Modulating Condensing Fuel-Fired Boilers

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Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

Modulating/Condensing Fuel-Fired Water Heater and Hydronic Boiler

Technology for increasing water heater/hydronic boiler efficiency

A modulating/condensing fuel-fired water heater or hydronic boiler can avoid losses associated, in conventional units, with cycling at less than full load and with unrecovered latent heat of water produced in the combustion process. A system which incorporates features that minimize cycling by modulating fuel and air flow to the combustor and that recover additional heat from condensing moisture in the flue gas stream can achieve reductions in fuel consumption, operating costs, and emissions.

This *Federal Technology Alert* (FTA) provides information on current commercial-size products with these and other features. Existing applications, energy-saving mechanisms, installation requirements, relevant case studies, sample specifications, and additional sources of information are presented.

Energy-Saving Mechanisms

Noncondensing-type hydronic boilers and water heaters are unable to recover the latent heat of water in the combustion products of fuels that contain hydrogen and are, therefore, subject to the theoretical limit of the fuel lower heating value resulting in published full-firing rate efficiencies of 78—85%. In addition, cycling losses of 10—50% may be incurred by non-modulating (on/off) units operating at less than full load. A modulating/condensing fuel-fired water heater or hydronic boiler can be an energy-efficient alternative to such conventional units.

Potential Benefits

With a condensing design, effective use of the full high heating value of the fuel may be approached when the water inlet temperature is low enough to allow substantial recovery of the latent heat of moisture in the exhaust. If wide-range combustion modulation is implemented by controlling fuel and air supply, most of the losses associated with cycling may also be avoided. Manufacturer-reported water heater and hydronic boiler efficiencies range from 93% to 99% and from 86% to 99%, respectively, depending on firing rate and inlet water temperature.

Technology Selection

The FTA series targets technologies that appear to have significant federal-sector potential and for which some federal installation experience exists. New technologies were identified through advertisements in the *Commerce Business Daily* and trade journals and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, federal sites, and other interested parties.

Technologies suggested were evaluated in terms of potential energy, cost, and environmental benefits to the federal sector. They were also categorized as those that are just coming to market and those for which field data already exist. Technologies classified as just coming to market are considered for field demonstration through the New Technology Demonstration Program, part of the U.S. Department of Energy s Federal Energy Management Program (FEMP) and industry partnerships. Technologies for which some field data already exist are considered as topics for FTAs.

Application

This design is in use at sites representing every major commercial-size building classification, including hospitals, universities, public schools, hotels, office buildings, apartment buildings, prisons, nursing homes, and industrial facilities. Of these, only 21 have been federal-sector projects in the majority of cases to provide domestic (service) hot water. The technology is appropriate for either retrofit or new construction applications and is intended to replace conventional on/off-controlled noncondensing gas-fired technology.

Water Heater Case Study

A hypothetical case study of a central natural gas-fired domestic-service water heating system for a 125-unit apartment complex in New Jersey is developed to illustrate the process required to determine the energy and cost effectiveness of a modulating/condensing water heater.

If this unit operates at an estimated annual average fuel-to-water efficiency of 95%, it will show energy savings of 21% when compared to a conventional unit with a corresponding efficiency of 75%.

The total installed cost of a modulating/condensing unit for this application is estimated to be $16,980. Annual maintenance costs are estimated to total $250 in odd service years and $474 in even service years. When entered as inputs to Building Life-Cycle Cost (BLCC) software developed by the National Institute of Standards and Technology, the estimates for these costs, the unit energy consumption, and natural gas costs for the area give a present value project cost of $124,572 for the estimated 15-year life cycle of the modulating/condensing unit.

For a conventional unit costing $14,000 installed and having the same maintenance costs as those attributed to the modulating/condensing unit, the corresponding base case software results give a present value project cost of $149,230 for the same life cycle.

Thus, the estimated advantages of the modulating/condensing unit when compared to a conventional unit in this situation are characterized on a life-cycle basis by a 21% energy saving, a 17% present value cost saving, a 9.27 savings-to-investment ratio, and a 20.65% adjusted internal rate of return.

Hydronic Boiler Case Study

The second case study considers a central natural gas-fired boiler system serving the hydronic space heating needs of a building located in Madison, Wisconsin, with a design heat loss estimated to be 5,000,000 Btu/h.

With the use of Madison hourly weather data to determine heating demand for each temperature bin, the associated annual fuel usage is estimated using the corresponding estimated efficiency of the modulating/condensing system (86% to 99% in this situation) and of a conventional system (45% to 82% here). The total heating season natural gas consumption was estimated to be 37% less for the modulating/condensing system than for the conventional system.

The total installed cost of a modulating/condensing system for this application is estimated to be $105,337. Annual maintenance costs are estimated to total $1,410 in odd service years and $1,920 in even service years. When entered as inputs to BLCC software, the estimates for these costs, the system energy consumption, and the natural gas costs for the area give a present value project cost of $886,355 for the estimated 15-year life cycle of the modulating/condensing system.

For a conventional system costing $75,000 installed and having the same maintenance costs as those attributed to the modulating/condensing system, the corresponding base case results from the BLCC computer program give a present value project cost of $1,304,638 for the same life cycle.

Thus, the estimated advantages of the modulating/condensing system when compared to a conventional system in this situation are characterized on a life-cycle basis by a 37% energy saving, a 32% present value cost saving, a 14.79 savings-to-investment ratio, and a 24.46% adjusted internal rate of return.

Federal Technology Alert

Modulating/Condensing Fuel-Fired Water Heater and Hydronic Boiler

Technology for increasing water heater/hydronic boiler efficiency

Abstract

A modulating/condensing fuel-fired water heater or hydronic boiler can avoid losses associated, in conventional units, with cycling at less than full load and with unrecovered latent heat of water produced in the combustion process. A system which incorporates features that minimize cycling by modulating fuel and air flow to the combustor and that recover additional heat from condensing moisture in the flue gas stream can achieve reductions in fuel consumption, operating costs, and emissions.

This *Federal Technology Alert* provides information on current commercial-size products with these and other features. Existing applications, energy-saving mechanisms, and installation requirements are described. Two relevant case studies with sample specifications are provided to illustrate procedures by which a federal energy manager may estimate energy savings and life-cycle costs for potential applications of this technology. A list of federal-sector users and a bibliography are included for prospective users who have specific questions not fully addressed here.

Modulating/Condensing Fuel-Fired Water Heater (photo courtesy of Aerco International, Inc.)

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About the Technology

Noncondensing-type hydronic boilers and water heaters are unable to recover the latent heat of water in the combustion products of fuels that contain hydrogen and are, therefore, subject to the theoretical limit of the fuel lower heating value resulting in published full-firing rate efficiencies of 78—85%. In addition, cycling losses of 10—50% may be incurred by non-modulating (on/off) units operating at less than full load.

A modulating/condensing fuel-fired water heater or hydronic boiler can be an energy-efficient alternative to such conventional units. For example, the Aerco International KC-1000 Series Domestic Water Heater/Hydronic Boiler is a direct fuel-fired heating unit featuring a modulating forced-draft combustion system (usable firing rate of 70,000—1,000,000 Btu/h), condensing heat exchanger design, and proportional integral derivative temperature control. It is offered in two basic models: water heater and hydronic boiler.

A water heater model (illustrated in Figure 1) is a semi-instantaneous, open loop system with a 23-gallon storage volume and a recovery capacity of 1,116 gal/h at a 100¡F temperature rise. Control in the water heater model is from an internal setpoint (constant temperature adjustable from 100¡F to 200¡F) with load feed-forward (based on a signal from an integral BTU transmitter) and outlet temperature feedback.

The hydronic boiler model can be employed either as a single stand-alone unit or as part of a multi-boiler arrangement (as shown in Figure 2) to supply closed loop heating systems. The single hydronic boiler has three control options: (1) internal setpoint [constant temperature adjustable from 50¡F to 220¡F] with outlet temperature feedback; (2) external setpoint [indoor/outdoor reset ratio adjustable from 0.3 to 3.0 based on building reference, outside air, and header temperatures] with outlet temperature feedback; and (3) remote setpoint [4—20 mA signal corresponding to 50—220¡F] with outlet temperature feedback. The hydronic multi-boiler (2—8 units) system may be controlled from internal, external, or remote setpoints by means of a Boiler Management System for sequential or parallel boiler firing (at rates up to 8,000,000 Btu/h in an eight-unit arrangement) with outlet temperature feedback.

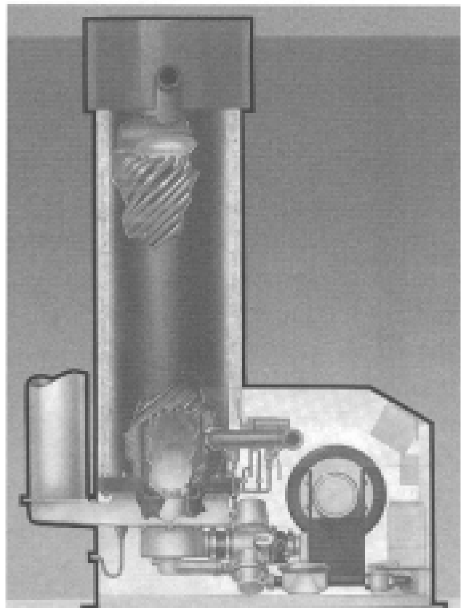

Figure 1. Cutaway View of Water Heater Unit

Each model is currently produced in two fuel versions: (1) natural gas and (2) propane.

