PN-ABL-624

RESOURCE MANAGEMENT ASSOCIATES
of Madison, Inc.

ENERGY EFFICIENCY AUDIT REPORT

VILNIUS FURNITURE FACTORY
Vilnius, Lithuania

JUNE 1992

PREPARED BY: RESOURCE MANAGEMENT ASSOCIATES OF MADISON, INC.
Madison, WI

U.S. EMERGENCY ENERGY PROGRAM FOR EASTERN AND CENTRAL EUROPE

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
BUREAU FOR EUROPE
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ENERGY & INFRASTRUCTURE DIVISION
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USAID Contract EUR-0015-C-1006-00

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i. Industrial Energy Efficiency Program

The countries of Eastern Europe face unprecedented changes both in their political and economic systems. To aid in the transition to market economies, the U.S. Agency for International Development (USAID) designed the Eastern Europe Emergency Energy Program. Resource Management Associates of Madison, Inc. (RMA) is the technical assistance contractor for the Industrial Energy Efficiency Component (IEEC) of the program in Lithuania.

The Industrial Energy Efficiency Component was designed to address the problems of industrial energy efficiency with a short term program aimed at the immediate needs of industry. The program involves three main activities:

1. To identify and implement cost-effective low-cost/no-cost industrial energy improvements, with an emphasis on oil savings.

2. To conduct industrial energy audits and transfer energy auditing and management techniques, including financial and economic analysis.

3. To provide energy auditing and/or energy efficiency equipment to implement the program objectives, improve energy management, and identify additional energy efficiency opportunities.

The IEEC program deliverables consist of plant audit reports, a policy and institutional analysis report, an industry profile report, and the in-country audits, training, and equipment delivery and installations. The tasks are being carried out by a team of energy specialists and policy analysis experts in four different phases:

- Phase One: Screening - During this phase the plants to be audited will be identified, and a specific plan to implement the following phases developed and put in place.

- Phase Two: Industrial Plant Energy Audit/Training - A team of energy specialists will arrive in-country and perform a detailed energy audit at the four selected industrial sites. They will identify short-term energy efficiency measures, develop recommendations to implement these measures, demonstrate and train plant personnel on auditing techniques, and demonstrate financial and economic methodologies for justifying energy improvement projects. Additional equipment will be ordered for Phase Three.

- Phase Three: Implementation - The recommendations identified in Phase Two will be implemented, evaluated, and modified as necessary. Additional training will be provided and the final energy efficiency equipment turned over to the host country.

- Phase Four: Analysis of Factors - This phase will analyze the factors that make up energy efficiency management and investment decision making. Recommendations for policy reform and options for enhanced energy management will be identified and a program for implementation suggested.

Energy monitoring and testing equipment will be turned over to the Lithuanian industrial sector and the Government of Lithuania. This will be provided with analysis and recommendations for further energy efficiency measures.

ii. Executive Summary

An industrial energy efficiency audit was conducted at the Vilnius Furniture Factory located in the city of Vilnius, Lithuania. The plant is designed to process raw wood, particle board plywood and laminate materials into finished furniture products. The primary products are consumer and office furniture items that are packaged and sold for assembly by the consumer. Wood frame upholstered furniture is also produced as well as cabinets for small refrigerators. Approximately 30,000 metric tons per year of raw materials are utilized to produce 20,000 metric tons per year of finished products.

Vilnius Furniture Factory utilizes steam, thermal water and electricity for the production of furniture. All energy resources are purchased from local utility companies. No fuels are consumed on-site. The steam and thermal water systems are in generally food repair. There are some areas where steam piping insulation has deteriorated or is non-existent (discussed under recommended improvements). A few minor steam leaks were apparent. Direct steam is used only in the wood drying process which uses approximately 12% of incoming steam directly. This direct steam is contaminated with wood oils and cannot be returned as condensate. Sixty-five percent of the incoming steam is returned as condensate. With only a few apparent small leaks and a known amount of steam used directly in drying, the remaining steam loss could not be accounted for.

The major electrical consumption is related to the various air handling systems used to remove sawdust from a variety of wood working operations and fumes from various painting and finishing operations. A major concern with the air handling system is the large amount of exhaust air in the buildings and the related heating requirements. Connected electric load of the dust collection and exhaust fan motors totals 3,102.5 kW while connected electric load of the make-up air fan motors is 598.05 kW. Power to draw air out of the building far exceeds the power to push air into the building. The result is that there is a large negative pressure in the building relative to the outside pressure. This negative pressure gradient forces large amounts of uncontrolled air into the building through open doors, broken windows and cracks around doors and windows. The uncontrolled air significantly increases the heating load on the building.

During the audit, it was clearly apparent that the personnel operating the plant were very aware of their greatest energy efficiency problems. With the right instrumentation and information on equipment available outside of Lithuania, plant personnel are in the best position to justify energy efficiency measures within the other constraints of the operation. Therefore, for short-term measures, the audit focused on identifying information and control needs in terms of instrumentation and foreign equipment not available to the plant. Both short-term measures and long-term measures were recommended for the plant.

Short-Term Energy Conservation Opportunities

As a result of the energy audit, several short-term energy conservation opportunities (ECOs) were identified. Short-term projects are characterized by low or no-cost to implement with

short payback periods. These projects could be implemented in two months. Long-term projects are characterized by a larger cost to implement and with longer payback periods. The audit team identified a number of ECOs for the facility. The emphasis of the short-term measures is to reduce the heating requirements caused by the high exhausted air rate. Once the heating requirements are reduced, increased control of the make-up and dust collection systems can be justified.

