ENERGY ENGINEERING ANALYSIS PROGRAM

REDSTONE ARSENAL, ALABAMA

ENERGY SURVEY OF ARMY BOILER AND CHILLER PLANTS

FINAL REPORT

JUNE, 1987

VOLUME I - EXECUTIVE SUMMARY

Prepared for

MOBILE DISTRICT, CORPS OF ENGINEERS

P.O. BOX 2288

MOBILE, ALABAMA 36628-0001

By

BENATECH, INC.

Engineering & Energy Consultants

1215 HIGHTOWER TRAIL

SUITE D-220

ATLANTA, GEORGIA 30350

ARMY CONTRACT NO. DACA01-85-C-0131,

PART I & II

DEPARTMENT OF THE ARMY
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES, CORPS OF ENGINEERS
P.O. BOX 9005
CHAMPAIGN, ILLINOIS 61826-9005

REPLY TO
ATTENTION OF: TR-I Library

17 Sep 1997

Based on SOW, these Energy Studies are unclassified/unlimited. Distribution A. Approved for public release.

Marie Wakefield,
Librarian Engineering

TABLE OF CONTENTS

VOLUME I - EXECUTIVE SUMMARY

TABLE OF VOLUMES

VOLUME I - EXECUTIVE SUMMARY

VOLUME II - NARRATIVE

APPENDIX A

APPENDIX A - CONTRACT SCOPE OF WORK

VOLUME IV

APPENDIX B - PROJECT DOCUMENTATION

VOLUME V

APPENDIX C - BOILER ECOs

BOOK 1 OF 3

VOLUME VI

APPENDIX C - BOILER ECOs

BOOK 2 OF 3

VOLUME VII

APPENDIX C - BOILER ECOs

BOOK 3 OF 3

VOLUME VIII

APPENDIX C - CHILLER ECOs

BOOK 1 OF 2

VOLUME IX

APPENDIX C - CHILLER ECOs

BOOK 2 OF 2

VOLUME X

APPENDIX E - BOILER EFFICIENCY CALCULATIONS

VOLUME XI

APPENDIX F - PERFORMANCE TESTING

1. INTRODUCTION

1.1 BACKGROUND

This report is the prefinal report of an Energy Engineering Analysis Program (EEAP) study of boilers and chillers at Redstone Arsenal, Huntsville, Alabama. Work was begun January, 1986 on the project by BENATECH, INC. under Contract No. DACA01-85-C-0131, Parts I and II, with the Mobile District, U.S. Army Corps of Engineers, Mobile, Alabama. The following activities have been accomplished:

- A detailed field investigation has been conducted.
- ECO calculations have been performed and ECIP analyses have been accomplished.
- Interim Report has been submitted.
- Low Cost/No Cost project documentation packages have been compiled.
- Prefinal Report is complete and submitted for review.

1.2 SCOPE

The Scope of Work specified in contract no. DACA01-85-C-0131, Parts I and II (and included in this report in Appendix A) requires the performance of a specific energy study. The Energy Conservation Opportunities analyzed under this study will serve as part of Redstone Arsenal's overall effort to reduce basewide energy use in accordance with the objectives set forth in the Army Energy Plan. The contract Scope of Work (SOW) for Redstone Arsenal outlines the following specific requirements:

- Determine the efficiency of the boiler/chiller plants by appropriate tests.
- Survey the boiler/chiller plants to determine if efficiency can be improved by the repair, addition, or modification of equipment and recommend improvements.
- Evaluate the control system and recommend changes, repairs, or new controls which will improve the efficiency of the plant.
- Review operation and maintenance procedures and provide site-specific recommendations which will increase the efficiency of the plants to the maximum level.
- Prepare a comprehensive report to document the work performed, the

results, and recommendations.

All of these Scope of Work items have been accomplished.

2. ENERGY CONSERVATION OPPORTUNITIES (ECOs)

2.1 TECHNICAL APPROACH

The Scope of Work contains a list of specific ECOs to be studied for Redstone Arsenal Boilers and Chillers. These ECOs were investigated after completing our field survey visits and compiling the raw data from the visits. The steps in collecting the field data are:

- Obtain nameplate data and methods of operation for the boilers and chillers.
- Inspect types and conditions of control systems.
- Take field measurements on boilers and chillers.

Using the field data, the various ECOs were analyzed for their feasibility of being enacted under Army guidelines.

2.2 ECOs ANALYSES

2.2.1 BOILERS

Boiler Feedwater Economizer.

This ECO investigates the energy savings achievable by preheating the boiler feedwater with recovered waste heat from the flue gas. Borosilicate heat exchangers are used so that potential corrosion problems are reduced in the temperature range between 100 F - 150 F. Feedwater economizers already exist in Building 3624, although these devices were inoperable when the boilers were surveyed.

Burner Replacement.

This ECO analyzes the energy savings achievable by replacing existing burners with modulating, cam-type burners. These burners modulate the air-to-fuel ratio as a function of boiler load. This modulation results in a combustion efficiency of approximately 80% over the operating range of the boiler. This ECO is not applicable to boilers in Buildings 3624 and 4725 which already employ modulating burners.

in the temperature range between 100 F - 150 F. Feedwater economizers already exist in Building 3624, although these devices were inoperable when the boilers were surveyed.

Boiler Tune-Up.

This ECO evaluates the potential for energy savings by performing semi-annual boiler tune-ups. The boilers should be tuned for minimum excess air at their respective average operating loads. A well-tuned boiler operates at its peak combustion efficiency at the load for which it is tuned.

Preheat Combustion Air.

The purpose of this ECO is to use waste heat recovered from the flue gas in order to preheat combustion air. Boiler efficiency can be improved by implementing this technique. For this ECO, improved combustion efficiencies are calculated using the higher preheated inlet air temperature; however, all other test conditions remain the same as the existing test conditions. Preheaters already exist in Building 4725. Borosilicate heat exchangers are used so that corrosion problems are reduced in the temperature range between 100 F - 150 F.

"Summer" Boiler.

This ECO analyzes the potential of installing a boiler to handle the steam production requirements during the "summer" months. The boiler fuel consumption and operating logs were examined to isolate the steam capacity requirements for each month. It was determined that during the period of May 16 - October 15, the boiler demands were at their minimum levels. The "summer" boilers were then sized to meet these average summer loads. The energy savings are realized in the increased efficiency of the new boilers (approximately 80%) as compared with the underloaded (in summer operation) existing boilers.

Variable-Speed Motor Drives.

This ECO analyzes the potential for savings by installing inverters on combustion air fan motors. Inverters save energy by controlling the fan power in response to actual air flow requirements.

Boiler Replacement.

This ECO evaluates the savings to be achieved by replacing the existing boiler with a new, 80% efficient boiler of the same size.

Downsize Boilers.

This ECO analyzes the energy savings that could be achieved by installing smaller boilers designed to meet the average operating load of the boiler plant. This ECO is applicable to boiler plants which are operating in underloaded conditions. The savings to be realized result from the increased efficiencies (approximately 80%) of the new boilers as compared with the existing underloaded boilers.

Installation of Turbulators.

This ECO analyzes the energy savings achievable by installing turbulators in fire-tube boilers. Turbulators are baffles which create turbulent flow in the core of hot combustion gases. This turbulent flow maximizes heat transfer from combustion gases through the tube walls to the boiler water. Thus, more heat is used in the generation of steam and less is lost out the exhaust stack. Fuel savings of 1% can be achieved by installing turbulators in fire-tube boilers. This ECO is not applicable to water-tube boilers. The use of Fuel Efficiency, Inc. information does not constitute an endorsement of their product, but merely an actual representation of achievable performance levels.

Oxygen Trim System.

The purpose of an oxygen trim system is to control the air/fuel ratio of a boiler within the most efficient operating parameters. This is achieved by using an oxygen analyzer in the flue stack in conjunction with a microprocessor controller. The oxygen analyzer measures the oxygen content in the flue gas, and a potentiometer monitors the fuel flow rate. The microprocessor controls adjust the air flow damper in order to get the most efficient combustion process. The use of Westinghouse "Veritrim" oxygen analyzer and control information does not constitute an endorsement of their product, but merely an actual representation of achievable performance levels.

Steel Feedwater Economizer.

This ECO investigates the energy savings achievable by preheating the boiler feedwater with recovered waste heat from the flue gas. Alloy steel heat exchangers are used so that potential corrosion problems are reduced

2.2.2 CHILLERS

Automatic Chiller Tube Cleaning.

This ECO establishes representative savings which result from the installation of an on-line condenser tube cleaning system. This system uses slightly oversized brushes fitted into each condenser tube to remove rust and deposits. The brushing action is initiated by a diverter valve, which changes the direction of water flow, pushing the brushes to either end of the condenser. Flow through the condenser automatically changes. Savings result from improved heat transfer from the condenser water through the condenser tube wall. The savings were calculated using manufacturers' data. The use of Water Services of America and ATB information does not constitute an endorsement of their product, but merely an actual representation of achievable performance levels.

Condenser Tube Cleaning.

This ECO analyzes the potential for savings by manually cleaning condenser tubes. This operation reduces the tube fouling factor to its minimum achievable value. Reduced fouling factor results in increased heat transfer capabilities of the system, and consequently less energy is required to achieve the same cooling capacity.

Chiller Shutdown.

This ECO analyzes the energy savings achievable when equipment is operated only when it is needed to provide comfort conditioning. The savings are calculated for chillers (partially loaded), chilled water and condenser water pumps, and the cooling tower. No credit is taken for reheating or air handling savings which will also result. The methodology used to calculate the savings is shown in "Standardized EMCS Energy Savings Calculations", CR 82.030, September 1982.

Chilled Water Temperature Reset.

