ and 350 Kc/GJ as compared to a levelized energy cost for the district heat-based efficiency resource of 146 Kc/GJ .

Acknowledgments

Gratitude is expressed to Len Rogers, AID, and Elaine Guthrie, DOE, for making this study possible. Special thanks is given to Jirka Zeman at SEVEn for leading the Czech effort, Andrew Popelka at Tecogen for technical support and oversight, and Tom Secrest at PNL for project management. Bill Chandler, Director of PNL's Advanced International Studies Unit, is recognized for his foresight in establishing SEVEn and guidance in this effort.

Endnote

1. For readers interested in converting the energy and currency units to British Thermal Units (BTUs) and dollars, one GJ equals one million BTUs and about 28 Kcs equals one U.S. dollar.