Filter and Return Dust Collection Air

About 50% of the heating requirements are due to the removal of air by the dust collection system. Many of the ducts are left open by the workers when they leave their cutting equipment. In addition to the dampers that were observed open, some ducts had no available dampers. However, all air from the dust collection system is currently discharged from the building. The installation of an additional dust filtration system on the discharge of the existing cyclone separators and the return of the discharge air to the building will significantly reduce heating requirements.

It is recommended that two pulse-jet baghouses be installed in series with two of the cyclones and the air be returned to the building. Estimated savings with this system is 172 Gcal/yr thermal energy and 41,200 kWh/yr electrical energy.

Install Curtains on Presses

The continuous and batch presses for laminating finish surfaces to wooden base material all require ventilation air to exhaust fumes. This measure recommends the installation of strip curtains on the side of the hood to more effectively capture the fumes from the pressed boards. The plant had used curtains on the side of the press in the past and they were removed by the employees. Using strip curtains may increase the accessibility to the press conveyor and reduce the chance that the employees will remove the curtain.

The estimated cost of the measure for one press is US$240. This would result in a payback of 7.5 years. The total energy savings for the plant to use curtains for 30 hoods is 768 Gcal and 216,000 kWh. This is about 2% of the electric use and about 3.7% of the thermal water energy consumption.

Install Strip Curtains on Large Doorways

This measure recommends the addition of strip curtains on the door entrance to the dryer area. This will allow fork lifts to enter and exit the door, but greatly reduce the loss of air and heat through the door. The strip curtains could certainly be applied to other doors that do not have an effective air curtain and/or a closed door such as on the entrance to the battery charging warehouse.

The savings from this measure includes both thermal and electric energy savings. The electric savings will occur by reducing the make-up air flow required after adding the curtain

by an estimated 4,000 m^3/hr. This will reduce the power requirements by about 2 kW. The annual electric savings would be 8,000 kWh. The reduction in thermal energy for make-up air would be 51.2 Gcal per year. The total cost savings for each door would therefore be 3,817 rubles or US$56 at 70R/US$. The cost of the measure is estimated to be US$225 per door. Therefore, the payback is 4.0 years.

Installation of Steam Meters

The steam and dryer systems are not effectively controlled to minimize the waste of steam from the system. It is difficult to maintain the proper pressure in all parts of the system including the condensate tank. Automatic controls could significantly reduce losses and optimize the use of the steam in the dryer operation.

Insulate Steam Pipes

A number of uninsulated pipes containing thermal water, steam and condensate were observed. The majority of the plant piping is adequately insulated. However, several areas experience over-heating due to large lengths of uninsulated piping. Ventilation air is required during parts of the year to maintain worker minimum comfort. This compounds an inefficient situation by using energy to mitigate the impacts of energy loss. Using pipe surface temperature measurements and unit pipe surface area, the heat loss from the uninsulated pipe was estimated. Insulation of all types of lines pays back in less than 16 years except for thermal water return. Piping such as hot water distribution to space heaters and hot water control valves should all be insulated to reduce heat loss. Reinstallation of insulation after piping repairs should be part of maintenance activities.

Repair Compressed Air Leaks

During the plant audit many compressed air leaks were observed. This is a common problem in many plants in the U.S. also. Compressed air is sometimes treated as a free commodity without regard to the electric power it represents. Although not every air leak can be eliminated, in this plant it is estimated that at least 5% of the compressed air is wasted. This ECO is basically a no-capital-cost measure that recommends a more diligent maintenance program to identify and rectify air leaks in the system.

The energy savings conservatively assumes that 25% of the existing air leaks can be eliminated with increased inspection. The annual energy savings would be about 15,500 kWh, which results in a cost savings of 1,250 rubles. For a 50% return on the labor time invested, the increase in maintenance time would be 10 hours/month. This should be enough time to realize the reduced air leakage and energy savings.

Table 1. Annual Energy Savings for Short-Term Measures

Measure	Thermal Energy Saved (Gcal)	Electricity Saved (MWh)	Annual Savings (1,000s R)	Annual Savings (1,000s US$)
Dust Filter	172	41.2	385	5.5
Press Curtains*	768	216.0	1831	26.2
Strip Curtains/Door	51	8.0	99	1.4
Install Steam Meters	481	-	99	3.07

* Note: Press curtains are not funded by USAID.

Long-Term Energy Conservation Opportunities

The long-term ECOs require larger capital investments than the short-term investments and have longer payback periods. Therefore, these measures should be performed after the short-term ECOs and should be investigated further by the plant staff. These items are not funded by USAID.

Heat Recovery from Air Compressors

The two-stage air compressors require cooling water to cool the air between stages. This heated water is then sent to a cooling pond and the heat is released to the atmosphere. This heat could be used to heat make-up air and reduce the thermal water requirements for the facility.

Replace Incandescent with Fluorescent Lights

There are a number of areas that use incandescent lighting. Many of these areas could use fluorescent lighting and reduce the electric energy consumed considerably.

Demand Control During Peak Hours

By installing a demand controller, the cost of the demand portion of the electric bill could be reduced. The demand controller may be linked to the "transport fans" that move dust to the briquette area. The demand period is only for five hours total per day and saw dust storage is enough to interrupt the transport system. These fans could then by turned off when necessary to reduce the electric demand.

Repair Windows to Reduce Leakage

After the ventilation system is brought into balance and the make-up air is sufficient to meet the exhaust air, tightening up the windows will reduce infiltration and reduce heating energy. Reparation of the windows could include complete replacement or maintenance of the windows to ensure a snug fit with frame.