This ECO analyzes the energy savings resulting from resetting the chilled water supply temperature upward, without appreciably affecting comfort conditions. Savings result from decreasing the demand on the chiller compressor, and therefore, the amount of energy input to the chiller. The methodology used to calculate the savings is shown in the "Standardized EMCS Energy Savings Calculations", CR 82.030, September 1982.

Water Treatment/Fill Replacement

This ECO analyzes the energy savings resulting from maximizing cooling tower performance. Water treatment and replacement of cooling tower fill are offered as one composite ECO, because one recommendation will improve and maintain the savings of the other. Considered separately, neither will offer long term savings. Replacing deteriorated cooling tower fill PVC polymer will ensure that the condenser water will flow through the cooling tower and achieve even distribution and maximum heat transfer with the air. Introduction of water treatment will maintain the desirable effects of the new fill, but will offer no improvement with the existing cooling tower fill. The reduction in condenser water supply temperature will result in reduced compressor load. The methodology used is similar to Chilled Water Temperature Reset. ECO's are presented for the buildings with the highest SIRs. The methodology used to calculate the savings is shown in the "Standardized EMCS Energy Savings Calculations", CR82.030, September 1982.

Waterside Economizer

This ECO evaluates the feasibility of installing a plate heat exchanger, new valves and controls to enable the chiller to be shutdown during periods of the year when the wet bulb temperatures will provide sufficient evaporative cooling effect. Building load fluctuates with internal and external loads. During the fall, winter, and spring, the external cooling loads on a building are at a minimum. During these seasons, the wet bulb temperatures are low enough to maintain evaporation in sufficient quantity to provide condenser water cold enough to meet the internal loads of the building. The analysis utilizes cooling tower performance data used to determine the expected cooling tower water temperatures for a given wet bulb temperature. It was recommended by plate heat exchanger sales representative (for analysis purposes) to use a heat exchanger with a four degree approach temperature because it is less expensive. It was assumed that the building loads could be adequately met with chilled water supply temperatures between 48 and 44 degrees F. In addition, the cooling tower is assumed to cycle half the time for all those hours when the cooling tower is less than 40 degrees F. The cooling tower will cycle off and on to prevent the cooling tower from freezing. This bin hour calculation determines the electrical savings resulting from shutting down the chiller (partially loaded) and the cooling tower when it is possible to do so. The

methodology used to calculate the savings is shown in "Standardized EMCS Energy Savings Calculations", CR 82.030, September 1982. The use of Marley and Mueller manufacturer's data does not constitute an endorsement of their product but merely an actual representation of achievable performance levels.

Variable Speed Pumping

This ECO analyzes the energy savings potential of installing variable speed pumping (accomplished with the installation of a variable frequency drive) in place of the existing constant speed pumping. Included with the installation of a variable speed drive is the replacement of all three-way valves with two-way valves and a differential pressure control system. Electrical energy is saved when the amount of energy devoted to pumping chilled water is varied as the cooling load on the building. It was assumed that the pump speed is proportional to the building load. The power required to operate the pump varies as the cube of the speed. Savings are determined by calculating the energy required for constant speed pumping and subtracting the energy necessary to operate the variable speed pump. The methodology used to calculate the savings is shown in ASHRAE Equipment 1983.

Two Speed Cooling Tower Fans

This ECO examines the energy savings resulting from replacing the constant speed cooling tower fan motor with a two speed motor. Savings result from the fan law which states that the power required to operate a fan varies as the cube of the fan speed. The methodology used to calculate the savings is shown in "Heating, Ventilating and Air Conditioning", Parker and McQuistone, 1982.

3. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

3.1 RESULTS

A complete listing of all Boiler ECO's and OMR's is provided in Table ES 1. This is sorted by SIR. A similar list for all Chiller ECOs and OMRs is shown in Table ES 2, sorted according to SIR.

All ECOs with SIRs greater than 1.0 were considered for project packaging.

3.2 CONCLUSIONS

Candidate ECOs for project packaging are show in Table ES 3 and ES 4. Both tables are sorted by Boiler/Chiller number and descending SIR for each boiler or chiller. BENATECH combined ECOs into projects to be implemented on a per boiler/chiller basis. This strategy allows for projects with low construction costs to be funded on a local level.

For a given boiler of chiller, some of the recommended ECOs were mutually exclusive. An example of two mutually exclusive ECOs are "Preheat Combustion Air" and "Steel Feedwater Economizer". Both of these ECOs function to recover waste heat from boiler exhaust gases. In a case where two ECOs indpendently have SIRs greater than 1.0, but are mutually exclusive, BENATECH used good engineering judgement to select the ECO yielding maximum energy savings.

Project synergy calculations between candidate boiler ECOs begins with the average boiler load (MBTU). Each **"Step"** is explained below:

Step 1. Calculations start with the determiniation of the Annual Savings. Annual savings are calculated in one of three ways:

a.) For ECOs where a nominal percentage reduction of energy consumption is known, the annual savings are calculated as shown below:

(% reduction)(average boiler load) = Annual Savings (MBTU/yr.)

Applicable ECOs: Turbulators

b.) In the cases where the expected boiler efficiency is used to calculate the annual savings as shown below:

(average boiler load)[1 - (average boiler eff./expected boiler eff.)] = Annual Savings (MBTU/yr.)

Applicable ECOs: Burner Replacement

c.) In the case of recommendation swher the consumption reduction is calculated in the ECO, the annual savings equals the expected consumption reduction.

Applicable ECOs: Summer Boiler, Boiler Tune-up

Second, the Annual Fuel Consumption is calculated by subtracting the annual savings from the average boiler load.

Third, the Boiler Efficiency is recalculated using the following formula:

(average boiler efficiency)/[1-(annual savings/average boiler load)]

Step 2, Step 3. The calculations for these steps are performed iteratively based on the number of analytical **Steps** in the project.

Per guidance received in the Prefinal Review Meeting, several ECOs identified by BENATECH had alredady been implemented, are currently in progress, or already have programming documentation in place. Given this information, BENATECH prepared low cost/no cost project documentation for all remaining recommended ECOs.

TABLE ES 1 - BOILER ECOs EVALUATED SORTED BY SIR

ECO	Boiler No.	Life (YRS)	MBTUs Saved Elec. MBTUs	Nat. Gas MBTUs	#2 Oil MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
Boiler Tune-Up OMR	4725 -3	15		57931		$251,998	$2,705	1341.68	0
Boiler Tune-Up OMR	3624 -4	10		34338		$149,372	$2,705	518.52	0
Boiler Tune-Up OMR	4725 -2	15		21293		$92,626	$2,705	495.49	0
Boiler Tune-Up OMR	3624 -3	10		8599		$37,407	$2,705	124.60	0
Boiler Tune-Up OMR	4725 -1	15		1945		$8,460	$2,705	36.27	0
Boiler Tune-Up OMR	3624 -1	10		2449		$10,655	$2,705	30.48	0
Boiler Tune-Up OMR	8977 -1	10		1965		$8,548	$2,705	23.08	0
Boiler Tune-Up OMR	115 -2	25		903		$3,927	$2,705	21.18	1
Boiler Tune-Up OMR	8028 -2	25			529	$3,125	$2,705	19.21	1
Turbulator Installation	8028 -2	25			98	$579	$861	12.43	1
Turbulator Installation	115 -2	25		120		$522	$1,295	9.10	3
Burner Replacement	115 -2	25		977		$4,248	$11,622	8.26	3
Turbulator Installation	7579 -1	10		156		$679	$861	7.50	1
Boiler Tune-Up OMR	7105 -4	10		925		$4,025	$2,705	7.16	1
Turbulator Installation	8874 -1	15			49	$290	$518	6.82	2
Turbulator Installation	7153 -1	5		82		$357	$287	5.64	1
Oxygen Trim System	8028 -2	25			853	$5,041	$16,420	5.49	3
Boiler Tune-Up OMR	3624 -2	10		748		$3,254	$2,705	4.45	1
Turbulator Installation	7105 -3	25		69		$300	$1,723	3.93	6
Turbulator Installation	8874 -2	15			28	$165	$518	3.90	3
Burner Replacement	7579 -1	10		858		$3,734	$10,319	3.44	3
Downsize Boiler	115 -2	25		1,488		$6,475	$45,285	3.23	7
Burner Replacement	8977 -1	10		749		$3,257	$10,319	3.00	3
Burner Replacement	7105 -3	25		413		$1,795	$13,575	2.99	8
Burner Replacement	8874 -1	15			319	$1,882	$9,017	2.55	5
Turbulator Installation	8977 -1	10		52		$226	$861	2.50	4
Summer Boilers	115 -2	25		559		$2,430	$25,478	2.16	11
Turbulator Installation	7105 -4	10		86		$374	$1,723	2.07	5
Downsize Boiler	7105 -3	25		774		$3,368	$40,907	1.86	12
Turbulator Installation	8977 -2	10		38		$165	$861	1.83	5
Boiler Replacement	115 -2	25		977		$4,248	$55,905	1.72	13
Burner Replacement	8874 -2	15			200	$1,182	$9,017	1.60	8
Turbulator Installation	7579 -2	10		33		$144	$861	1.59	6
Burner Replacement	7770 -2	10		345		$1,499	$10,319	1.38	7
Burner Replacement	7770 -1	10		344		$1,497	$10,319	1.38	7
Oxygen Trim System	115 -2	25		238		$1,037	$16,420	1.24	16
Burner Replacement	8977 -2	10		303		$1,317	$10,319	1.22	8
Preheat Combustion Air	115 -2	25		580		$2,523	$46,257	1.16	18
Steel Feedwater Economizer	115 -2	25		306		$1,331	$23,496	1.15	18
Burner Replacement	7579 -2	10		283		$1,232	$10,319	1.14	8
Steel Feedwater Economizer	7579 -1	10		607		$2,640	$20,862	1.12	6
Downsize Boiler	7105 -4	10		1102		$4,792	$40,907	1.12	9
Turbulator Installation	8028 -1	10			39	$230	$1,723	1.12	7
Turbulator Installation	7770 -2	10		44		$191	$1,723	1.06	9
Turbulator Installation	7770 -1	10		44		$191	$1,723	1.06	9
Boiler Tune-Up OMR	7153 -1	5		705		$3,067	$2,705	1.05	1
Summer Boilers	7291 -1	15		257		$1,118	$16,100	1.01	14
Burner Replacement	7105 -4	10		732		$3,184	$30,026	1.01	9
Preheat Combustion Air	8028 -2	25			522	$3,085	$53,996	1.00	18
Downsize Boiler	7770 -1	10		517		$2,251	$22,041	0.97	10
Downsize Boiler	7770 -2	10		517		$2,251	$22,041	0.97	10
Burner Replacement	8028 -1	10			192	$1,134	$10,319	0.92	9