Figure 2. Typical Multi-Unit Water Heater and Hydronic Boiler Installation (photo courtesy of Aerco International, Inc.)

Application Domain

This design is in use at sites representing every major commercial-size building classification. More than 2,700 units have been installed from Alaska to Jamaica at 1,200 facilities including hospitals, universities, public schools, hotels, office buildings, apartment buildings, prisons, nursing homes, and industrial facilities. Of these, only 21 have been federal-sector projects (Department of Defense, Department of Housing and Urban Development, Federal Reserve System, and Veterans Administration) in the majority of cases to provide domestic (service) hot water.

The technology is appropriate for either retrofit or new construction applications and is intended to replace conventional on/off-controlled non-condensing gas-fired technology such as copper/copper clad fin tube or cast iron type hydronic boilers and water heaters combining a boiler-type baffled U-tube heat exchanger with a storage tank.

As a rough sizing guide (based on installations at altitudes below 2,000 feet assuming 40¡F inlet water temperature and building recirculation), one of these water heaters can supply buildings with approximately 85—150 apartments, 50—100 nursing home beds, 80—100 hospital/medical facility beds, 800—1000 commuting students, 140 resident (dormitory) college students, 1400—1800 office workers, or 30 showers in prisons/correctional facilities/gymnasiums (gang shower applications in prisons or gymnasiums may require additional stratified storage to satisfy the load requirement at an economical cost).

Energy-Saving Mechanisms

To avoid condensation with associated acidic conditions and potential corrosion of metals used in conventional units, a secondary pumping loop may be required to ensure that the inlet water is warm enough to keep flue-side surface temperatures higher than the local dew points (see Figure 3) of the exhaust stream.

With a condensing design, effective use of the full high heating value of the fuel may be approached when the water inlet temperature is low enough to allow substantial recovery of the latent heat of moisture in the exhaust. If wide-range combustion modulation (see, for example, Figure 4) is implemented by controlling fuel and air supply, most of the losses associated with cycling may also be avoided. In addition, the semi-instantaneous fire-tube design provides a compact configuration with minimum storage to reduce radiant heat losses. Manufacturer reported efficiencies range from 93% to 99% on the water heater model (in Underwriters Laboratories tests) and 86% to 99% on the hydronic boiler model (as given in Figure 5), depending on firing rate and inlet water temperature. The average annual efficiency for both units is estimated by a manufacturer to be approximately 95%.

Other Benefits

The capability of the unit to maintain tight temperature control (–4¡F for the water heater version; –2¡F for the boiler version), modulate firing rate with load, and operate in the condensing mode eliminates the

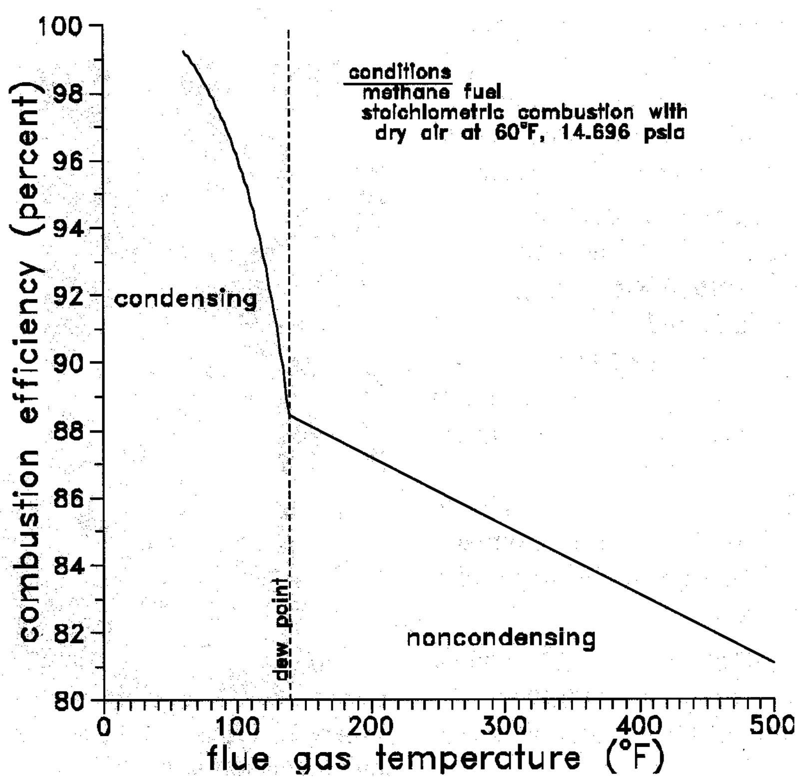

Figure 3. Combustion Efficiency Versus Flue Gas Temperature

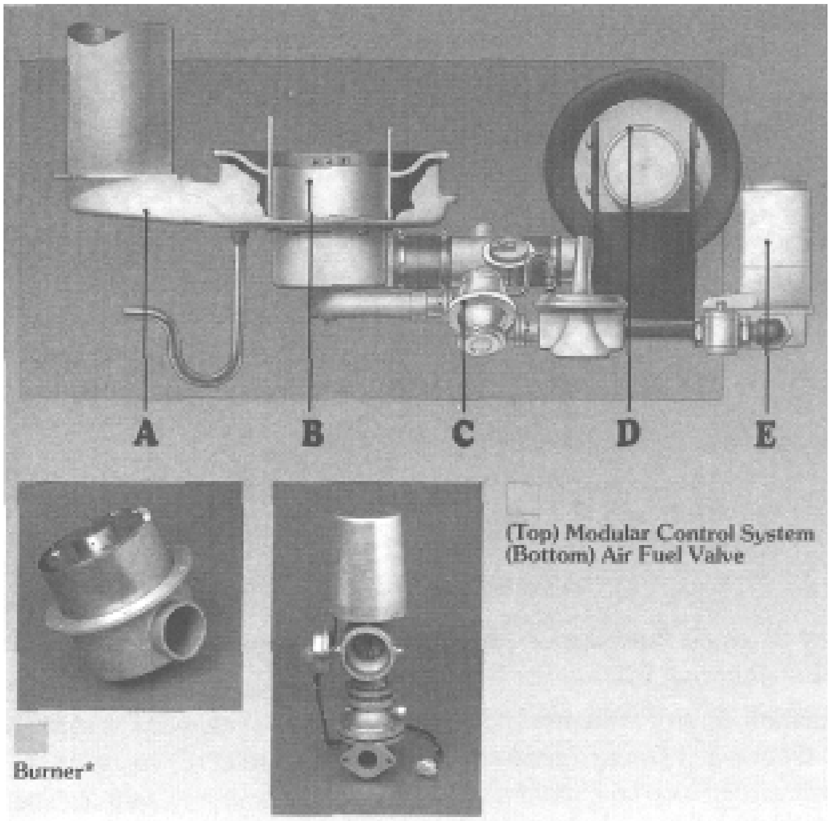

Figure 4. Air/Fuel Supply System

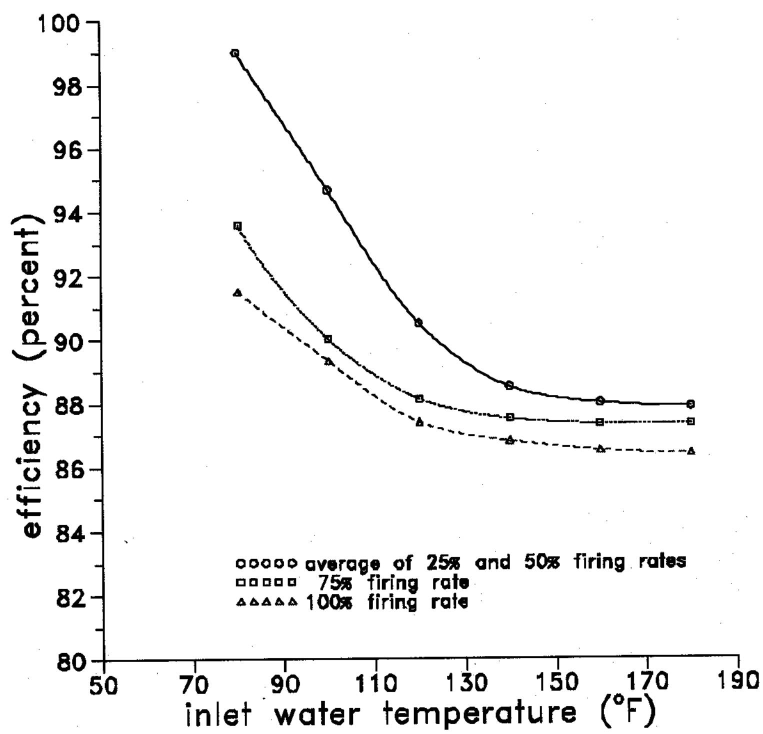

Figure 5. An Example Hydronic Boiler Efficiency Versus Inlet Water Temperature

need for additional system storage, temperature control blending valves, and primary-secondary pumping systems in most applications. Because this water heater does not include appreciable water storage, the risk of *Legionella pneumophila* bacteria proliferation is considerably diminished.