In summary, plant management has not had the luxury to maintain their equipment properly due to the continual demand on the plant. They have been much more concerned with maintaining the operation of the equipment than improving the efficiency. They are just now in a position to use economic justification to request authorization to purchase energy efficient equipment. Besides being inadequately maintained and of inadequate capacity, the system is very old. Therefore, in the long-term, management will need to be making decisions about large investments in new equipment. The equipment recommended in this report will allow them to make informed decisions optimizing short and long-term investments.

1.0 Plant Description

1.1 General

The Vilnius Furniture Factory is located in the city of Vilnius, Lithuania. The plant is designed to process raw wood, particle board plywood and laminated materials into finished furniture products. The primary products are home and office furniture items that are packaged and sold for assembly by the consumer. Wood frame upholstered furniture is also produced, as well as cabinets for small refrigerators. Approximately 30,000 metric tons per year of raw materials are utilized to produce 20,000 metric tons per year of finished products. Ninety-five percent of their product is consumed domestically and five percent is exported to Belgium (US$2 million annually). Plans are underway to increase sales of exports to US$10 million annually. This plant operates independently of the USSR, both in raw materials and product markets.

The factory operates one full shift and a second, partial shift, five days per week, employing a total of 2,000 people. The telephone number, FAX number and address are:

Vilnius State Furniture Factory
178 Savanoriu Av.
Vilnius 2600 Lithuania
Telephone: 635503
FAX: 633395

1.2 Organization

The key plant staff with whom the U.S. audit team met are the following individuals:

Mr. Vatslovas Tchepas, General Director
Mr. Vytautas Radzius, Technical Director
Mr. Kazimierai Slankunas, Chief Energy Manager

The plant organizational chart is provided in *Figure 1*. The Construction Director is responsible for major improvements and modifications to the facility. The Chief Energy Manager is responsible for the maintenance, repair, and up-grade of the plant energy system. He has a staff of 68, including four engineers. During 1991, the budget for the Energy Department was 178,000 rubles. Funding for any major project in his area would come from the Construction Department. Decisions between the Technical Director, where the Energy Management Department is located, and the Construction Director are passed on to the General Director.