TABLE ES 1 - BOILER ECOs EVALUATED SORTED BY SIR

ECO	Boiler No.	Life (YRS)	MBTUs Saved Elec. MBTUs	Nat. Gas MBTUs	#2 Oil MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
Steel Feedwater Economizer	7105 -3	25		254		$1,105	$24,773	0.88	22
Summer Boilers	7855 -1	15		347		$1,512	$25,478	0.86	17
Oxygen Trim System	7105 -3	25		172		$748	$16,420	0.84	22
Boiler Feedwater Economizer	7579 -1	10		1054		$4,585	$51,720	0.81	11
Turbulator Installation	7105 -2	5		34		$148	$862	0.78	6
Turbulator Installation	7105 -1	5		34		$148	$862	0.78	6
Boiler Replacement	7579 -1	10		858		$3,734	$45,285	0.78	12
Boiler Feedwater Economizer	115 -2	25		472		$2,053	$58,185	0.74	28
Boiler Tune-Up OMR	7105 -1	5		660		$2,872	$2,705	0.73	1
Steel Feedwater Economizer	8028 -2	25			168	$993	$20,862	0.73	21
Summer Boilers	7579 -1	10		441		$1,917	$25,478	0.72	13
Preheat Combustion Air	7579 -1	10		724		$3,149	$41,117	0.68	13
Burner Replacement	7153 -1	5		346		$1,506	$10,319	0.66	7
Boiler Feedwater Economizer	7105 -3	25		440		$1,914	$61,418	0.65	32
Oxygen Trim System	7579 -1	10		295		$1,285	$16,420	0.63	13
Summer Boilers	8874 -1	15			140	$827	$16,100	0.63	20
Oxygen Trim System	8874 -1	15			174	$1,028	$16,420	0.62	16
Preheat Combustion Air	7105 -3	25		337		$1,466	$48,827	0.61	33
Burner Replacement	7105 -1	5		314		$1,365	$10,319	0.60	8
Burner Replacement	7105 -2	5		314		$1,365	$10,319	0.60	8
Variable-Speed Fans	4725 -4	15	1518			$5,644	$86,064	0.59	15
Downsize Boiler	7105 -2	5		1177		$5,122	$40,907	0.57	8
Downsize Boiler	7105 -1	5		1177		$5,122	$40,907	0.57	8
Boiler Feedwater Economizer	8028 -2	25			365	$2,157	$67,883	0.54	31
Summer Boilers	7770 -1	10		238		$1,033	$19,226	0.51	19
Steel Feedwater Economizer	7105 -4	10		373		$1,623	$27,381	0.50	17
Preheat Combustion Air	8874 -1	15			265	$1,566	$35,978	0.46	23
Boiler Replacement	8874 -2	15			200	$1,182	$32,361	0.45	27
Oxygen Trim System	7105 -4	10		221		$963	$16,420	0.44	17
Boiler Feedwater Economizer	8874 -1	15			311	$1,838	$45,255	0.44	25
Steel Feedwater Economizer	8874 -1	15			137	$810	$18,254	0.41	23
Variable-Speed Fans	4725 -3	15	1032			$3,837	$86,064	0.40	22
Variable-Speed Fans	3624 -4	10	535			$1,989	$34,725	0.40	17
Boiler Replacement	7105 -4	10		732		$3,184	$77,646	0.39	24
Boiler Feedwater Economizer	7105 -4	10		645		$2,806	$67,883	0.37	24
Downsize Boiler	7153 -1	5		592		$2,574	$32,361	0.36	13
Variable-Speed Fans	3624 -2	10	470			$1,747	$34,725	0.35	20
Variable-Speed Fans	4725 -2	15	860			$3,197	$86,064	0.33	27
Steel Feedwater Economizer	8977 -1	10		212		$922	$20,862	0.33	23
Summer Boilers	7153 -1	5		346		$1,506	$22,353	0.31	15
Boiler Replacement	7770 -1	10		344		$1,497	$45,285	0.31	30
Boiler Replacement	7770 -2	10		344		$1,497	$45,285	0.31	30
Preheat Combustion Air	7105 -4	10		431		$1,875	$53,966	0.30	29
Oxygen Trim System	8874 -2	15			100	$592	$16,420	0.29	28
Boiler Feedwater Economizer	8977 -1	10		367		$1,596	$51,720	0.26	32
Boiler Replacement	7579 -2	10		283		$1,232	$45,285	0.26	37
Variable-Speed Fans	3624 -1	10	338			$1,256	$34,725	0.25	28
Preheat Combustion Air	8874 -2	15			152	$898	$35,978	0.24	40
Oxygen Trim System	8028 -1	10			115	$682	$16,420	0.23	24
Preheat Combustion Air	8977 -1	10		267		$1,161	$41,117	0.22	35
Variable-Speed Fans	3624 -3	10	299			$1,112	$34,725	0.22	31
Preheat Combustion Air	8028 -1	10			216	$1,277	$41,117	0.21	32

TABLE ES 1 - BOILER ECOs EVALUATED SORTED BY SIR

ECO	Boiler No.	Life (YRS)	MBTUs Saved Elec. MBTUs	Nat. Gas MBTUs	#2 Oil MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
Boiler Feedwater Economizer	8874 -2	15			168	$993	$45,255	0.21	46
Boiler Replacement	8028 -1	10			192	$1,134	$45,285	0.21	40
Oxygen Trim System	8977 -1	10		125		$542	$16,420	0.20	30
Boiler Replacement	8977 -1	10		749		$3,257	$170,520	0.18	52
Steel Feedwater Economizer	7153 -1	5		194		$844	$15,646	0.18	19
Steel Feedwater Economizer	7579 -2	10		133		$579	$20,862	0.17	36
Downsize Boiler	8977 -1	10		640		$2,786	$164,058	0.16	59
Steel Feedwater Economizer	8874 -2	15			74	$437	$18,254	0.16	42
Boiler Replacement	7153 -1	5		346		$1,506	$45,285	0.15	30
Boiler Feedwater Economizer	7579 -2	10		230		$1,001	$51,720	0.15	52
Boiler Replacement	7105 -1	5		314		$1,365	$45,285	0.14	33
Preheat Combustion Air	8977 -2	10		180		$783	$41,117	0.14	53
Boiler Replacement	7105 -2	5		314		$1,365	$45,285	0.14	33
Oxygen Trim System	7770 -2	10		99		$429	$16,420	0.14	38
Oxygen Trim System	7770 -1	10		99		$429	$16,420	0.14	38
Preheat Combustion Air	7153 -1	5		325		$1,414	$41,117	0.13	29
Oxygen Trim System	7579 -2	10		93		$406	$16,420	0.12	40
Oxygen Trim System	7153 -1	5		155		$676	$16,420	0.12	24
Boiler Feedwater Economizer	8028 -1	10			158	$934	$51,720	0.11	55
Boiler Feedwater Economizer	7153 -1	5		341		$1,483	$51,720	0.11	35
Preheat Combustion Air	7770 -1	10		179		$779	$51,396	0.11	66
Preheat Combustion Air	7770 -2	10		179		$779	$51,396	0.11	66
Preheat Combustion Air	7579 -2	10		145		$631	$41,117	0.10	65
Oxygen Trim System	8977 -2	10		83		$363	$16,420	0.10	45
Downsize Boiler	8977 -2	10		361		$1,569	$164,058	0.09	105
Steel Feedwater Economizer	8028 -1	10			82	$485	$27,381	0.08	57
Steel Feedwater Economizer	7770 -2	10		90		$392	$26,077	0.07	67
Boiler Feedwater Economizer	7770 -2	10		158		$687	$64,650	0.07	94
Steel Feedwater Economizer	7770 -1	10		90		$392	$26,077	0.07	67
Boiler Replacement	8977 -2	10		303		$1,317	$170,520	0.07	130
Boiler Feedwater Economizer	7770 -1	10		158		$687	$64,650	0.07	94
Boiler Feedwater Economizer	7105 -2	5		184		$800	$51,720	0.05	64
Boiler Feedwater Economizer	7105 -1	5		183		$796	$51,720	0.05	65
Variable-Speed Fans	4725 -1	15	138			$513	$86,064	0.05	168
Steel Feedwater Economizer	7105 -1	5		105		$457	$20,862	0.05	46
Steel Feedwater Economizer	7105 -2	5		106		$461	$20,862	0.05	45
Preheat Combustion Air	7105 -1	5		141		$613	$41,117	0.04	67
Preheat Combustion Air	7105 -2	5		141		$613	$41,117	0.04	67
Oxygen Trim System	7105 -1	5		76		$329	$16,420	0.03	50
Oxygen Trim System	7105 -2	5		76		$329	$16,420	0.03	50
Boiler Tune-Up OMR	8874 -1	15			33	$197	$2,705	-8.20	14
Boiler Tune-Up OMR	7105 -3	25		102		$443	$2,705	-7.91	6
Boiler Tune-Up OMR	8977 -2	10		45		$196	$2,705	-6.31	14
Boiler Tune-Up OMR	8028 -1	10			151	$895	$2,705	-5.51	3
Boiler Tune-Up OMR	7579 -2	10		103		$448	$2,705	-5.42	6
Boiler Tune-Up OMR	8874 -2	15			245	$1,447	$2,705	-2.54	2
Boiler Tune-Up OMR	7770 -2	10		307		$1,336	$2,705	-2.30	2
Boiler Tune-Up OMR	7105 -2	5		288		$1,252	$2,705	-1.99	2