The incorporation of a baffle-free vertical-helical combustion chamber/ heat exchanger design (see Figure 6) using 70-30 copper-nickel for the

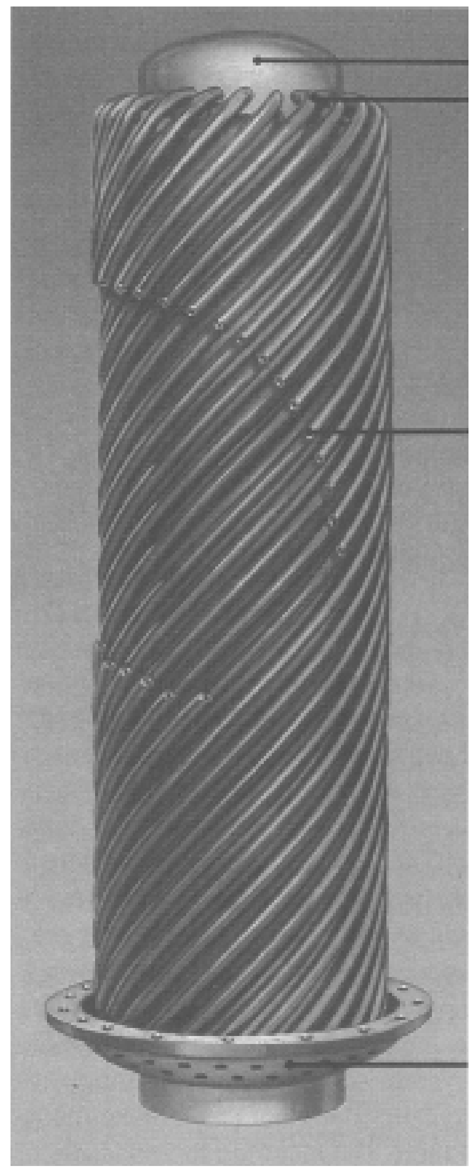

Figure 6. Vertical-Helical Combustion Chamber/Heat Exchanger

tubes and 90-10 copper-nickel for the wall, head, and tube sheet (combined in the water heater version with a copper-lined pressure vessel) in a counterflow configuration reduces stress points, scaling tendencies, and corrosion impacts which can restrict service life in competing units which employ heat exchangers using carbon steel and/or alternate configurations. An equal-capacity water heater of conventional design employing a storage tank will typically have a footprint four times larger than the example KC-1000 and may incur increased construction costs if structurally reinforced floors or special supports are required.

A stainless steel/Inconel high-velocity nozzle-mix burner with interrupted direct spark ignition, rectification flame detection, and water volume damping restricts noise levels of the unit to about 6 dB below those associated with pulsed-combustion models (which also require vibration isolators and flexible connections to the building piping systems).

Variations

Generally it is recommended that separate water heating and space heating (hydronic boiler) systems be employed wherever possible to achieve the greatest benefits of high efficiency and precise temperature control. However, in special situations where certain limitations on space, weight, or fuel supply lines apply, multiple hydronic boiler units can be employed in a dual service system as a combination domestic water/boiler plant (see, for example, Figure 7). Operation in this fashion would require the addition of dual-service controls (boiler management/combination control systems) and an external hot water storage/generator tank with closed loop coil, motorized valve, and circulation pump.

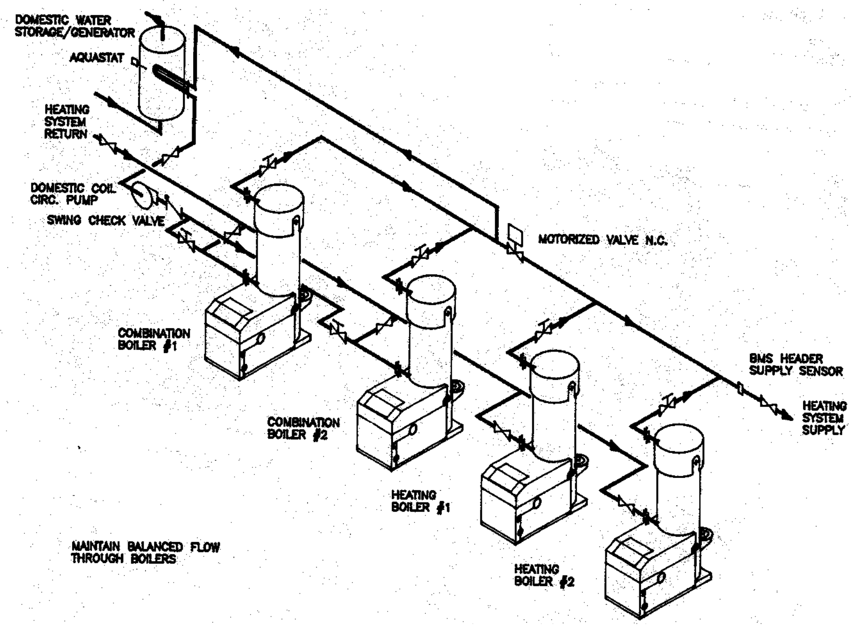

Figure 7. Example Combination Plant Piping Arrangement

Installation

The dimensions of the unit, 57" (L) x 22" (W) x 8" (H), allow easy clearance through most doorways. Unit weights are 1,210 lb dry; 1,250 lb shipping; and 1,399 lb installed (wet).

Manufacturer published installation guidelines are in accordance with the current National Electrical Code (National Fire Protection Association 70) and the National Fuel Gas Code (National Fire Protection Association 54/American National Standards Institute Z223.1).

Fuel supply requirements are 14" WC maximum static, 10" WC maximum/8.5" WC minimum operating over the entire firing range for natural gas or propane ($1^{1}/_{4}$" NPT), provided by an external pressure regulator with no more than 1" WC droop at full volume flow (1,000 scfh for natural gas).

Adequate provision must also be made per National Fire Protection Association codes for 250 scfm of combustion air from within the building (if air infiltration to the building is sufficient) or from outside the building (through either louvered envelope openings or a sealed combustion air duct between the outdoors and the unit) to the blower in each unit. The minimum diameter of a sealed combustion air duct for one unit is 6 inches.

For gas-fired equipment such as the hydronic boiler, classified as an American National Standards Institute Category III and IV appliance (operating temperatures of up to 480¡F, positive pressure with direct side wall venting capability, condensing flue gas service), the only exhaust vent material approved by both Underwriters Laboratories Inc. and the American Gas Association and available in the required 6" diameter is AL-29-4C stainless steel.

Electrical service requirements are 120 V, single-phase, 60 Hz, 20 A (8-A current requirement at full firing, 4-A current draw at minimum firing, 40-W power consumption in standby mode).

Water connections are 2" NPT for the water heater model (maximum constant water flow: 30 gal/min) and 4" ANSI 150-lb flange for the hydronic boiler model (minimum water flow: 25 gal/min to maintain stable boiler operation; maximum water flow: 150 gal/min to prevent construction material erosion). The condensate (less than 5 gal/h) connection is $^5/_8$" ID hose and the drain valve is 1 inch.

Both models are Underwriters Laboratories Inc. and Underwriters Laboratories of Canada listed for alcove installation on combustible flooring.

Certifications

The example KC-1000 series hydronic boiler and domestic water heater design is in accordance with and approved by the following classification organizations:

- Underwriters Laboratories Inc. listed in accordance with UL 7 9 5 *Standards for Safety: Commercial-Industrial Gas Heating Equipment*;
- Factory Mutual System approved combustion system (standard gas train in accordance with CSD-1, optional gas train in accordance with Industrial Risk Insurers is available);
- American Society of Mechanical Engineers in accordance with the *ASME Boiler and Pressure Vessel Code, Section IV: Rules for Construction of Heating Boilers* (hydronic boiler stamped with code symbol H certifying 150 psig maximum allowable working pressure, water heater stamped with code symbol HLW certifying 160 psig maximum allowable working pressure at 200¡F maximum temperature); and
- Underwriters Laboratories of Canada listed.

The hydronic boiler is classified according to the American National Standards Institute as a Category III and IV appliance; hence it is capable of direct side-wall venting.

Emissions

Unit emissions are in accordance with all current national and state standards, meeting the requirements of Underwriters Laboratories 795 as well as American National Standards Institute Z21.13 and Z21.10.3.

Maintenance

The hydronic boiler version requires the following routine maintenance: (1) inspect the spark ignitor and flame detector every 6 months and replace each every 12 months [20 min labor]; (2) check the combustion settings 6 months after the initial installation, and check/recalibrate the combustion settings every 12 months thereafter [90 min]; and (3) inspect the combustion chamber every 24 months [60 min, including replacement of the burner gasket and the burner release gasket]. The water heater version requires all the routine maintenance items indicated above for the hydronic boiler plus two additional items: (4) lubricate the BTU transmitter pump 6 months after initial installation and then every 12 months thereafter [15 min] and (5) inspect the heat exchanger [90 min with access through bolted upper heater head, including replacement of the head gasket and the head release gasket] for scale build-up every 24 months under typical conditions or as frequently as every 4 months if the unit is subjected to severe hard water conditions.

No unusual maintenance issues were noted by contacts at existing federal sites.

Water Heater Case Study

Requirement

Consider a central natural gas-fired domestic-service water heating system for a 125-unit apartment complex located in New Jersey with dishwashers, building recirculation, and public residential-type clothes washing areas. The annual average water temperature entering the heater is 55¡F, the specified supply temperature at the heater outlet is 140¡F, and the local altitude is less than 2,000 feet.

According to American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE) guidelines [Table 7 in Chapter 44 (Service Water Heating) of the *1991 ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Applications*], this complex will require an average hot water flow of 4,625 gal/day. The useful heat required to achieve the specified 85¡F temperature rise at this flow is 3,219,300 Btu/day [(4,625 gal/day) x (85¡F) x (8.189 Btu/gal/¡F)].