Figure 1. Plant Organizational Chart

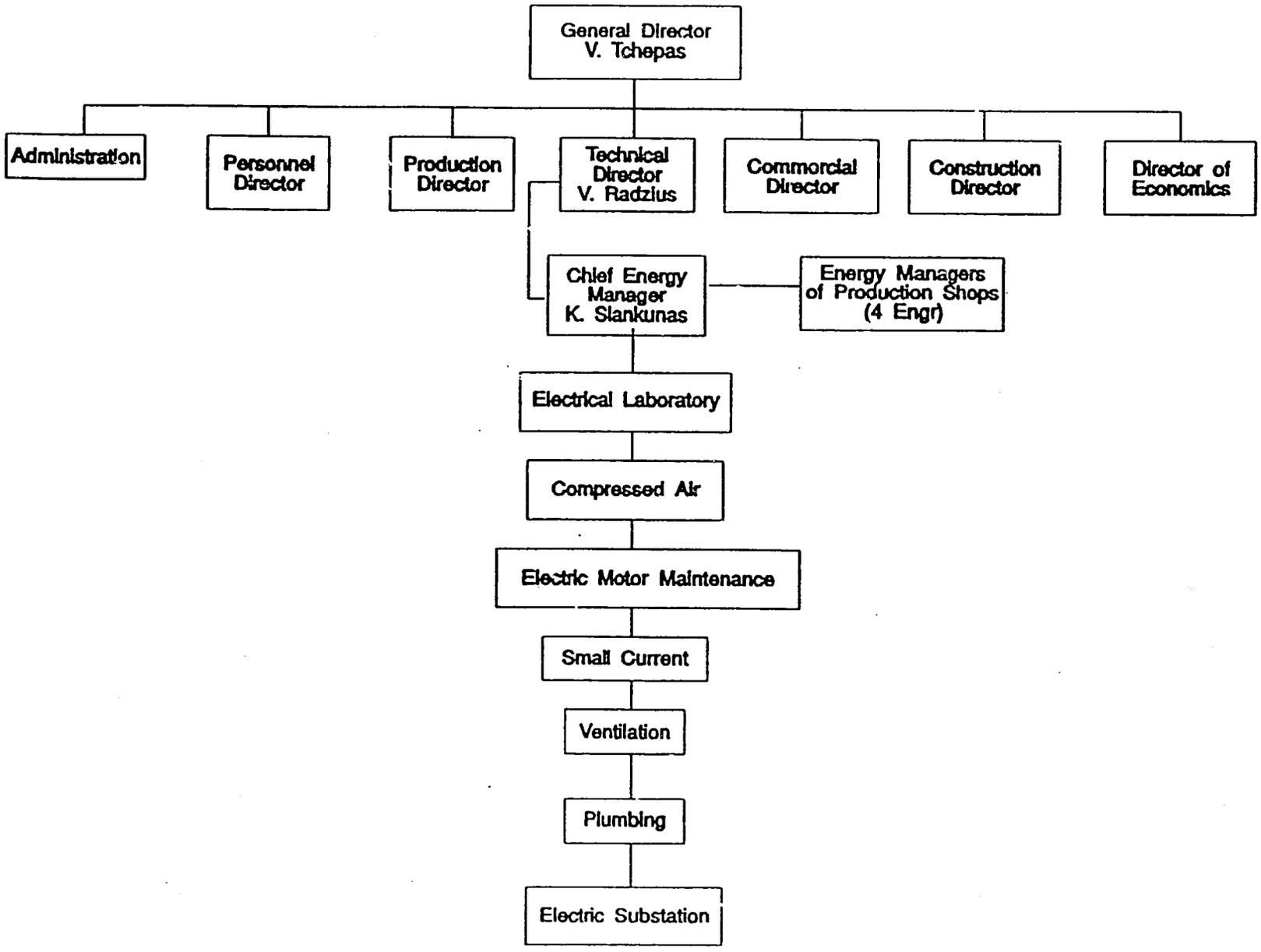


Figure 1. Plant Organizational Chart

1.3 Electrical Description

The facility is directly connected to the power grid via four transformers through two separate substations. These transformers feed the 380V/220V plant electrical distribution system. Key electrical parameters are the following:

Connected Load:	12,000 kW
Peak Loading:	4,000 kW
Normal Load:	2,800 - 3,700 kW (operating shifts)
Power Factor:	0.95 to 0.98
Electricity Cost:	66.8 R/kWh
Demand Charge:	10 R/kW month
Annual Consumption:	12,344 MWh

Electric energy use is distributed between process, ventilation, compressed air, and lighting. *Figure 2* presents the distribution of electric energy.

1.4 Thermal Description

Steam and thermal water are supplied to the plant from the Vilnius district heating system as follows:

Steam demand (nominal):	4 metric tons/hour
Steam demand (capacity):	18 metric tons/hour
Pressure:	7 bar saturated steam
Temperature:	160 °C
Condensate:	65%, returned at 90 °C
Cost:	64 R/Gcal
Annual Consumption:	13,501 Gcal
Water demand (nominal):	7.5 Gcal/hour
Water demand (capacity):	28.3 Gcal/hour
Pressure:	12 bar
Temperature:	70 - 80 °C, depending on outdoor temperature
Cost:	64 R/Gcal
Annual Consumption:	20,801 Gcal

Steam is distributed throughout the plant at 5 bar and 2 bar. Steam is utilized for wood drying, laminate presses in both the old and new building, finish drying, and hot water preheating. Distribution data for steam use is shown in *Figure 3*. Thermal water is used for space heating at the radiators and heating make-up air in the ventilation system.

1.5 Process Description

Raw materials come into the plant in the forms illustrated in *Table 2*.

Figure 2. Electric End-Use Distribution

Figure 2. Electric End-use Distribution
(Annual consumption 12,344 MWh)

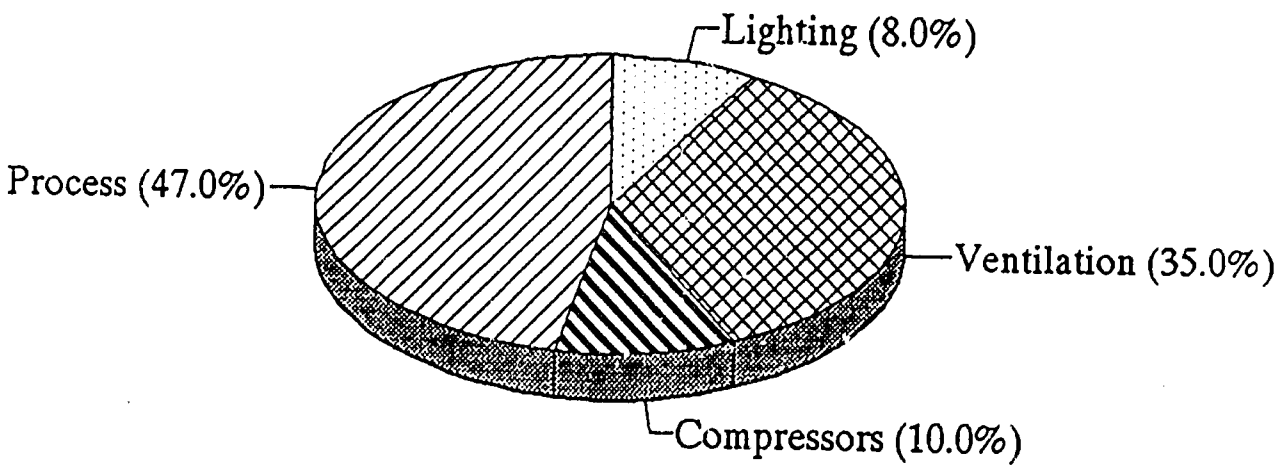


Figure 3. Steam End-Use Distribution

Figure 3 Steam End-use Distribution
(Annual Consumption 13,501 Gcal)