TABLE ES 2 - CHILLER ECOs SORTED BY SIR

ECO's PERFORMED	TONS	Chiller No.	Life (Yrs)	Elec. MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
CHILLER SHUTDOWN	440	4488-2	15	12396	$46,088	$1,496	277.22	0.03
CHILLER SHUTDOWN	373	5250-1	10	15600	$58,001	$1,496	271.61	0.03
CHILLER SHUTDOWN	160	7120-1	20	5170	$19,222	$1,496	133.29	0.08
CHILLER SHUTDOWN	200	4484-1	10	3206	$11,920	$1,496	71.70	0.13
CHILLER SHUTDOWN	225	3220-1	10	3961	$14,727	$1,496	68.96	0.10
CHILLED WATER TEMPERATURE RESET	660	5400-1	20	343	$1,276	$329	40.21	0.3
CHILLED WATER TEMPERATURE RESET	670	3305-1	10	229	$850	$329	18.13	0.4
CHILLED WATER TEMPERATURE RESET	440	4488-2	15	162	$603	$329	16.47	0.5
CHILLED WATER TEMPERATURE RESET	225	3220-1	10	135	$503	$329	10.70	0.7
CHILLED WATER TEMPERATURE RESET	250	5681-2	10	133	$496	$329	10.53	0.7
CHILLED WATER TEMPERATURE RESET	373	5250-2	5	132	$492	$329	10.45	0.7
CHILLED WATER TEMPERATURE RESET	373	5250-1	10	132	$492	$329	10.45	0.7
CHILLED WATER TEMPERATURE RESET	200	4484-1	10	81	$301	$329	8.24	1.1
CHILLED WATER TEMPERATURE RESET	160	7120-1	20	68	$254	$329	7.97	1.3
CHILLED WATER TEMPERATURE RESET	155	5681-1	10	83	$307	$329	6.57	1.1
CHILLED WATER TEMPERATURE RESET	180	7770-1	10	70	$262	$329	5.54	1.3
CHILLED WATER TEMPERATURE RESET	155	5681-3	10	55	$205	$329	4.35	1.6
WATERSIDE ECONOMIZER	247	4500-1	20	2953	$10,979	$31,696	3.59	2.9
WATERSIDE ECONOMIZER	660	5400-1	20	3215	$11,953	$81,131	1.53	6.8
TWO SPEED COOLING TOWER FAN - 2	200	3485-1	20	110	$410	$3,156	1.35	7.7
TWO SPEED COOLING TOWER FAN - 2	130	109-1	15	110	$410	$3,156	1.17	7.7
WATERSIDE ECONOMIZER	180	7770-1	10	1247	$4,637	$30,408	1.07	6.6
TWO SPEED COOLING TOWER FAN - 2	225	3220-1	10	110	$410	$3,156	0.91	7.7
VARIABLE SPEED PUMPING	225	3220-1	10	874	$3,250	$44,612	0.69	13.7
TWO SPEED COOLING TOWER FAN - 2	180	7770-1	10	74	$273	$2,800	0.68	10.3
WATERSIDE ECONOMIZER	670	3305-1	10	1895	$7,046	$74,707	0.66	10.6
WATERSIDE ECONOMIZER	204	4505-1	10	813	$3,022	$33,132	0.64	11.0
VARIABLE SPEED PUMPING	200	3485-1	20	586	$2,178	$32,462	0.64	14.9
VARIABLE SPEED PUMPING	155	5681-1	10	1904	$7,080	$118,325	0.57	16.7
TWO SPEED COOLING TOWER FAN - 1	200	3485-1	20	42	$157	$3,156	0.52	20.1
TWO SPEED COOLING TOWER FAN - 1	130	109-1	15	42	$157	$3,156	0.45	20.1
TWO SPEED COOLING TOWER FAN - 2	247	4500-1	20	37	$137	$3,156	0.45	23.1
WATERSIDE ECONOMIZER	440	4488-1	10	725	$2,696	$56,074	0.43	20.8
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	660	5400-1	20	369	$1,373	$25,092	0.42	18.3
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	660	5400-2	20	369	$1,373	$25,092	0.42	18.3
WATERSIDE ECONOMIZER	160	7120-1	20	297	$1,104	$30,408	0.38	27.5
TWO SPEED COOLING TOWER FAN - 1	225	3220-1	10	42	$157	$3,156	0.35	20.1
TWO SPEED COOLING TOWER FAN - 2	204	4505-1	10	37	$137	$2,800	0.34	20.4
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	670	3305-2	10	370	$1,376	$25,463	0.32	18.5
VARIABLE SPEED PUMPING	200	4484-1	10	274	$1,020	$31,133	0.31	30.5
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	670	3305-1	10	370	$1,376	$25,463	0.29	18.5
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	200	3485-1	20	131	$487	$13,789	0.27	28.3
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	160	7120-1	20	110	$411	$11,709	0.26	28.5
TWO SPEED COOLING TOWER FAN - 1	180	7770-1	10	28	$105	$2,800	0.26	26.7
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	200	4484-1	10	131	$487	$13,789	0.23	28.3
WATERSIDE ECONOMIZER	130	109-1	15	212	$786	$30,408	0.23	38.7
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	247	4500-1	20	138	$513	$16,336	0.22	31.8
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	130	109-1	15	85	$316	$9,514	0.21	30.1
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	373	5250-1	10	214	$796	$21,006	0.20	26.4
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	373	5250-2	5	214	$796	$21,006	0.20	26.4
WATERSIDE ECONOMIZER	200	3485-1	20	154	$571	$31,856	0.19	55.8
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	225	3220-1	10	146	$541	$14,881	0.19	27.5
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	180	7770-1	10	114	$424	$13,173	0.17	31.1
TWO SPEED COOLING TOWER FAN - 1	247	4500-1	20	14	$52	$3,156	0.17	60.4

TABLE ES 2 - CHILLER ECOs SORTED BY SIR

ECO's PERFORMED	TONS	Chiller No.	Life (Yrs)	Elec. MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	204	4505-1	10	117	$435	$13,777	0.16	31.7
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	155	5681-1	10	89	$331	$11,343	0.15	34.3
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	155	5681-3	10	89	$331	$10,906	0.15	32.9
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	250	5681-2	10	144	$534	$16,531	0.14	31.0
TWO SPEED COOLING TOWER FAN - 1	204	4505-1	10	14	$52	$2,800	0.13	53.8
WATERSIDE ECONOMIZER	225	3220-1	10	142	$528	$32,011	0.12	60.6
AUTOMATIC CHILLER TUBE CLEANING SYSTEM	200	5400-3	5	115	$427	$13,789	0.11	32.3
CENTRIFUGAL CHILLER REPLACEMENT	373	5250-2	5	405	$1,506	$113,074	0.05	75.1
WATERSIDE ECONOMIZER	373	5250-1	10	77	$286	$49,612	0.04	173.5
WATER TREATMENT / FILL REPLACEMENT	130	109-1	15	24	$88	$14,150	-1.73	160.8
CONDENSER TUBE CLEANING	373	5250-2	5	428	$1,591	$5,412	-2.87	3.4
CONDENSER TUBE CLEANING	200	5400-3	5	230	$855	$2,902	-2.87	3.4
WATER TREATMENT / FILL REPLACEMENT	180	7770-1	10	35	$131	$8,782	-2.99	67.0
WATER TREATMENT / FILL REPLACEMENT	204	4505-1	10	36	$134	$9,765	-3.06	72.9
WATER TREATMENT / FILL REPLACEMENT	225	3220-1	10	45	$167	$10,263	-3.20	61.5
WATER TREATMENT / FILL REPLACEMENT	440	4488-1	10	78	$290	$18,380	-3.51	63.4
WATER TREATMENT / FILL REPLACEMENT	373	5250-1	10	66	$245	$15,153	-3.60	61.8
WATER TREATMENT / FILL REPLACEMENT	670	3305-1	10	114	$425	$24,957	-3.94	58.7
WATER TREATMENT / FILL REPLACEMENT	670	3305-2	10	114	$425	$24,957	-3.94	58.7
WATER TREATMENT / FILL REPLACEMENT	247	4500-1	20	44	$163	$13,796	-3.96	84.6
WATER TREATMENT / FILL REPLACEMENT	160	7120-1	20	34	$126	$8,307	-4.23	65.9
WATER TREATMENT / FILL REPLACEMENT	440	4488-2	15	81	$301	$18,380	-4.55	61.1
CONDENSER TUBE CLEANING	225	3220-1	10	291	$1,082	$3,265	-4.67	3.0
CONDENSER TUBE CLEANING	180	7770-1	10	228	$848	$2,612	-4.72	3.1
CONDENSER TUBE CLEANING	155	5681-1	10	178	$662	$2,249	-4.93	3.4
CONDENSER TUBE CLEANING	250	5681-2	10	287	$1,067	$3,627	-4.93	3.4
CONDENSER TUBE CLEANING	155	5681-3	10	178	$662	$2,249	-4.93	3.4
CONDENSER TUBE CLEANING	440	4488-1	10	505	$1,878	$6,384	-4.94	3.4
CONDENSER TUBE CLEANING	373	5250-1	10	428	$1,591	$5,412	-4.94	3.4
CONDENSER TUBE CLEANING	204	4505-1	10	234	$870	$2,960	-4.94	3.4
CONDENSER TUBE CLEANING	670	3305-2	10	740	$2,751	$9,721	-5.01	3.5
CONDENSER TUBE CLEANING	670	3305-1	10	740	$2,751	$9,721	-5.01	3.5
WATER TREATMENT / FILL REPLACEMENT	200	3485-1	20	40	$149	$8,259	-5.33	55.4
WATER TREATMENT / FILL REPLACEMENT	660	5400-1	20	114	$424	$24,719	-5.91	58.3
WATER TREATMENT / FILL REPLACEMENT	660	5400-2	20	114	$424	$24,676	-5.92	58.2
CONDENSER TUBE CLEANING	200	4484-1	10	262	$974	$2,902	-6.06	3.0
CONDENSER TUBE CLEANING	440	4488-2	15	524	$1,948	$6,384	-6.33	3.3
CONDENSER TUBE CLEANING	130	109-1	15	153	$569	$1,886	-6.36	3.3
CONDENSER TUBE CLEANING	160	7120-1	20	221	$822	$2,322	-6.88	2.8
CONDENSER TUBE CLEANING	200	3485-1	20	262	$974	$2,902	-7.07	3.0
CONDENSER TUBE CLEANING	247	4500-1	20	276	$1,026	$3,584	-7.58	3.5
CONDENSER TUBE CLEANING	660	5400-1	20	739	$2,748	$9,576	-7.58	3.5
CONDENSER TUBE CLEANING	660	5400-2	20	737	$2,740	$9,576	-7.58	3.5
SIM DRIVEN VS. ELEC. DRIVEN CHILLERS	225	3220-1	10	4650	$2,028	$188,975	NA	93.2