Energy Savings Potential

Manufacturer sizing guidelines indicate that one KC-1000 unit will provide adequate capacity for this application. If the unit operates at an annual average fuel-to-water ef-ficiency of 95% as suggested by the manufacturer, its annual natural gas consumption will be 12,369 therms [(3,219,300 Btu/day) x (365 days/yr) / (0.95) / (100,000 Btu/therm)]. If the conventional system has an annual average fuel-to-water efficiency of 75%, its associated annual natural gas consumption will be 15,667 therms. In this case, the modulating/condensing option would provide energy savings of 21% when compared to the conventional system reflected in a corresponding reduction in natural gas consumption of 3,298 therms per year. Over the estimated 15-year life of the units, the total savings amount to 49,470 therms.

Life-Cycle Cost

The current local natural gas price is assumed to be $0.63/therm and future fuel price escalation is taken to be that for commercial customers in Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont) as incorporated in the Building Life-Cycle Cost (BLCC) software available from the National Institute of Standards and Technology.

If a KC-1000 (Model GWW) costs $14,000, installation parts $504 (gas pressure regulator $154 and vent material $350), installation labor $2,176, and startup labor $300, then the total cost to startup is $16,980. Based on the five routine requirements detailed earlier, annual maintenance costs are estimated by the manufacturer to total $250 ($105 parts and $145 labor) in odd service years and $474 ($179 parts and $295 labor) in even service years.

These costs and the annual natural gas consumption determined above were entered as inputs to BLCC. For compatibility with the program data format, maintenance cost estimates were entered in two components: $250 annual recurring costs attributed to Items 1, 2, and 4 (to which one uniform present value factor is applied in BLCC) and $224 nonannually recurring costs attributed to Items 3 and 5 (to which a different single present value factor for each relevant year is applied in BLCC). To estimate fuel costs, BLCC employs DOE energy price escalation rates for the designated time period, fuel type, region, and class of service to calculate modified uniform present value factors which are applied to the given consumption and current energy price. Based on the indicated 4.0% discount rate for federal energy conservation and renewable energy projects, the results for the estimated 15-year life of the water heater are as given in Appendix A, with an estimated present value life-cycle project cost of $124,572.

If the conventional unit costs $14,000 installed and has the same maintenance costs as those attributed to the modulating/condensing unit, the corresponding base case result from the BLCC computer program gives an estimated present value life-cycle project cost of $149,230.

When the BLCC comparison routine is exercised, the output (Figure 8) shows that the present value of the net savings achieved by choosing the modulating/condensing option is $24,658, the associated savings-to-investment ratio is 9.27, and the related adjusted internal rate of return is 20.65%. An example information sheet, recasting the items already described in the format required if this case had been considered under the Energy Conservation Investment Program (ECIP), is presented in Appendix B. For simplified comparison purposes here, the SIOH (supervision, inspection and overhead) and Design Cost elements, Items 1B and 1C of the ECIP format, have been assumed to be included in the construction cost given as Item 1A. The simple payback for this case is estimated to be 1.43 years. An associated sample specification is included as Appendix C.

Hydronic Boiler Case Study

Requirement

Consider a central natural gas-fired boiler system serving the hydronic space heating needs of a building located in Madison, Wisconsin. Heat loss from the building under design conditions (-20¡F for this location from ASHRAE) is estimated to be 5,000,000 Btu/h. The building balance point temperature is specified as 60¡F. Supply water temperature at design conditions is specified to be 170¡F. The design temperature differential is 30¡F.

Energy Savings Potential

Manufacturer sizing methods indicate that six KC-1000 units controlled by a boiler management system will provide adequate capacity for this application. Madison hourly weather data for each temperature bin are taken from *ASHRAE RP-385: Bin and Degree Hour Weather Data for Simplified Energy Calculations*. As

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NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS

BASE CASE: CFTTWHWP
ALTERNATIVE: KC1000GWW

PRINCIPAL STUDY PARAMETERS:
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ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD:      15 YEARS (1995 THROUGH 2009)
DISCOUNT RATE:   4.0% Real (exclusive of general inflation)
BASE CASE LCC FILE:   CFTTWHWP.LCC
ALTERNATIVE LCC FILE: KC1000GW.LCC

    COMPARISON OF PRESENT-VALUE COSTS

                    BASE CASE:    ALTERNATIVE:    SAVINGS
                    CFTTWHWP      KC1000GWW       FROM ALT.
INITIAL INVESTMENT ITEM(S):      ------------  ------------  ------------
 CASH REQUIREMENTS AS OF OCCUPANCY       $14,000      $16,980      -$2,980
                    ---------     ---------     ---------
   SUBTOTAL                 $14,000       $16,980       -$2,980
FUTURE COST ITEMS:
 ANNUAL AND NON-AN. RECURRING COSTS       $3,939       $3,939        $0
 ENERGY EXPENDITURES                $131,290      $103,653      $27,637
                    ---------     ---------     ---------
   SUBTOTAL                 $135,230      $107,592      $27,638
                    ---------     ---------     ---------
  TOTAL P.V. LIFE-CYCLE COST          $149,230      $124,572      $24,658

     NET SAVINGS FROM PROJECT KC1000GWW COMPARED TO PROJECT CFTTWHWP

     Net Savings  =  P.V. of non-investment savings      $27,638
              -  Increased total investment          $2,980
                                  -------------
                         Net Savings:       $24,658

          SAVINGS-TO-INVESTMENT RATIO (SIR)
       FOR PROJECT KC1000GWW COMPARED TO PROJECT CFTTWHWP

            P.V. of non-investment savings
       SIR  =  ---------------------------  = 9.27
             Increased total investment

         ADJUSTED INTERNAL RATE OF RETURN (AIRR)
       FOR PROJECT KC1000GW COMPARED TO PROJECT CFTTWHWP
     (Reinvestment rate =  4.00%; Study period = 15 years)

              AIRR =  20.65%

Note: the NS, SIR, and AIRR computations include differential capital
replacement costs and resale value (if any) as investment costs, per
NIST Handbook 135 (FEMP analysis only).
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Figure 8. Water Heater Comparative Analysis from NIST BLCC

indicated in the table below, heating demand is assumed to be proportional to the difference between balance point temperature and outside air temperature for each bin. Annual fuel usage for each bin is determined by multiplying the heating demand by the hours, dividing by estimated unit efficiency, and converting to therms. As an example, using the 20¡F bin for the Aerco system operating with the boiler management system set for external setpoint mode and parallel boiler firing, one finds its annual natural gas consumption to be 15,156 therms [(2,500,000 Btu/h) x (565 h) / (0.932) / (100,000 Btu/therm)]. Summing over all bins gives a total heating season natural gas consumption of 111,146 therms for the modulating/condensing hydronic boiler system. If the conventional system has a design point efficiency of 82%, decreasing 5% for each 10¡F above design outdoor temperature, its associated natural gas consumption will be 176,522 therms. In this case, the modulating/condensing system option would provide energy savings of 37% when compared to the conventional system reflected in a corresponding reduction in natural gas consumption of 65,376 therms per year. Over the estimated 15-year life of the system, the total savings amount to 980,640 therms. The relative efficiency and energy consumption values are presented in bar graph form in Figures 9 and 10. The substantially lower estimated energy consumption for the Aerco unit, especially in the mid to upper bin temperature ranges, reflects the higher efficiencies achievable with its modulating and condensing capabilities under the part load, low inlet temperature conditions which dominate the heating season.

Life-Cycle Cost

The current local natural gas price is assumed to be $0.50/therm and future fuel price escalation is taken to be that for commercial customers in Census Region 2 (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin).

If the six KC-1000 (Model GWB) units cost $84,000, installation parts $3,024 (gas pressure regulators $924 and vent material $2,100), boiler management system $2,760, outdoor reset kit (including outside air and common discharge header temperature sensors) $248 installation labor $13,505 and startup labor $1,800, then the total cost to startup

Hydronic Boiler Energy Savings Analysis by Bin Method

Bin Minimum Outside Air Temperature (¡F)	Heating Demand (10^6 Btu/h)	Annual Occurrence (h)	Conventional System		Aerco System		Aerco Savings	
			Efficiency (%)	Fuel (therms)	Efficiency (%)	Fuel (therms)	(%)	(therms)
55	0.312	626	44.5	4,396	96.5	2,027	53.9	2,369
50	0.625	569	47.0	7,566	99.1	3,589	52.6	3,977
45	0.938	548	49.5	10,379	99.0	5,189	50.0	5,190
40	1.250	533	52.0	12,812	98.3	6,778	47.1	6,034
35	1.562	658	54.5	18,865	97.9	10,502	44.3	8,363
30	1.875	865	57.0	28,454	97.3	16,669	41.4	11,785
25	2.188	657	59.5	24,154	96.0	14,971	38.0	9,183
20	2.500	565	62.0	22,782	93.2	15,156	33.5	7,626
15	2.812	267	64.5	11,642	91.3	8,225	29.4	3,417
10	3.125	235	67.0	10,961	90.1	8,151	25.6	2,810
5	3.438	174	69.5	8,606	89.0	6,721	21.9	1,885
0	3.750	220	72.0	11,458	88.2	9,354	18.4	2,104
-5	4.062	71	74.5	3,872	87.4	3,300	14.8	572
-10	4.375	8	77.0	455	87.1	402	11.6	53
-15	4.688	1	79.5	59	86.8	54	8.5	5
-20	5.000	1	82.0	61	86.6	58	4.9	3
heating season		**7,401**	**59.3**	**176,522**	**94.2**	**111,146**	**37.0**	**65,376**

is $105,337. Based on the three routine requirements detailed earlier, annual maintenance costs are estimated to total $1,410 ($630 parts and $780 labor) in odd service years and $1,920 ($780 parts and $1,140 labor) in even service years.