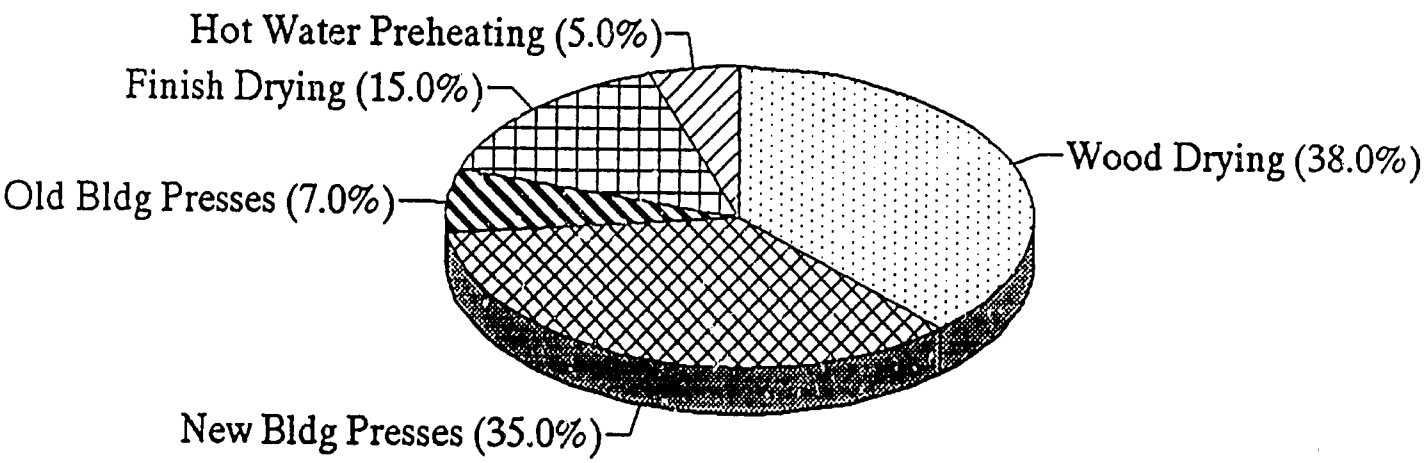


Table 2. Raw Materials

Material	Amount (metric tons)
Particle Board	22,482
Hard Board	1,856
Spruce	3,739
Plywood	2,711
Veneer	893
Synthetic	540
Layer Covering	115
TOTAL	32,796

Spruce arrives at the plant as rough cut wood requiring drying. The wood is dried using steam heated dryers that also use some direct steam injection to control the rate of drying. Rough cut wood is prepared to specific dimensions using planers and cut to the required length. Particle board is cut to size and covered with a press-glued synthetic laminate or a veneer. The synthetic laminate is finished with a wood grain. All components are finished with a lacquer finish and packaged.

2.0 Plant Energy Profile

Vilnius Furniture Factory utilizes steam, thermal water, and electricity for the production of furniture. All energy resources are purchased from local utility companies. No fuels are consumed on-site. The steam and thermal water systems are in generally good repair. There are some areas where steam piping insulation has deteriorated or is non-existent (discussed under recommended improvements). A few minor steam leaks were apparent. Injection steam is used only in the wood drying process, which uses approximately 12% of incoming steam directly. This direct steam becomes contaminated with wood oils and can not be returned as condensate. Sixty-five percent of the incoming steam is returned as condensate. Therefore, twenty-three percent of the steam is not returned. With only a few apparent small leaks and a known amount of steam used directly in drying, the remaining steam loss could not be accounted for. Plant personnel suspect that the commercial metering equipment is faulty. This could be checked against make-up water.

Table 3 contains the annual steam, thermal water, and electrical profiles for 1991. All energy sources have both a demand charge and an energy charge associated with the billing. Demand charges for steam and thermal water are based on the rated capacity of the system and 2,000 R/Gcal per peak hour per month for steam and thermal water. If less than 60 percent of the condensate is not returned, a penalty of approximately 400 R/metric ton is assessed. However, this limit is rarely met because the 60% amount is almost always returned. The demand charge for electricity is 10 R/kW per peak hour per month. The demand charge is based on the planned demand estimated by the plant. If demand actually exceeds the estimated amount, the demand charge increases to 100 R/kW per peak hour per month. Energy charges are based on the actual energy consumed by the plant. Energy costs are 66.8 R/kWh for electricity and 44 R/Gcal for steam and water. *Figures 4 and 5* show graphically the annual use profile and cost of electricity for 1991 by month. Energy requirements vary slightly through the year. However, the cost increased by a factor of three from December 1990 to November 1991. This is due to a shift to world energy prices. A typical hourly electric demand profile for the current full first shift and partial second shift is shown in *Figure 6*.

Figures 7 and 8 show graphically the annual use profile and cost of steam for 1991 by month. Energy requirements vary slightly through the year. However, the cost increased by a factor of eight from December 1990 to November 1991. Again, this is due to the introduction of free market forces.

Figures 9 and 10 show graphically the annual use profile and cost of thermal water for 1991 by month. Energy requirements vary slightly through the year. However, the cost increased by a factor of 4.4 from December 1990 to November 1991. The major increase was due to the addition of a capacity charge based on the capacity of the facility to draw thermal water from the system. In April 1991, a thermal water access charge was added to the utility bill of the factory. During the months of May through September the access charge was paid even though there was little or no use of thermal water. This will further increase the total annual bill. *Figure 11* shows the total energy cost per month.

A large number of medium size electric motors comprise the process and ventilation electric loads. Ventilation air motor loads include dust collection motors, exhaust fan motors, and make-up air fan motors. *Table 4* presents a list of the number and capacity of these motors.