ECO	Boiler No.	Economic life	MBTUs Saved Elec. MBTUs	Nat. Gas MBTUs	#2 Oil MBTUs	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
* Boiler Tune-Up OMR	115-2	25		903		$3,927	$2,705	21.18	0.69
Turbulator Installation	115-2	25		120		$522	$1,295	9.10	2.50
** Burner Replacement	115-2	25		977		$4,248	$11,622	8.26	2.70
** Boiler Downsizing	115-2	25		1488		$6,475	$45,285	3.23	7.00
Steel Economizer	115-2	25		306		$1,333	$23,496	1.15	18.00
Summer Boiler	115-2	25		559		$2,430	$25,478	2.16	10.50
** Boiler Replacement	115-2	25		977		$4,248	$55,905	1.72	13.20
Oxygen Trim System	115-2	25		238		$1,037	$16,420	1.24	16.00
Preheat Combustion Air	115-2	25		580		$2,523	$46,257	1.16	18.00
* Boiler Tune-Up OMR	3624-1	10		2449		$10,655	$2,705	30.48	0.25
* Boiler Tune-Up OMR	3624-2	10		748		$3,254	$2,705	4.45	0.83
* Boiler Tune-Up OMR	3624-3	10		8599		$37,407	$2,705	124.60	0.07
* Boiler Tune-Up OMR	3624-4	10		34338		$149,372	$2,705	518.52	0.02
* Boiler Tune-Up OMR	4725-1	15		1945		$8,460	$2,705	36.27	0.32
* Boiler Tune-Up OMR	4725-2	15		21293		$92,626	$2,705	495.49	0.03
* Boiler Tune-Up OMR	4725-3	15		57931		$251,998	$2,705	1341.68	0.01
Turbulator Installation	7105-3	25		69		$300	$1,723	3.93	5.70
Burner Replacement	7105-3	25		413		$1,795	$13,575	2.99	7.60
Boiler Downsizing	7105-3	25		774		$3,368	$40,907	1.86	12.10
*** Boiler Tune-Up OMR	7105-4	10		925		$4,025	$2,705	7.16	0.67
*** Turbulator Installation	7105-4	10		86		$374	$1,723	2.07	4.60
*** Boiler Downsizing	7105-4	10		1102		$4,792	$40,907	1.12	8.50
*** Burner Replacement	7105-4	10		732		$3,184	$30,026	1.01	9.40
Turbulator Installation	7153-1	5		82		$357	$287	5.64	0.80
* Boiler Tune-Up OMR	7153-1	5		705		$3,067	$2,705	1.05	0.88
Summer Boiler	7291-1	15		257		$1,118	$16,100	1.01	14.40
Turbulator Installation	7579-1	10		156		$679	$861	7.50	1.27
Burner Replacement	7579-1	10		858		$3,734	$10,319	3.44	2.80
Steel Economizer	7579-1	10		607		$2,640	$20,862	1.12	6.00
Turbulator Installation	7579-2	10		33		$144	$861	1.59	6.00
Burner Replacement	7579-2	10		283		$1,232	$10,319	1.14	8.40
**** Burner Replacement	7770-1	10		344		$1,497	$10,319	1.38	6.90
Turbulator Installation	7770-1	10		44		$191	$1,723	1.06	9.00
**** Burner Replacement	7770-2	10		345		$1,499	$10,319	1.38	6.90
Turbulator Installation	7770-2	10		44		$191	$1,723	1.06	9.00
Turbulator Installation	8028-1	10			39	$230	$1,723	1.12	7.48
* Boiler Tune-Up OMR	8028-2	25			529	$3,125	$2,705	19.21	0.87
Turbulator Installation	8028-2	25			98	$579	$1,723	6.21	2.98
Oxygen Trim System	8028-2	25			279	$1,649	$16,420	1.67	9.96
Preheat Combustion Air	8028-2	25			522	$3,085	$53,996	1.00	18.00
Turbulator Installation	8874-1	15			49	$290	$518	6.82	1.79
Burner Replacement	8874-1	15			319	$1,882	$9,017	2.55	4.80
Turbulator Installation	8874-2	15			28	$165	$518	3.90	3.13
Burner Replacement	8874-2	15			200	$1,182	$9,017	1.60	7.60
* Boiler Tune-Up OMR	8977-1	10		1965		$8,548	$2,705	23.08	0.32
Burner Replacement	8977-1	10		749		$3,257	$10,319	3.00	3.20
Turbulator Installation	8977-1	10		52		$226	$861	2.50	3.81
Turbulator Installation	8977-2	10		38		$165	$861	1.83	5.21
Burner Replacement	8977-2	10		303		$1,317	$10,319	1.22	7.80

* Package in place (work to be completed in summer 1987)
** Work completed
*** Discontinued - new system in place
**** Boiler rehabilitation package # 1 (work in progress)

} Per guidance through letter dated May 18, 1987, from Keith Kirkly for Paul W. Hancock, Director of Engineering and Housing, to Norm Meinert of Benatech, Inc.

TABLE ES 4 - CHILLER ECOs WITH SIR > 1 (SORTED BY BUILDING)

ECO's PERFORMED	TONS	Chiller No.	Life (YRS.)	Elec. MBTUs Savings	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
TWO SPEED COOLING TOWER FAN - 2	130	109-1	15	110	$410	$3,156	1.17	7.70
CHILLER SHUTDOWN	225	3220-1	10	3961	$14,727	$1,496	68.96	0.10
CHILLED WATER TEMPERATURE RESET	225	3220-1	10	135	$503	$329	10.70	0.65
* CHILLED WATER TEMPERATURE RESET	670	3305-1	10	229	$850	$329	18.13	0.39
TWO SPEED COOLING TOWER FAN - 2	200	3485-1	20	110	$410	$3,156	1.35	7.70
CHILLER SHUTDOWN	200	4484-1	10	3206	$11,920	$1,496	71.70	0.13
CHILLED WATER TEMPERATURE RESET	200	4484-1	10	81	$301	$329	8.24	1.09
CHILLER SHUTDOWN	440	4488-2	15	12396	$46,088	$1,496	277.22	0.03
* CHILLED WATER TEMPERATURE RESET	440	4488-2	15	162	$603	$329	16.47	0.55
WATERSIDE ECONOMIZER	247	4500-1	20	2953	$10,979	$31,696	3.59	2.89
CHILLER SHUTDOWN	373	5250-1	10	15600	$58,001	$1,496	271.61	0.03
* CHILLED WATER TEMPERATURE RESET	373	5250-1	10	132	$492	$329	10.45	0.67
* CHILLED WATER TEMPERATURE RESET	373	5250-2	5	132	$492	$329	10.45	0.67
CHILLED WATER TEMPERATURE RESET	660	5400-1	20	343	$1,276	$329	40.21	0.26
WATERSIDE ECONOMIZER	660	5400-1	20	3215	$11,953	$81,131	1.53	6.79
CHILLED WATER TEMPERATURE RESET	155	5681-1	10	83	$307	$329	6.57	1.07
CHILLED WATER TEMPERATURE RESET	250	5681-2	10	133	$496	$329	10.53	0.66
CHILLED WATER TEMPERATURE RESET	155	5681-3	10	55	$205	$329	4.35	1.60
CHILLER SHUTDOWN	160	7120-1	20	5170	$19,222	$1,496	133.29	0.08
CHILLED WATER TEMPERATURE RESET	160	7120-1	20	68	$254	$329	7.97	1.30
CHILLED WATER TEMPERATURE RESET	180	7770-1	10	70	$262	$329	5.54	1.26
WATERSIDE ECONOMIZER	180	7770-1	10	1247	$4,637	$30,408	1.07	6.56

* Work to be accomplished in FY88 per guidance of letter dated May 13, 1987, from Keith Kirkley for Paul W. Hancock, Director of Engineering and Housing, to Norm Meinert of Beratech, Inc.

3.3 RECOMMENDATIONS

Once all the ECOs which offered project potential were isolated, the synergistic effects of each combination were evaluated. The results of the iterative analysis are the No cost/Low Cost Projects. There are four projects as described below.