As in the first case study, these costs and the annual natural gas consumption determined above were entered as inputs to the BLCC computer program. Again, for compatibility with the program data format, maintenance cost estimates were entered in two components: $1,410 annual recurring costs attributed to Items 1 and 2 (to which one uniform present value factor is applied in BLCC) and $510 nonannually recurring costs attributed to Item 3 (to which a different single present value factor for each relevant year is applied in BLCC). Based on the indicated 4.0% discount rate for federal energy conservation and renewable energy projects, the results for the estimated 15-year life of the modulating/condensing boiler system give an estimated present value life-cycle project cost of $886,355.

If the conventional unit costs $75,000 installed and has the same maintenance costs as those attributed to the modulating/condensing system, the corresponding base case result from the BLCC computer program gives an estimated present value life-cycle project cost of $1,304,638.

When the BLCC comparison routine is exercised, it shows that the present value of the net savings achieved by choosing the modulating/condensing system option is $418,283, the associated savings-to-investment ratio is 14.79, and the related adjusted internal rate of return is 24.46%. The corresponding ECIP information sheet (showing an estimated simple payback of 0.93 year) and sample specification are presented in Appendixes D and E.

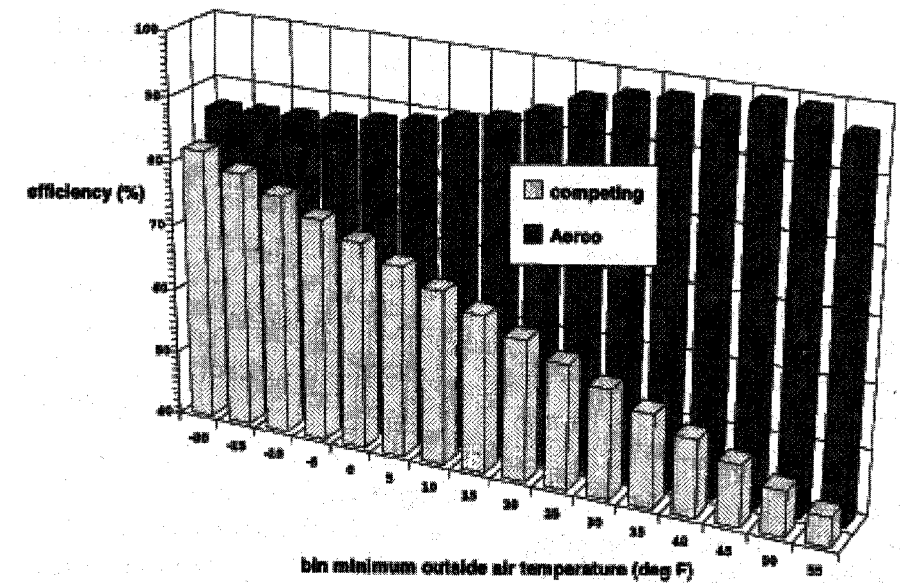

Figure 9. Hydronic Boiler Efficiency Versus Bin Minimum Outside Air Temperature

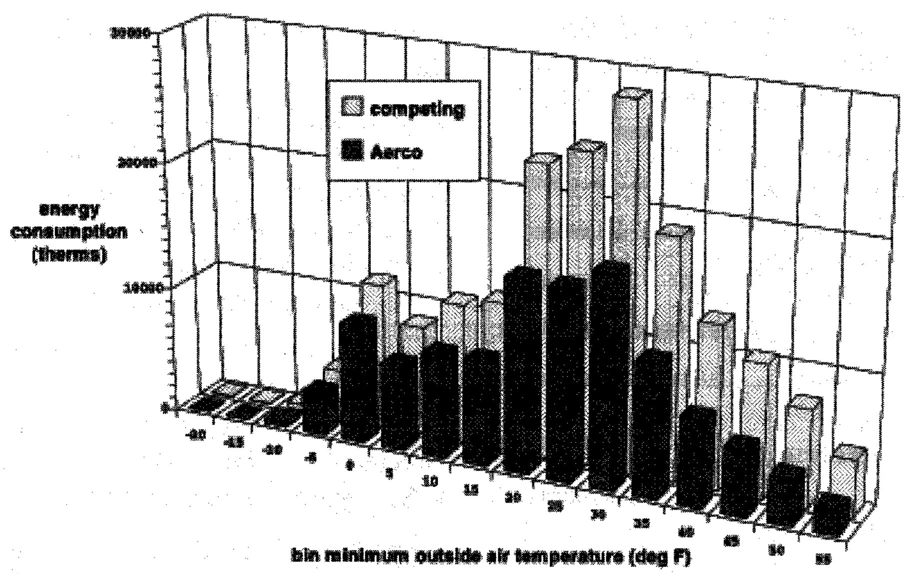

Figure 10. Hydronic Boiler Energy Consumption Versus Bin Minimum Outside Air Temperature

Manufacturers

The firms listed below were identified as suppliers of the technology at the time of development of this FTA. This listing does not purport to be complete, to indicate the right to practice the technology, or to reflect future market conditions.

Aerco International, Inc.
159 Paris Avenue
Northvale, NJ 07647
(201) 768-2400
Fax: (201) 784-8073

PVI Industries, Inc.
P.O Box 7124
Fort Worth, TX 76111
(800) 433-5654

Who is Using the Technology

The list below includes government sector contacts, agencies, and locations that have the technology currently installed and operating. The reader is invited to broaden his/her understanding of the equipment by making use of available knowledge concerning such applications in federal facilities.

Existing Sites:

Department of Defense
Department of the Air Force
377th Air Base Wing
Kirtland AFB
2050 Wyoming Boulevard, S.E.
Kirtland Air Force Base, NM 87117
Julian Nesbitt
West Zone Manager
(505) 846-5293
(three natural gas-fired hydronic boilers for an office/computer building installed in 1994)

Department of Defense
Department of the Air Force
377th Air Base Wing
Kirtland AFB
2050 Wyoming Boulevard, S.E.
Kirtland Air Force Base, NM 87117
Leonard Garcia
East Zone Manager
(505) 846-0123
(one propane-fired hydronic boiler for a fire station installed in 1993)

Federal Reserve System
Federal Reserve Bank of San Francisco
(12th District)
Salt Lake City Branch
120 South State Street
Salt Lake City, UT 84111
Ted Cruze
Building Supervisor
(801) 322-7801
(one natural gas-fired water heater for an office building installed in 1994)

Wisconsin National Guard
2402 Bowman Street
Madison, WI 53704
Ray Steinich
(608) 242-3370
(one natural gas-fired water heater for an office building installed in 1991)

Department of Defense
Department of the Army
Ft. Lewis
Fort Lewis, WA 98433
Jim Thayer
Mechanical Branch Chief
Operations and Maintenance Division
(206) 967-5237
(one natural gas-fired water heater for Building 8085, a noncommissioned officers club, installed in 1994)

Department of Defense
Department of the Air Force
62 AW/PA
100 Main Street
McChord AFB
McChord Air Force Base, WA 98438
Jim Hill
Construction Management
(206) 984-5739
(one natural gas-fired hydronic boiler for Building 555, an office building, installed in 1991)

For Further Information

Manufacturer s Application Notes:

Aerco, 1995. *Aerco Gas-Fired Product Catalog*, Aerco International, Inc.

Aerco, 1995. *Aerco Gas-Fired Equipment Service Start-Up and Training (SST) Manual*, Aerco International, Inc.

Case Studies:

Agulnick, S., 1995. High-tech Heat, *The Post-Star*, Glens Falls, New York, January 31, 1995.

Reese, M. R., 1994. Johnson Elementary: A state-of-the-art school building, *Engineered Systems*, April 1994.

Eade, R., 1994. Multiple Boilers Appeal to the Cost-Conscious, *Engineered Systems*, April 1994.

Ideas for Mechanical Retrofits: Boiler retrofit options are side-stepped for decentralized space and water heater installations, *Buildings*, Vol. 87, No. 2, February 1993.

Wisconsin Natural Gas Company, 1990. Water Heaters: Part of the Energy Plan Greenbriar Hospital of Greenfield, Energy Profile from *Blueprint for Savings*, 1990.

Herring, J., 1992. Strauss Bros. Veal Keeps Water Sizzling Efficiently, *Resource*, August 1992.

Aerco, 1995. The newly-built Maple Avenue Middle School, Saratoga Springs, NY, must install: The most energy-efficient heating and hot water systems, GF-3200, Aerco International, Inc., May 1995.

Aerco, 1995. Quality Inn, Waterbury, CT, must decide: Fix or replace original heating and hot water systems? , GF-3201, Aerco International, Inc., May 1995.

Other References:

ASHRAE, 1991. *1991 ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Applications*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE, 1992. *1992 ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Systems and Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

ASHRAE, 1993. *1993 ASHRAE Handbook: Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

Degelman, L. O. 1984. *Development of Bin Weather Data Simplified Energy Calculations and Variable Base Degree Information*, Final Report, ASHRAE Research Project 385, Department of Architecture, Texas A&M University, College Station, Texas.