Table 3. Annual Electric, Steam, Thermal Water Energy and Cost

Table 3. Annual Electric, Steam, Thermal Water Energy and Cost

Month 1991	Steam (Gcal)	Steam Cost (R)	Ther Water (Gcal)	Ther Water Cost (R)	Electric Demand (kW)	Electric Energy (MWh)	Electric Cost (R)	Total Energy Cost (R)	Total Energy Cost (USD*)
Dec. 1990	1184	13943	3911	44976	3720	1047	29710	88629	1266
January	1268	29989	3246	74658	3720	1240	79141	183788	2626
February	1148	27159	3737	85951	3720	1110	74180	187290	2676
March	1294	30569	2564	58972	3360	1134	75092	164633	2352
April	1097	48512	2485	112588	3456	1049	68654	229754	3282
May	1152	49998	140	59826	3408	1032	68006	177830	2540
June	1064	47933	0	56676	3432	830	60346	164955	2357
July	949	45273	41	57605	3288	828	58682	161560	2308
August	720	40510	0	56676	3312	958	63597	160783	2297
September	1124	50254	0	56676	3360	881	60688	167618	2395
October	1279	80856	1840	136900	3960	1115	92879	310635	4438
November	1222	78288	2837	180369	3936	1120	93120	351777	5025
Total	13501	543284	20801	981873		12344	824095	2349252	33561

Average Demand: 3556

Average Cost 1991:

Steam (R/Gcal)	Ther Water (R/Gcal)	Electric (R/kWh)
40.20	47.20	0.067

* 70 R = 1 USD

Average Thermal Cost for Steam & Water: 44 R/Gcal

Figure 4. Electricity Consumption 1991

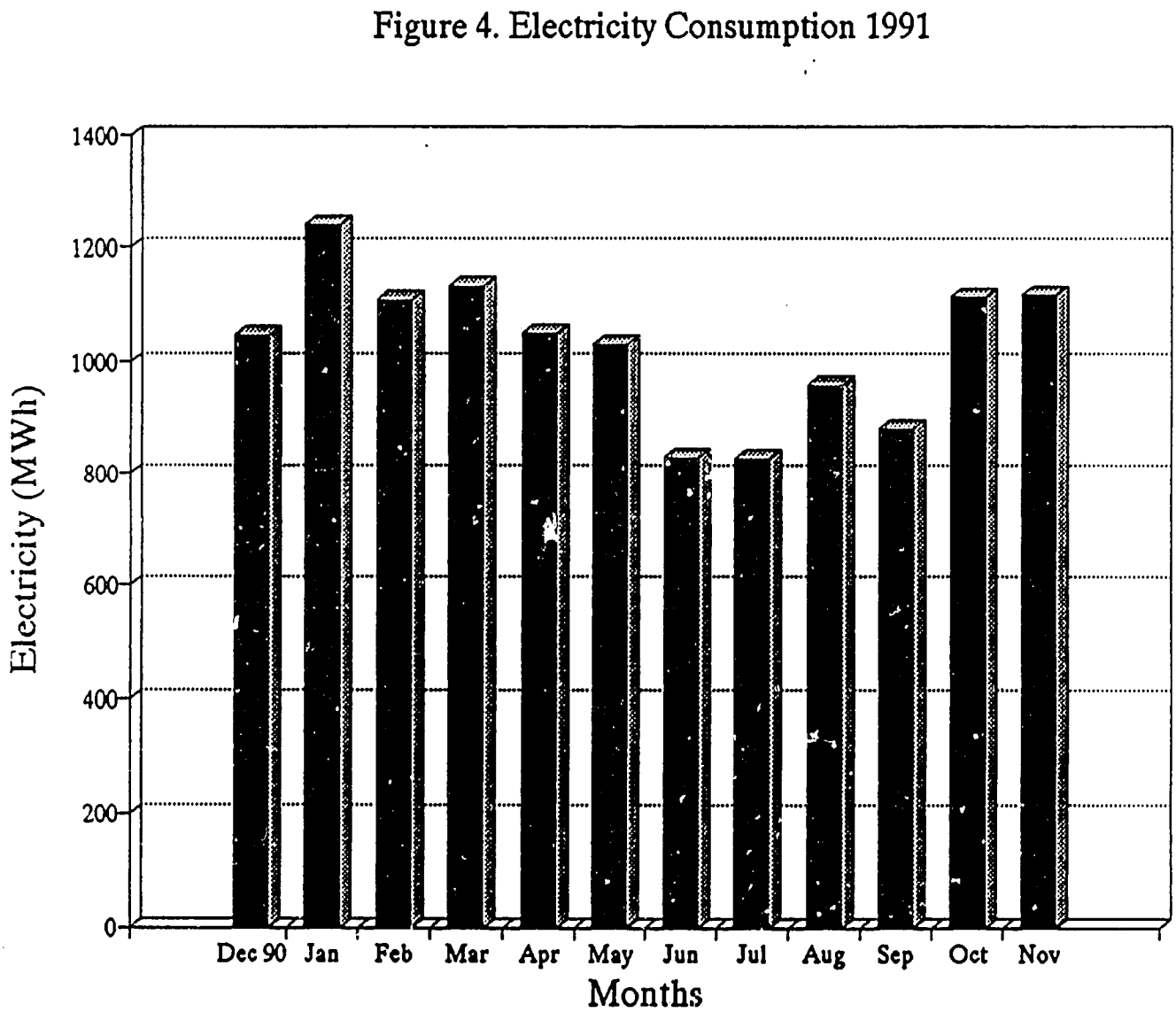


Figure 5. Electricity Cost 1991