1. Boiler Optimization
   - These projects are on a per-boiler basis. They include all ECOs per respective boiler, with SIRs greater than 1.0, that are not already being implemented and are not mutually exclusive with other ECOs for the same boiler.
2. Chiller Optimization
   - These projects are on a per-chiller basis and include ECOs for the respective chiller with SIRs greater than 1.0. ECOs included in optimization projects are chilled water reset and chiller shutdown if they already are not implemented. The term optimization describes chiller operation and obtaining the appropriate amount of refrigeration affect when it is necessary.
3. Chiller Economizer
   - These projects are on a per-chiller basis and include ECOs for the respective chiller with SIRs greater than 1.0. ECOs included in optimization projects are water side economizer and two-speed cooling tower unless they have already been implemented. The term economizer refers to the condenser water side of the chilled water system.
4. Complete Chiller Optimization
   - These projects are on a per-chiller basis and include ECOs for the respective chiller with SIRs greater than 1.0. ECOs included in complete optimization projects include chilled water reset, condenser tube cleaning, automatic chiller tube cleaner, water treatment/fill replacement, water side economizer, variable speed pumping, two-speed cooling tower and chiller shutdown. The term economizer refers to all projects which will enhance the performance of the chiller.

The results of the Boiler and Chiller study are shown in Table ES 5. Table ES 6 is a summary of boiler projects by type of project. Table ES 7 is a summary of chiller projects sorted by building number. Graphs ES 1 and ES 2 depict current boiler plant fuel consumption compared with the reduced energy consumption should all boiler projects be implemented. Graphs ES 3 through ES 5 show the energy savings from the Chiller Projects, broken down by type and by building number. Graph ES 6, shows energy savings by fuel type for both Boiler and Chiller Projects.

TABLE ES 5 - SUMMARY OF PROJECTS

	ANNUAL SAVINGS					Simple
	ELECTRIC (MBTUs)	NAT GAS (MBTUs)	#2 OIL (MBTUs)	Annual $$	Cost Estimate	Payback (Years)
BOILER TOTALS	0	4,821	1,636	$30,636	$231,957	7.57
CHILLER TOTALS	48,820	0	0	$181,178	$159,659	0.88
STUDY TOTALS	48,820	4,821	1,636	$211,814	$391,616	1.85

TOTAL MBTUs/YR: 55,277

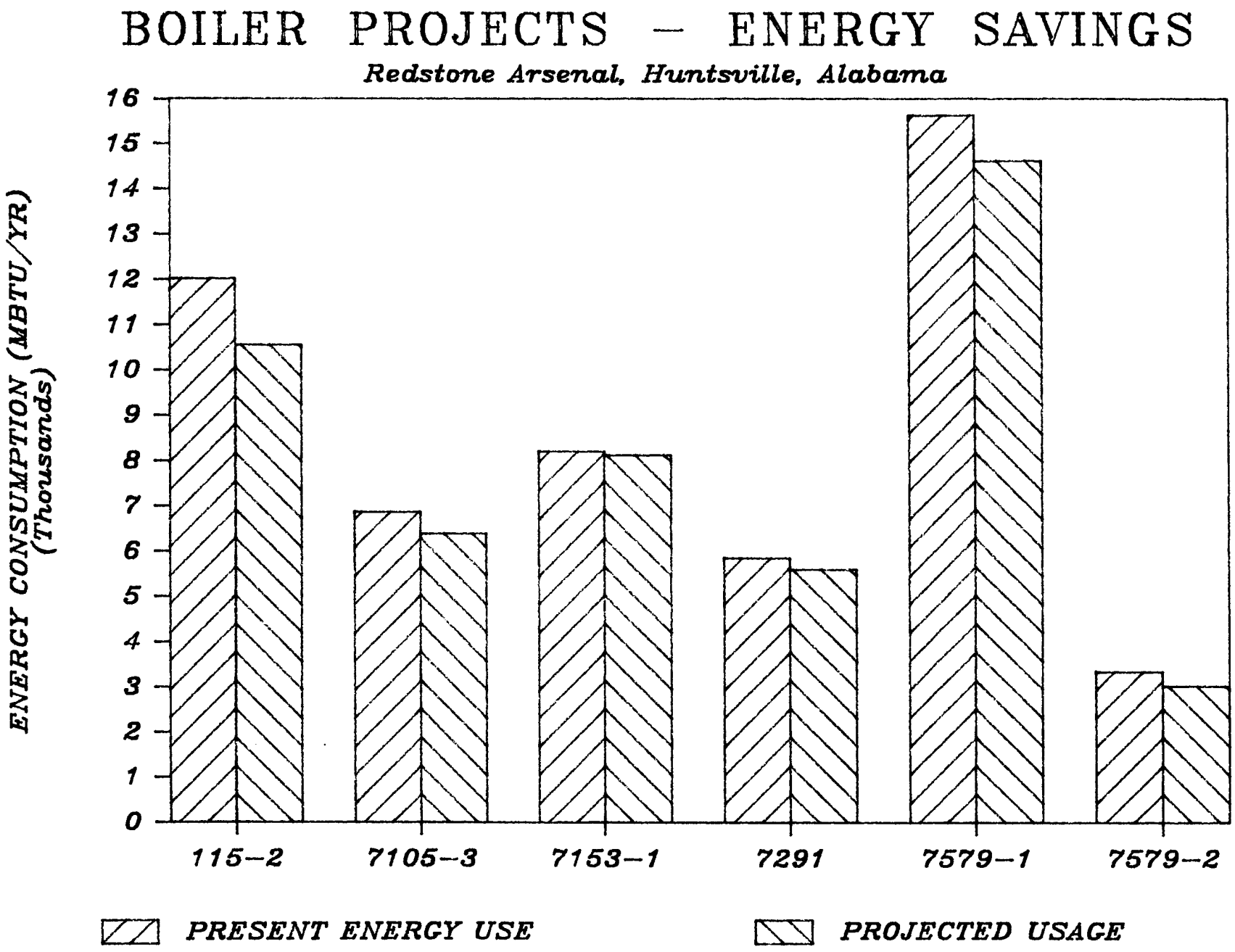
TABLE ES 6 - SUMMARY OF BOILER PROJECTS BY BUILDING

PROJECT TITLE	Boiler No.	Life (YRS)	SAVINGS NAT GAS (MBTUs)	SAVINGS #2 OIL (MBTUs)	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
BOILER OPTIMIZATION	115-2	25	1466		$6,375	$59,174	2.38	9.28
BOILER OPTIMIZATION	7105-3	25	477		$2,076	$15,298	3.06	7.37
BOILER OPTIMIZATION	7153-1	5	82		$357	$287	5.65	0.80
BOILER OPTIMIZATION	7291	15	257		$1,118	$16,100	1.01	14.40
BOILER OPTIMIZATION	7579-1	10	1006		$4,377	$11,180	3.73	2.55
BOILER OPTIMIZATION	7579-2	10	314		$1,365	$11,180	1.16	8.19
BOILER OPTIMIZATION	7770-1	10	44		$190	$1,723	1.05	9.07
BOILER OPTIMIZATION	7770-2	10	44		$190	$1,723	1.05	9.07
BOILER OPTIMIZATION	8028-1	10		39	$232	$1,723	1.12	7.43
BOILER OPTIMIZATION	8028-2	25		1006	$5,947	$72,139	1.44	12.13
BOILER OPTIMIZATION	8874-1	15		365	$2,154	$9,535	2.76	4.43
BOILER OPTIMIZATION	8874-2	15		226	$1,336	$9,535	1.71	7.14
BOILER OPTIMIZATION	8897-1	10	794		$3,452	$11,180	2.94	3.24
BOILER OPTIMIZATION	8897-2	10	337		$1,467	$11,180	1.25	7.62
	TOTALS:		4821	1636	$30,636	$231,957		7.57

TABLE ES 7 - SUMMARY OF CHILLER PROJECTS BY BUILDING

PROJECT TITLE	TONS	Chiller No.	Life (YRS)	Elec. MBTUs Savings	Annual Savings	Cost Estimate	SIR	Simple Payback (Years)
CHILLER ECONOMIZER	130	109-1	15	110	$409	$3,156	1.17	7.72
CHILLER OPTIMIZATION	225	3220-1	10	4096	$15,229	$1,825	58.46	0.12
CHILLER ECONOMIZER	200	3485-1	20	110	$410	$3,156	1.35	7.70
CHILLER OPTIMIZATION	200	4484-1	10	3287	$12,221	$1,825	60.26	0.15
CHILLER OPTIMIZATION	440	4488-2	15	12396	$46,088	$1,496	277.22	0.03
CHILLER ECONOMIZER	247	4500-1	20	2953	$10,979	$31,696	3.59	2.89
CHILLER OPTIMIZATION	373	5250-1	10	15600	$58,001	$1,496	271.61	0.03
COMPLETE CHILLER OPTIMIZATION	660	5400-1	20	3387	$12,593	$81,460	1.60	6.47
CHILLER OPTIMIZATION	155	5681-1	10	83	$309	$329	6.57	1.06
CHILLER OPTIMIZATION	250	5681-2	10	133	$494	$329	10.53	0.67
CHILLER OPTIMIZATION	155	5681-3	10	55	$204	$329	4.35	1.61
CHILLER OPTIMIZATION	160	7120-1	20	5328	$19,475	$1,825	110.70	0.09
COMPLETE CHILLER OPTIMIZATION	180	7770-1	10	1282	$4,766	$30,737	1.09	6.45
			TOTALS:	48820	$181,178	$159,659		0.88