Degelman, L. O. 1986. *Bin and Degree Hour Weather Data for Simplified Energy Calculations*, ASHRAE RP-385, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Ruegg, R. T. 1980. *Life-Cycle Costing Manual for the Federal Energy Management Programs*, National Bureau of Standards Handbook 135, U.S. Department of Commerce.

Lippiatt, B. C. 1992. *Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1993*, NISTIR 85-3273-7, U.S. Department of Commerce.

Petersen, S. R. 1993. *The NIST Building Life-Cycle Cost Program User s Guide and Reference Manual*, NISTIR 4481, National Institute of Standards and Technology.

Appendixes

Appendix A.1: Building Life-Cycle Cost Analysis of Modulating/Condensing Water Heater

Appendix A.2: Building Life-Cycle Cost Analysis of Hydronic Boiler

Appendix B: Water Heater Life-Cycle Cost Analysis Summary: Energy Conservation Investment Program

Appendix C: Sample Specification for Modulating/Condensing Water Heating Plant

Appendix D: Hydronic Boiler Life-Cycle Cost Analysis Summary: Energy Conservation Investment Program

Appendix E: Sample Specification for Modulating/Condensing Hydronic Boiler System

Appendix F: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix A.1

Building Life-Cycle Cost Analysis for Modulating/Condensing Water Heater

```
***************************************************
*     NIST BLCC INPUT DATA LISTING     *
***************************************************
```

FILE NAME: KC1000GW

FILE LAST MODIFIED ON 08-23-1995/16:12:33

PROJECT TITLE: KC1000GWW

COMMENT: KC1000 water heater case study

GENERAL DATA:

ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects

BASE DATE FOR LCC ANALYSIS: 1995

STUDY PERIOD: 15 years

PLANNING/CONSTRUCTION PERIOD: 0 years

OCCUPANCY DATE: 1995

DISCOUNT AND INTEREST RATES Real (exclusive of general inflation)

DISCOUNT RATE: 4.0%

CAPITAL ASSET COST DATA:

INITIAL COST ($)	16,980
EXPECTED COMPONENT LIFE(YRS)	15
RESALE VALUE FACTOR	0.00%
NUMBER OF REPLACEMENTS	0

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:

ANNUAL RECUR O&M COST ($): 250

NON-AN RECURRING O&M COSTS ($):

YR	AMOUNT
2	$224
4	$224
6	$224
8	$224
10	$224
12	$224
14	$224

ENERGY COST DATA:

NUMBER OF ENERGY TYPES = 1

DOE energy price escalation rates filename: ENCOST93.RAN

DOE region (state code): 1 (NJ)

DOE rate schedule type: Commercial

DOE energy price escalation rates used with energy type(s)

TYPE 1

ENERGY TYPE: natural gas

AVG ANNUAL CONSUMPTION: 12369

UNITS: therms

PRICE PER UNIT ($): 0.630

ANNUAL DEMAND CHARGE ($): 0.00

ESCALATION RATES BY YEAR: Escalation rates do not include general inflation

1995	1.55
1996	1.43
1997	1.99
1998	2.76
1999	3.25
2000	3.15
2001	3.20
2002	3.03
2003	2.66
2004	2.66
2005	2.33
2006	2.01
2007	2.16
2008	2.67
2009	3.10

****

*   NIST BLCC ANALYSIS   *

****

PART I - INITIAL ASSUMPTIONS AND COST DATA
Project name: KC1000GWW
Run date: 08-23-1995 16:14:34
Comment: KC1000 water heater case study
Input data file: KC1000GW.DAT, last modified: 08-23-1995/16:12:33

LCC output file: KC1000GW.LCC, created: 08-23-1995 16:12:39

Study period: 15 years (1995 through 2009)

Discount rate: 4.0% Real (exclusive of general inflation)

Run type: Federal Analysis--Energy Conservation Projects

BLCC uses end-of-year discounting convention

Initial Capital Asset Costs (not discounted)

	Total Cost
Total Initial Capital Asset Costs	$16,980

Energy-Related Costs

Energy Type	Units/ Year	Price ($/Unit)	Demand Cost	Total P.V. Cost
natural gas	12,369	$0.630	$0	$103,653

PART II - LIFE-CYCLE COST ANALYSIS
DISCOUNT RATE = 4.0% Real (exclusive of general inflation)
PROJECT NAME: KC1000GWW RUN DATE: 08-23-1995/16:14:34

	Present Value (1995 dollars)	Annual Value (1995 dollars)
A. cash requirements as of occupancy	$16,980	$1,527
C. operating, maintenance & related costs:		
annually recurring costs (non-energy)	$2,780	$250
non-annually recurring costs	$1,160	$104
energy costs	$103,653	$9,323
subtotal	$107,592	$9,677
F. residual value of capital assets	($0)	($0)
G. total life-cycle project cost	$124,572	$11,204

****

*   NIST BLCC CASH FLOW ANALYSIS   *

****

PROJECT NAME: KC1000GWW

COMMENT: KC1000 water heater case study

RUN DATE: 08-23-1995 16:14:48

INPUT DATA FILE: KC1000GW.DAT, last modified 08-23-1995/16:12:33

STUDY PERIOD: 15 years (1995 through 2009)

ANALYSIS TYPE: Federal Analysis Energy Conservation Projects

All costs in constant 1995 dollars (i.e., excluding general inflation)

Initial Capital Costs

Year	Total (By Year)
1995	16980
Total:	16980

Capital Investment Costs

Year	Init Capital Investment	Capital Replacements	Capital Disposal	Total Cap. Investment
1995	16,980	0	0	16,980
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0	0	0	0
2008	0	0	0	0
2009	0	0	0	0
Total	16,980	0	0	16,980

Operating-Related Costs During Occupancy

Year	An Recurring	Non-An Rec	Energy	Total Oper. Cost
	-operating and maintenance costs-			
1995	250	0	7,913	8,163
1996	250	224	8,026	8,500
1997	250	0	8,186	8,436
1998	250	224	8,412	8,886
1999	250	0	8,686	8,936
2000	250	224	8,959	9,433
2001	250	0	9,246	9,496
2002	250	224	9,527	10,001
2003	250	0	9,780	10,030
2004	250	224	10,040	10,514
2005	250	0	10,274	10,524
2006	250	224	10,481	10,955
2007	250	0	10,708	10,958
2008	250	224	10,994	11,468
2009	250	0	11,334	11,584
Total	3,750	1,568	142,568	147,886

Sum of All Cash Flows

Year	Capital Investment	Operating Costs	Total Cost
1995	16,980	8,163	25,143
1996	0	8,500	8,500
1997	0	8,436	8,436
1998	0	8,886	8,886
1999	0	8,936	8,936
2000	0	9,433	9,433
2001	0	9,496	9,496
2002	0	10,001	10,001
2003	0	10,030	10,030
2004	0	10,514	10,514
2005	0	10,524	10,524
2006	0	10,955	10,955
2007	0	10,958	10,958
2008	0	11,468	11,468
2009	0	11,584	11,584
Total	16,980	147,886	164,866

Appendix A.2
Building Life-Cycle Cost Analysis of Hydronic Boiler

****
*   NIST BLCC INPUT DATA LISTING   *
****

FILE NAME: KC1000GB

FILE LAST MODIFIED ON 12-05-1995/14:43:18

PROJECT TITLE: KC1000GWB

COMMENT: KC1000 hydronic boiler example

GENERAL DATA:

ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects

BASE DATE FOR LCC ANALYSIS: 1995

STUDY PERIOD: 15 years

PLANNING/CONSTRUCTION PERIOD: 0 years

OCCUPANCY DATE: 1995

DISCOUNT AND INTEREST RATES Real (exclusive of general inflation)

DISCOUNT RATE: 4.0%

CAPITAL ASSET COST DATA:

INITIAL COST ($)	105,337
EXPECTED COMPONENT LIFE(YRS)	15
RESALE VALUE FACTOR	0.00%
NUMBER OF REPLACEMENTS	0

NO REPLACEMENTS

OPERATING AND MAINTENANCE COST DATA:

ANNUAL RECUR O&M COST ($): 1,410

NON-AN RECURRING O&M COSTS ($):

YR	AMOUNT
2	$510
4	$510
6	$510
8	$510
10	$510
12	$510
14	$510

ENERGY COST DATA:

NUMBER OF ENERGY TYPES = 1

DOE energy price escalation rates filename: ENCOST93.RAN

DOE region (state code): 2 (WI)

DOE rate schedule type: Commercial

DOE energy price escalation rates used with energy type(s)

TYPE 1

ENERGY TYPE: natural gas

AVG ANNUAL CONSUMPTION: 111146

UNITS: therms

PRICE PER UNIT ($): 0.500

ANNUAL DEMAND CHARGE ($): 0.00

ESCALATION RATES BY YEAR: Escalation rates do not include general inflation

1995	1.78
1996	1.74
1997	2.42
1998	3.34
1999	3.82
2000	3.58
2001	3.63
2002	3.59
2003	3.23
2004	2.96
2005	2.57
2006	2.35
2007	2.44
2008	3.02
2009	3.51

****

*   NIST BLCC ANALYSIS   *

****

PART I - INITIAL ASSUMPTIONS AND COST DATA
Project name: KC1000GWB
Run date: 12-05-1995 14:43:26
Comment: KC1000 hydronic boiler example
Input data file: KC1000GB.DAT, last modified: 12-05-1995/14:43:18