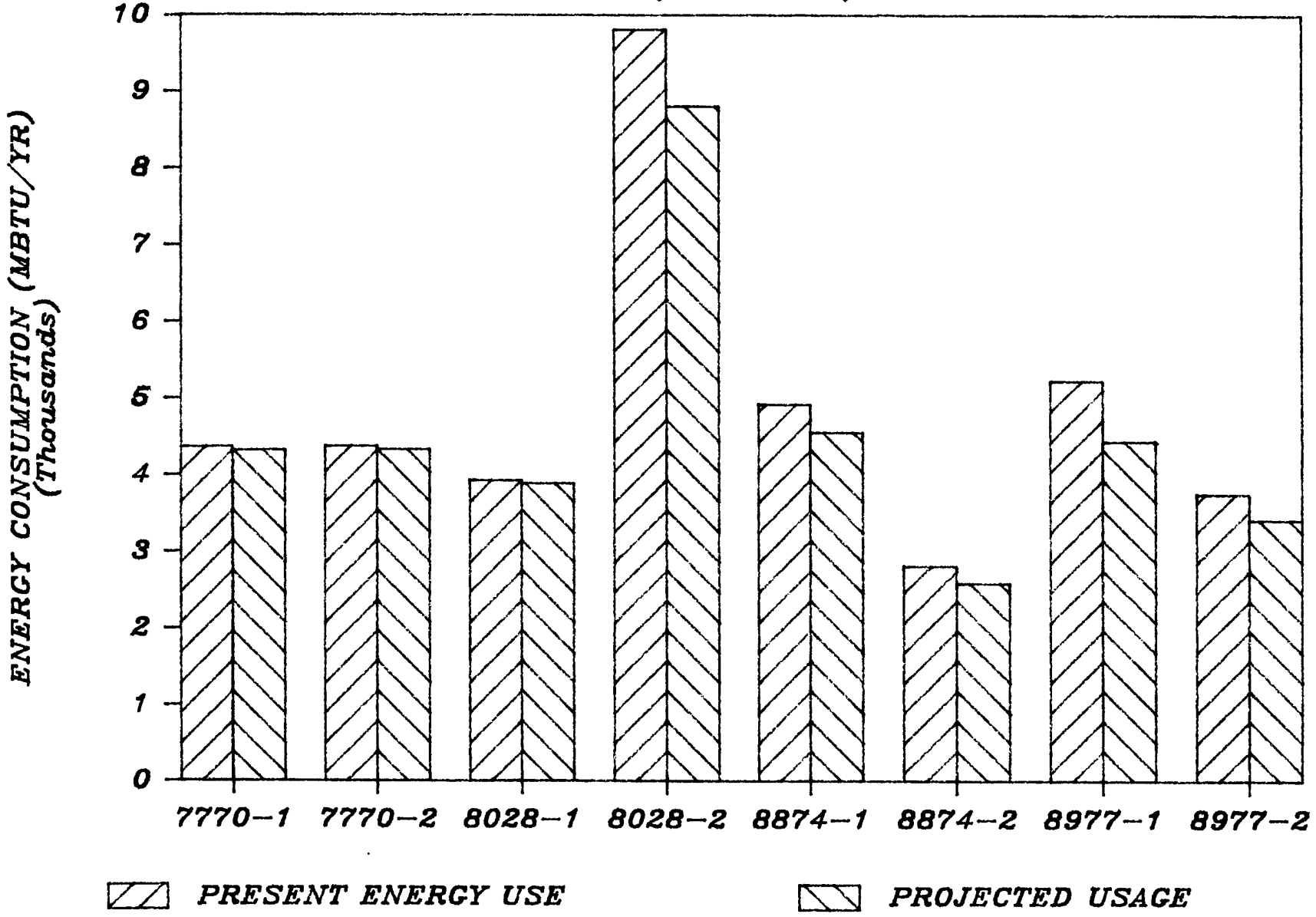
GRAPH ES 1 BOILER SAVINGS BY BUILDING



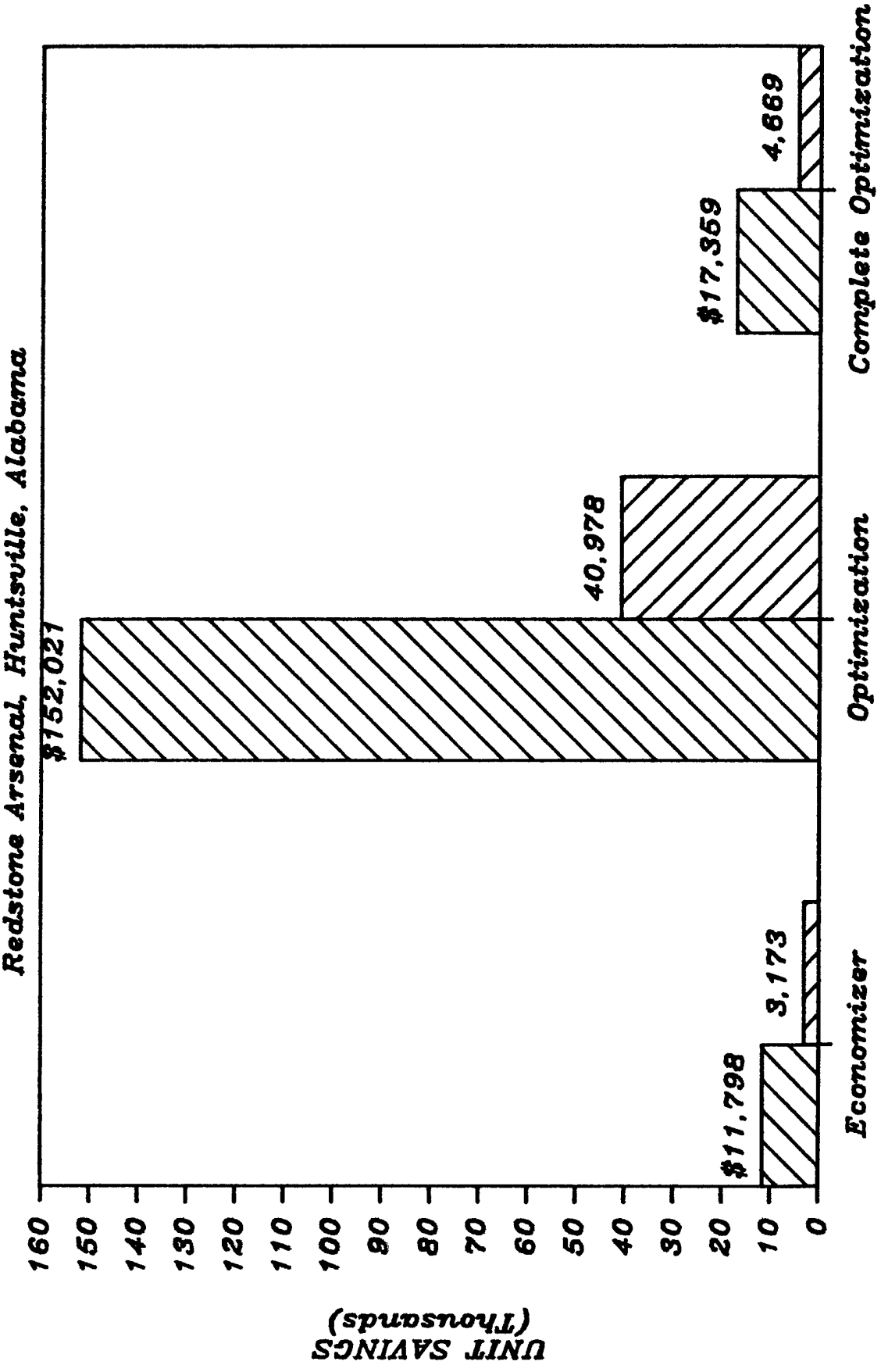
GRAPH ES 2 BOILER SAVINGS BY BUILDING

BOILER PROJECTS – ENERGY SAVINGS

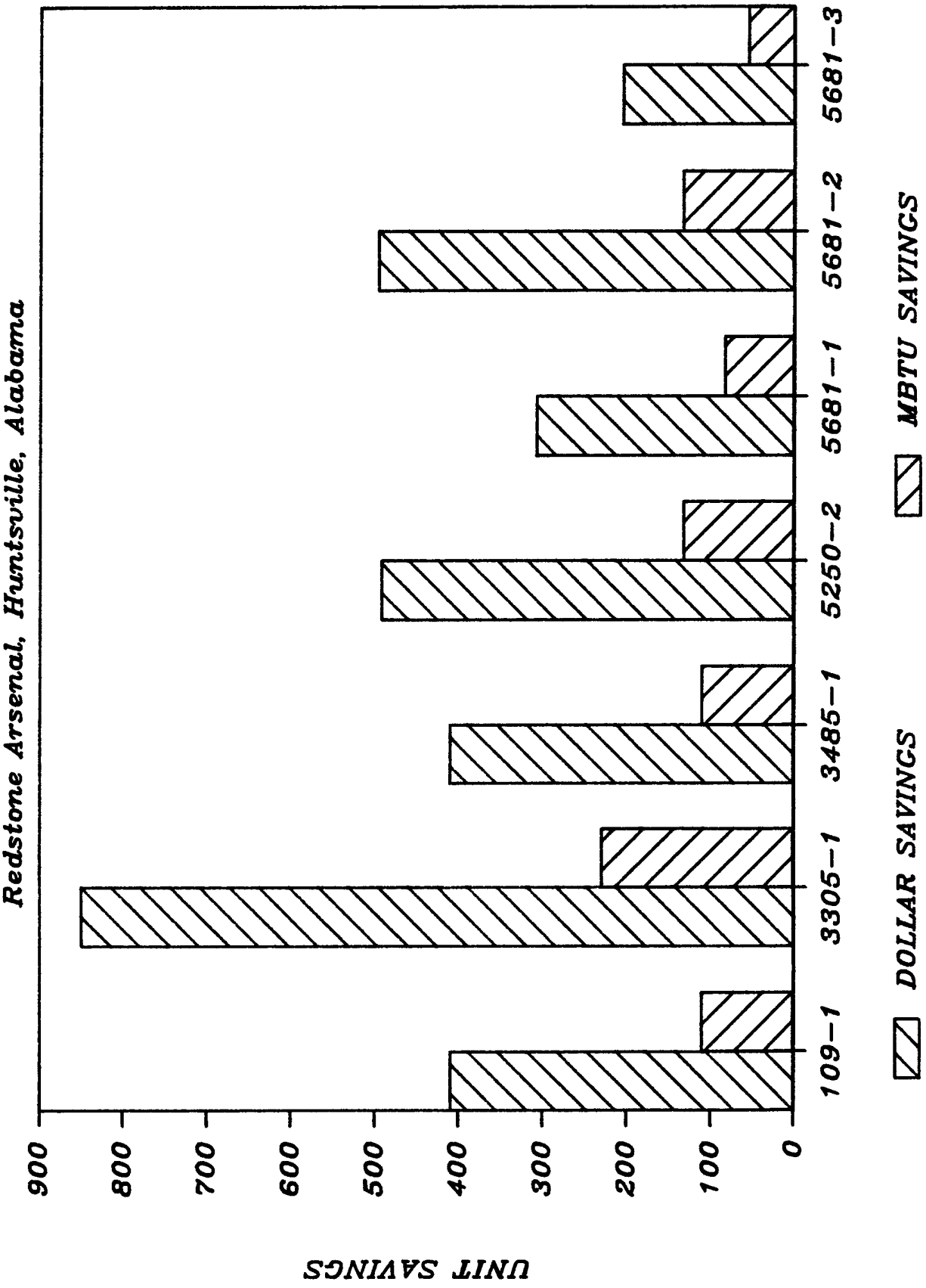
Redstone Arsenal, Huntsville, Alabama



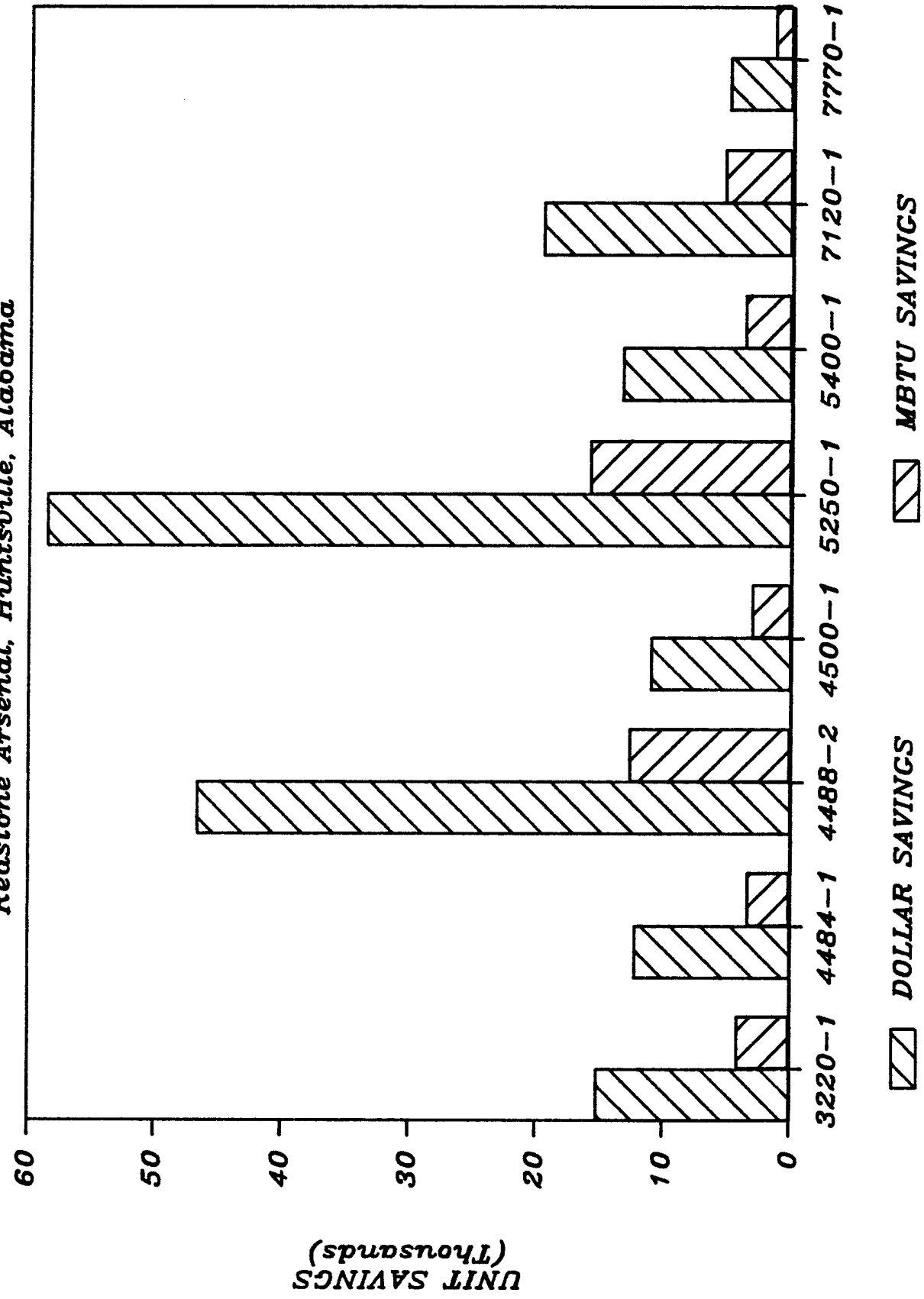
GRAPH ES 3 CHILLER SAVINGS BY PROJECT



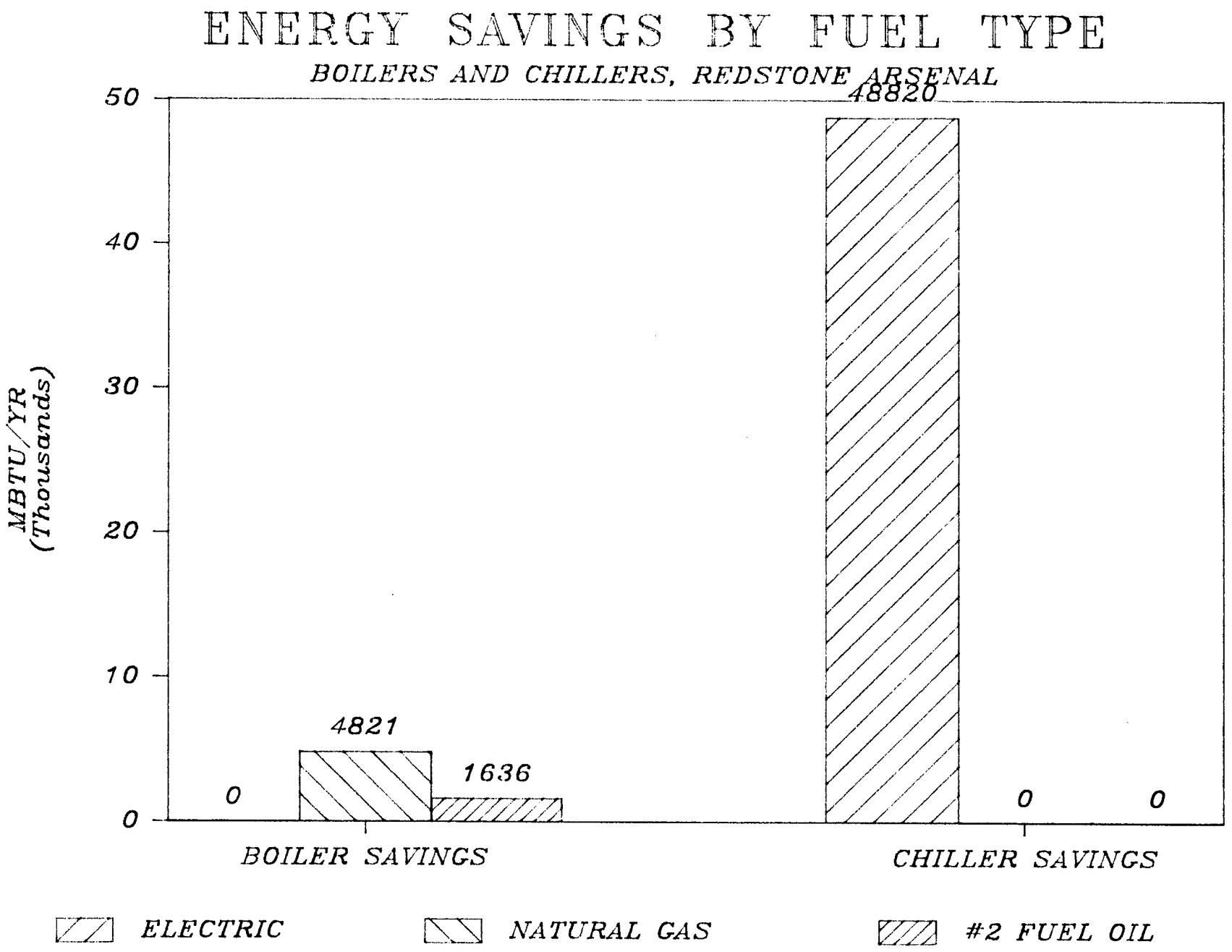
GRAPH ES 4 CHILLER SAVINGS BY BUILDING



GRAPH ES 5 CHILLER SAVINGS BY BUILDING



GRAPH ES 6 ENERGY SAVINGS BY FUEL TYPE



I N D E X

I N D E X

I N D E X

I N D E X

I N D E X

I N D E X

I N D E X

I N D E X

I N D E X