LCC output file: KC1000GB.LCC, created: 12-05-1995 14:43:24

Study period: 15 years (1995 through 2009)

Discount rate: 4.0% Real (exclusive of general inflation)

Run type: Federal Analysis--Energy Conservation Projects

BLCC uses end-of-year discounting convention

Initial Capital Asset Costs (not discounted)

	Total Cost
Total Initial Capital Asset Costs	$105,337

Energy-Related Costs

Energy Type	Units/ Year	Price ($/Unit)	Demand Cost	Total P.V. Cost
natural gas	111,146	$0.500	$0	$762,701

PART II - LIFE-CYCLE COST ANALYSIS
DISCOUNT RATE = 4.0% Real (exclusive of general inflation)
PROJECT NAME: KC1000GWB RUN DATE: 12-05-1995/12:05:95

	Present Value (1995 dollars)	Annual Value (1995 dollars)
A. cash requirements as of occupancy	$105,337	$9,474
C. operating, maintenance & related costs:		
annually recurring costs (non-energy)	$15,677	$1,410
non-annually recurring costs	$2,641	$238
energy costs	$762,701	$68,598
subtotal	$781,018	$70,246
F. residual value of capital assets	($0)	($0)
G. total life-cycle project cost	$886,355	$79,720

****

*   NIST BLCC CASH FLOW ANALYSIS   *

****

PROJECT NAME: KC1000GWB

COMMENT: KC1000 hydronic boiler example

RUN DATE: 12-05-1995 14:54:05

INPUT DATA FILE: KC1000GWB.DAT, last modified 12-05-1995/14:43:18

STUDY PERIOD: 15 years (1995 through 2009)

ANALYSIS TYPE: Federal Analysis Energy Conservation Projects

All costs in constant 1995 dollars (i.e., excluding general inflation)

Initial Capital Costs

Year	Total (By Year)
1995	105337
Total:	105337

Capital Investment Costs

Year	Init Capital Investment	Capital Replacements	Capital Disposal	Total Cap. Investment
1995	105,337	0	0	105,337
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0	0	0	0
2008	0	0	0	0
2009	0	0	0	0
Total	105,337	0	0	105,337

Operating-Related Costs During Occupancy

-operating and maintenance costs-

Year	An Recurring	Non-An Rec	Energy	Total Oper. Cost
1995	1,410	0	56,563	57,973
1996	1,410	510	57,548	59,468
1997	1,410	0	58,940	60,350
1998	1,410	510	60,907	62,827
1999	1,410	0	63,233	64,643
2000	1,410	510	65,497	67,417
2001	1,410	0	67,877	69,287
2002	1,410	510	70,317	72,237
2003	1,410	0	72,585	73,995
2004	1,410	510	74,733	76,653
2005	1,410	0	76,653	78,063
2006	1,410	510	78,452	80,372
2007	1,410	0	80,369	81,779
2008	1,410	510	82,800	84,720
2009	1,410	0	85,706	87,116
Total	21,150	3,570	1,052,178	1,076,898

Sum of All Cash Flows

Year	Capital Investment	Operating Costs	Total Cost
1995	105,337	57,973	163,310
1996	0	59,468	59,468
1997	0	60,350	60,350
1998	0	62,827	62,827
1999	0	64,643	64,643
2000	0	67,417	67,417
2001	0	69,287	69,287
2002	0	72,237	72,237
2003	0	73,995	73,995
2004	0	76,653	76,653
2005	0	78,063	78,063
2006	0	80,372	80,372
2007	0	81,779	81,779
2008	0	84,720	84,720
2009	0	87,116	87,116
Total	105,337	1,076,898	1,182,235

****

*   NIST BLCC COMPARATIVE ECONOMIC ANALYSIS   *

****

BASE CASE: CNVHYDGB

ALTERNATIVE: KC1000GWB

Principal Study Parameters

ANALYSIS TYPE: Federal Analysis Energy Conservation Projects

STUDY PERIOD: 15 years (1995 through 2009)

DISCOUNT RATE: 4.0% Real (exclusive of general inflation)

BASE CASE LCC FILE: CNVHYDGB.LCC

ALTERNATIVE LCC FILE: KC1000GB.LCC

Comparison of Present-Value Costs

Initial Investment Item(s):	Base Case: CNVHYDGB	Alternative KC1000GWB	Savings From Alt..
Cash Requirements as of Occupancy	$75,000	$105,337	-$30,337
Subototal	$75,000	$105,337	-$30,337
Future Cost Items:			
Annual and Non-An. Recurring Costs	$18,318	$18,318	$0
Energy Expenditures	$1,211,320	$762,701	$448,620
Subtotal	$1,229,638	$781,018	$448,620
Total P.V. Life-Cycle Cost	$1,304,638	$886,335	$418,283

NET SAVINGS FROM PROJECT KC1000GWB COMPARED TO PROJECT CNVHYDGB

Net Savings =	P.V. of non-investment savings	$448,620
-	Increased total investment	$30,337
	Net Savings:	$418,283

SAVINGS-TO-INVESTMENT RATIO (SIR)
FOR PROJECT KC1000GWB COMPARED TO PROJECT CNVHYDGB

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 14.79$$

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR PROJECT KC1000GWB COMPARED TO PROJECT CNVHYDGB
(Reinvestment rate = 4.00%; Study period = 15 years)

AIRR = 24.46%

Note: the NS, SIR, and AIRR computations include differential capital replacement costs and resale value (if any) as investment costs, per NIST Handbook 135 (FEMP analysis only).

Appendix B

Water Heater Life Cycle Cost Analysis Summary Energy Conservation Investment Program

If this project had been for a Department of Defense installation, it might have been funded as part of the Energy Conservation Investment Program (ECIP). The life-cycle cost analysis for each element of an ECIP proposal is required in the standard format shown here. Other federal agencies have similar life-cycle cost documentation requirements.

Location: Census Region 1 Project No. 1
Project Title: Case Study for Federal Technology Alert Fiscal Year 1995
Discrete Portion Name: Modulating/Condensing Water Heater
Analysis Date: 08/23/95 Economic Life: 15 years Preparer: Richard Murphy

1. Investment Costs:

A.	Construction Cost	$ 16,980
B.	SIOH	$ 0
C.	Design Cost	$ 0
D.	Total Cost (1A+1B+1C)	$ 16,980
E.	Salvage Value of Existing Equipment	$ 14,000
F.	Public Utility Company Rebate	$ 0
G.	Total Investment (1D-1E-1F)	$ 2,980

2. Energy Savings (+) / Cost (-):
Date of NISTIR 85-3273-X Used for Discount Factors FY 1993

Energy Source	Cost $/MBtu (1)	Savings MBtu/yr (2)	Annual $ Savings (3)	Discount Factor (4)	Discounted Savings (5)
A. ELEC					
B. DIST					
C. RESID					
D. NG	$6.30	329.8	$2,078	13.30	$27,638
E. PPG					
F. COAL					
G. SOLAR					
H. GEOTH					
I. BIOMA					
J. REFUS					
K. WIND					
L. OTHER					
M. DEMAND SAVINGS	$6.30	329.8	$2,078	13.30	$27,638
N. TOTAL					

3. Non Energy Savings (+) or Cost (-):

A. Annual Recurring (+/-) $ 0
(1) Discount Factor (Table A) 11.12
(2) Discounted Savings/Cost (3A x 3A1) $ 0

B. Non Recurring Savings (+) or Cost (-)

Item	Savings (+) Cost (-) (1)	Year of Occur. (2)	Discount Factor (3)	Discounted Savings (+) Cost (-) (4)
a.	$			$
b.				
c. Total	$			$ 0

C. Total Non Energy Discounted Savings (3A2+3Bc4) $ 0

4. Simple Payback 1G/[2N3+3A+(3Bc1/Economic Life)]: 1.43 years
5. Total Net Discounted Savings (2N5+3C): $ 27,638
6. Savings to Investment Ratio (SIR) 5/1G: 9.27
7. Adjusted Internal Rate of Return (AIRR): 20.65%

Appendix C

Sample Specification for Modulating/Condensing Water Heating Plant

Water Heating Plant

Furnish and install as shown on plans, in accordance with all codes and authorities having jurisdiction, a modulating/condensing water heating plant consisting of Model KC-1000 Style 210711 (as manufactured by Aerco International, Inc.) or approved equivalent unit. The plant shall be UL/FM-approved and have a minimum gross output of 930,000 Btu/h with an input of 1,000,000 Btu/h when fueled with natural gas. The plant shall operate with a minimum ANSI Z-21 efficiency of 93% and a minimum recovery capacity of 1,265 gallons per hour at an 85¡F temperature rise.

Construction

The heating unit shall be of natural gas-fueled, condensing fire-tube design with a modulating power burner and positive pressure discharge. The heating unit burner shall be capable of a minimum 14:1 turndown of firing rate without loss of combustion efficiency. The heating unit heat exchanger/combustion chamber configuration shall incorporate a helical fire-tube design that will be self-supporting, baffle-free, and warranted to withstand thermal shock. The heat exchanger shall be ASME-stamped for a working pressure not less than 160 psig. The unit shall have an ASME-approved temperature/pressure relief valve with a setting of 150 psig. The exhaust manifold shall be of corrosion-resistant porcelain-enameled cast iron with a 6" diameter flue connection. The exhaust manifold shall have a gravity drain for the elimination of condensation with a collecting reservoir.

The flame monitoring system shall incorporate a UL-recognized combustion safeguard system utilizing interrupted direct spark ignition and a rectification-type flame sensor. An electro-hydraulic double-seated safety shutoff valve shall be an inherent part of the gas train.

The heating unit shall incorporate electric probe-type low-water cutoff and dual over-temperature protection including a manual reset in accordance with the ASME Boiler and Pressure Vessel Code (Section IV) and CSD-1. Remote fault alarm contacts, sensor failure detection, and auxiliary contacts shall be standard equipment. The heating unit shall operate on single-phase 120-V/60-Hz electrical service.

Installation

All installation aspects of the water heater plant shall be in strict accordance with manufacturer s instructions. Materials shall conform with all manufacturer s recommendations and shall include an AL-29-4C stainless steel UL-listed positive pressure vent system. Water heater piping shall be field-constructed of materials as specified. The water heater shall have individually isolating shutoff valves for service and maintenance and a supply hose connection for field testing.

Mode of Operation

The heating unit shall include integral factory-wired operating controls to govern all operations and energy input. Regulation of discharge water temperature shall be through an internal setpoint with a field adjustment of 100¡F to 200¡F. The heating unit shall maintain discharge temperature within the specified range through domestic water flow variations from 0% to 100%.

The heating unit shall be capable of maintaining the outlet temperature within an accuracy of –4¡F. This shall be accomplished by modulation of firing rate from 100% to 7% of rated input. The heating unit shall operate with an inverse efficiency curve, with known part load value efficiencies. Maximum efficiency shall be achieved at minimum firing input.

Warranty

The pressure vessel of the heating unit shall carry an unconditional ten-year warranty against leakage due to defective materials or workmanship. The heat exchanger tubes/combustion chamber assembly shall be warranted against failure due to thermal stress or corrosion for a five-year period. A warranty certificate shall be issued to the owner from the manufacturer, and a copy of the warranty shall be submitted for the approval of the cognizant engineer.

Field Services

The contractor shall provide the services of a local factory-authorized representative to supervise all phases of equipment startup. A letter of compliance with all factory recommendations and installation instructions shall be submitted to the cognizant engineer with operation and maintenance instructions.

Appendix D

Hydronic Boiler System Life Cycle Cost Analysis Summary Energy Conservation Investment Program

If this project had been for a Department of Defense installation, it might have been funded as part of the Energy Conservation Investment Program (ECIP). The life-cycle cost analysis for each element of an ECIP proposal is required in the standard format shown here. Other federal agencies have similar life-cycle cost documentation requirements.

Location: Census Region 2 Project No. 2
Project Title: Case Study for Federal Technology Alert Fiscal Year 1995
Discrete Portion Name: Modulating/Condensing Hydronic Boiler System
Analysis Date: 08/23/95 Economic Life: 15 years Preparer: Richard Murphy

1. Investment Costs:
   - A. Construction Cost $ 105,337
   - B. SIOH $ 0
   - C. Design Cost $ 0
   - D. Total Cost (1A+1B+1C) $ 105,337
   - E. Salvage Value of Existing Equipment $ 75,000
   - F. Public Utility Company Rebate $ 0
   - G. Total Investment (1D-1E-1F) $ 30,337
2. Energy Savings (+) / Cost (-):
   Date of NISTIR 85-3273-X Used for Discount Factors FY 1993

Energy Source	Cost $/MBtu (1)	Savings MBtu/yr (2)	Annual $ Savings (3)	Discount Factor (4)	Discounted Savings (5)
A. ELEC					
B. DIST					
C. RESID					
D. NG	$5.00	6,537.6	$32,688	13.72	$448,620
E. PPG					
F. COAL					
G. SOLAR					
H. GEOTH					
I. BIOMA					
J. REFUS					
K. WIND					
L. OTHER					
M. DEMAND SAVINGS		6,537.6	$32,688		$448,620
N. TOTAL					

3. Non Energy Savings (+) or Cost (-):
   - A. Annual Recurring (+/-) $ 0
     - (1) Discount Factor (Table A) 11.12
     - (2) Discounted Savings/Cost (3A x 3A1) $ 0
   - B. Non Recurring Savings (+) or Cost (-)

Item	Savings (+) Cost (-) (1)	Year of Occur. (2)	Discount Factor (3)	Discounted Savings (+) Cost (-) (4)
a.	$			$
b.				
c. Total	$			$ 0

   - C. Total Non Energy Discounted Savings (3A2+3Bc4) $ 0
4. Simple Payback 1G/[2N3+3A+(3Bc1/Economic Life)]: 0.93 years
5. Total Net Discounted Savings (2N5+3C): $ 448,620
6. Savings to Investment Ratio (SIR) 5/1G: 14.79
7. Adjusted Internal Rate of Return (AIRR): 24.46%

Appendix E

Sample Specification for Modulating/Condensing Hydronic Boiler Heating Plant

Multiple Boiler Heating Plant

Furnish and install as shown on plans, in accordance with all codes and authorities having jurisdiction, a modulating/condensing hydronic boiler heating plant consisting of Model KC1000-6 (six multiple boilers, Model KC-1000 as manufactured by Aerco International, Inc.) or approved equivalent. The plant shall be UL/FM-approved and have a minimum combined gross output of 5,000,000 Btu/h with an input of 5,774,000 Btu/h. The plant shall operate with a minimum of 86.6% efficiency at design conditions when fueled with natural gas.

Boiler Construction

Boiler modules shall be of natural gas-fueled, condensing fire-tube design with modulating power burner and positive pressure discharge. Each boiler module shall be capable of a minimum 14:1 turndown of firing rate without loss of combustion efficiency. The boiler module heat exchanger/combustion chamber configuration shall incorporate a helical fire-tube design that will be self-supporting, baffle-free, and warranted to withstand thermal shock. Each heat exchanger module shall be ASME-stamped for a working pressure not less than 150 psig. Each boiler module shall have an ASME-approved relief valve with a setting of 150 psig. Each boiler module exhaust manifold shall be of corrosion-resistant porcelain-enameled cast iron, with a 6" diameter flue connection. Each boiler exhaust manifold shall have a gravity drain for the elimination of condensation with a collecting reservoir.

Each boiler module s flame monitoring system shall incorporate a UL-recognized combustion safeguard system utilizing interrupted direct spark ignition and a rectification-type flame sensor. An electro-hydraulic double-seated safety shutoff valve shall be an inherent part of each boiler module gas train.

Each boiler module shall incorporate electric probe-type low-water cutoff and dual over-temperature protection including a manual reset in accordance with the ASME Boiler and Pressure Vessel Code (Section IV) and CSD-1. Remote fault alarm contacts, sensor failure detection, and auxiliary contacts shall be standard equipment. The heating plant shall operate on single-phase 120-V/60-Hz electrical service.

Installation

All installation aspects of the hydronic boiler heating plant shall be in strict accordance with manufacturer s instructions. Materials shall conform with all manufacturer s recommendations and shall include an AL-29-4C stainless steel UL-listed positive pressure vent system. Boiler plant piping shall be field-constructed of materials as specified. Each boiler module shall have individually isolating shutoff valves for service and maintenance.

Mode of Operation

The boiler manufacturer shall supply as part of the boiler package a completely integrated boiler management system consisting of Model 168 (as manufactured by Aerco International, Inc.) or approved equivalent to control all operation and energy input of the heating plant. The system shall comprise a microprocessor-based control unit utilizing pulse width modulation to accommodate either parallel firing of all modules or sequential staging of modules with bumpless energy transfer at adjustable firing rates to track changing heating demands. The controller shall have the ability to vary each individual module input throughout its full range to maximize the condensing capability of the module and the entire plant without header temperature swings. The controller shall be of the proportional integral derivative type for accurate temperature control with excellent frequency response. The boiler management system shall provide contact closure for automatic plant activation at an adjustable outdoor temperature setpoint and contact closure for auxiliary equipment such as pumps and combustion air dampers.

The boiler management system shall operate on an adjustable inverse ratio in response to outdoor temperature to control the main header temperature outlet to –2¡F. Each boiler module shall operate with an inverse efficiency curve, with known part load value efficiencies. Maximum efficiency shall be achieved at minimum firing input. Reset ratio shall be fully field adjustable from 0.3 to 3.0 in operation. The controller shall have a liquid crystal display for monitoring of all sensors and interlocks. Non-volatile backup of all control setpoints shall be internally provided with a communication interface for monitoring by building management computer. The controller shall automatically balance operating time on each module by a first-on/first-off sequence with random lead module selection and shall provide for setback and remote alarm contacts. Connection between the boiler management system and the individual modules shall be twisted-pair low-voltage field wiring to internal terminal strips for easy installation.

Warranty

The pressure vessel of each boiler module shall carry an unconditional ten-year warranty against leakage due to defective materials or workmanship. The heat exchanger tubes/combustion chamber assemblies shall be warranted against failure due to thermal stress or corrosion for a five-year period. A warranty certificate shall be issued to the owner from the manufacturer, and a copy of the warranty shall be submitted for the approval of the cognizant engineer.

Field Services

The contractor shall provide the services of a local factory-authorized representative to supervise all phases of equipment startup. A letter of compliance with all factory recommendations and installation instructions shall be submitted to the cognizant engineer with operation and maintenance instructions.

Appendix F

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). 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. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (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 the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, 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* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of Federal Technology Alerts that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the Federal Technology Alerts attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the Alert as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

For More Information

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