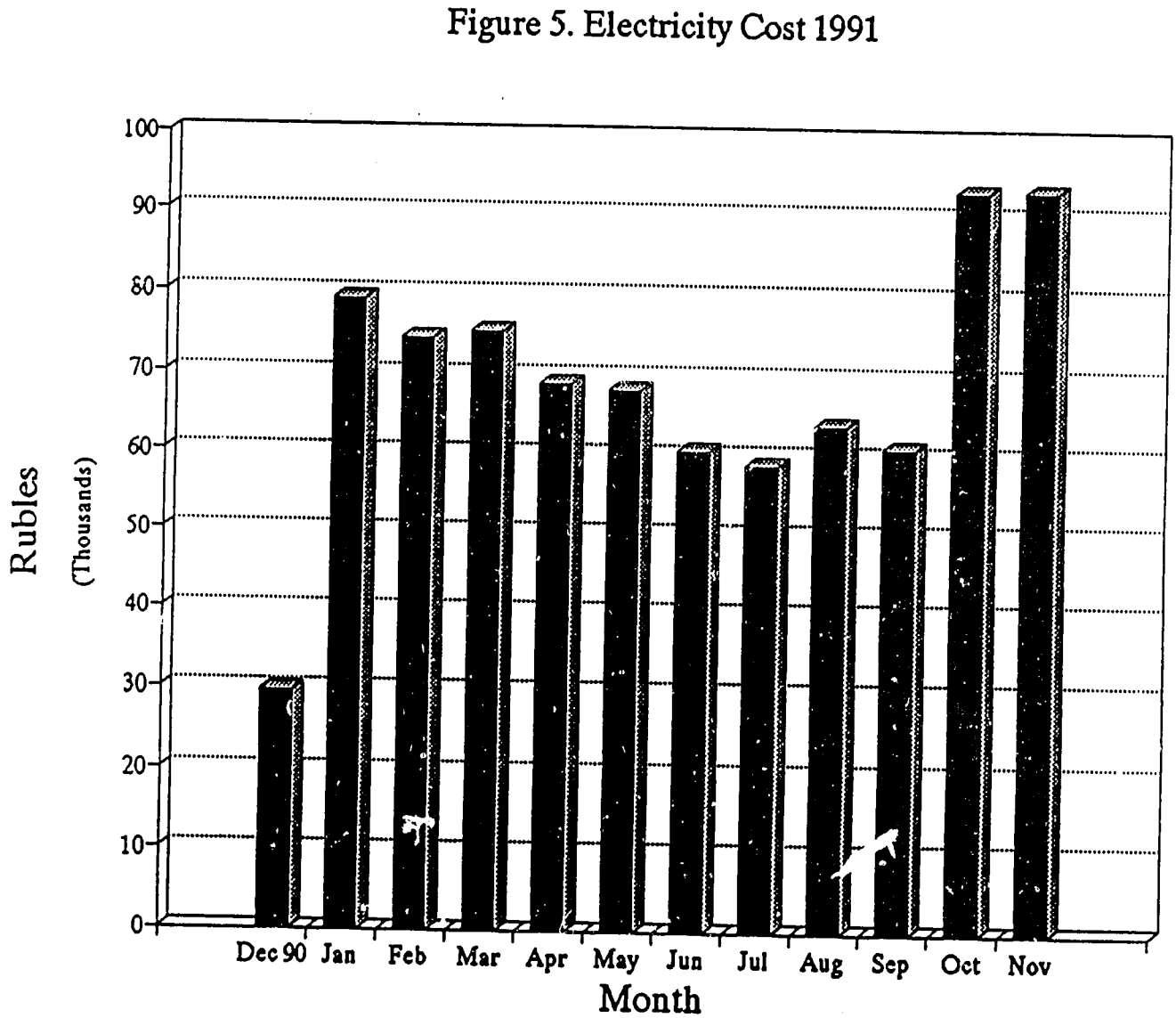


Figure 6. Hourly Electric Demand

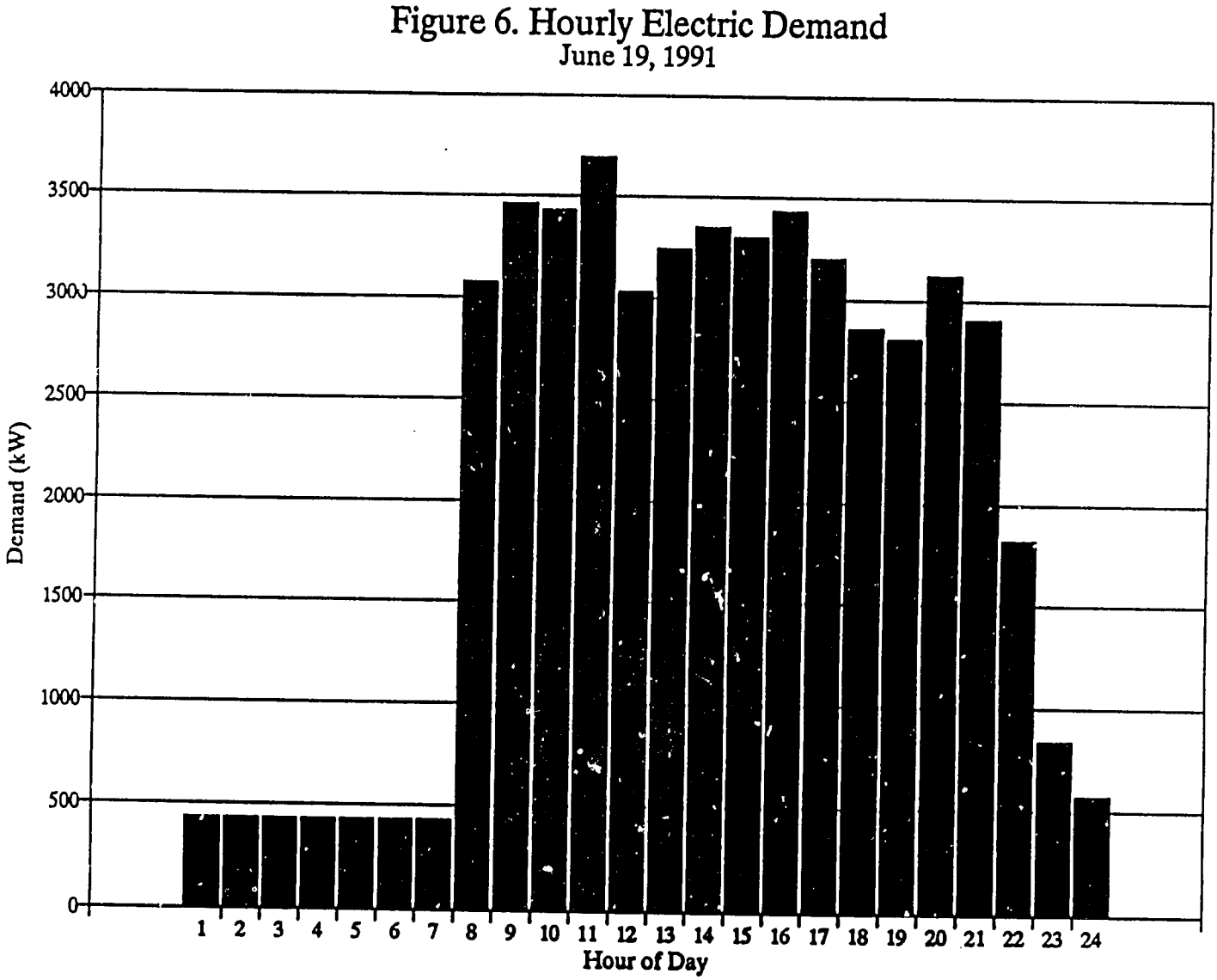


Figure 7. Steam Consumption 1991

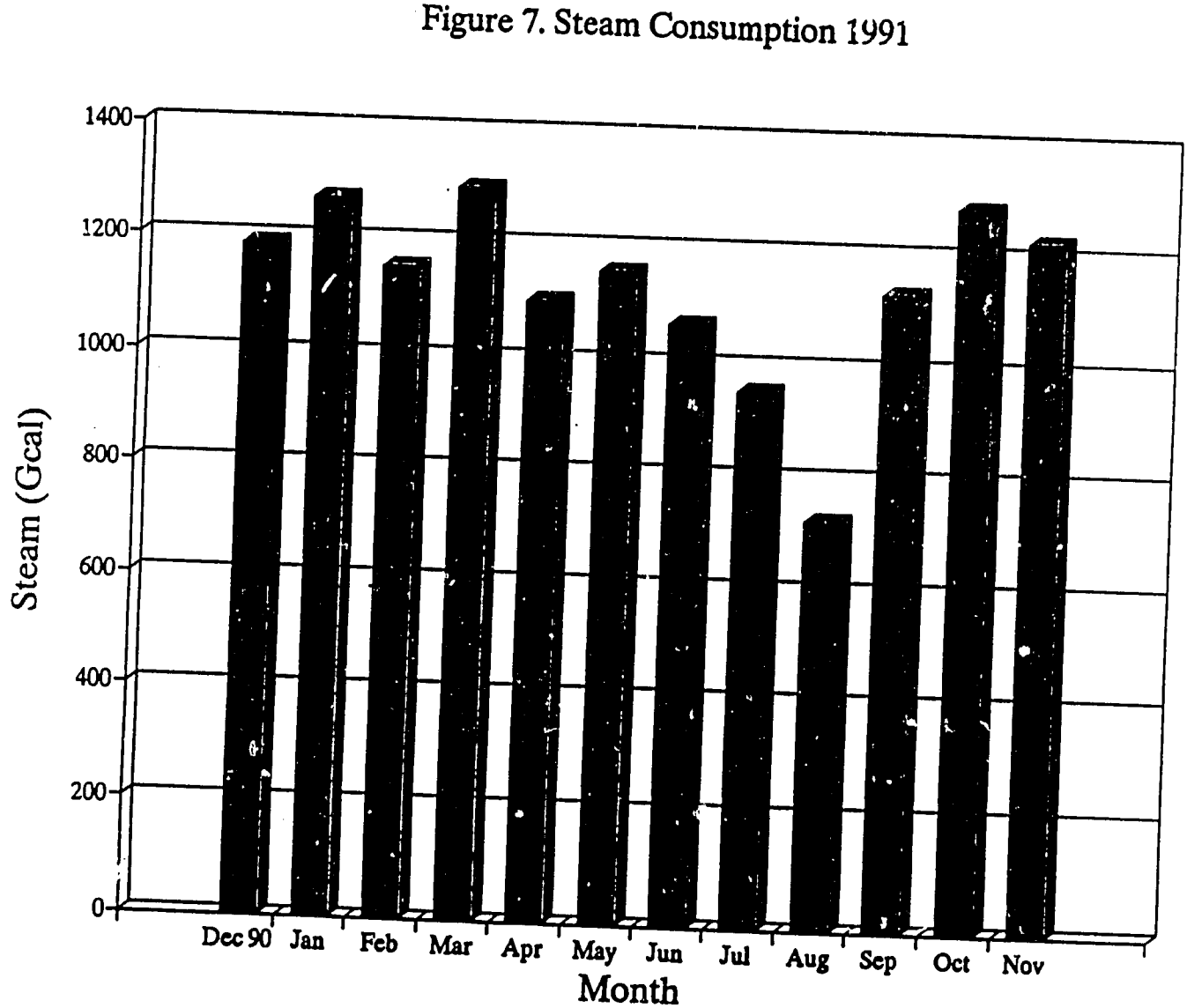


Figure 8. Steam Cost 1991

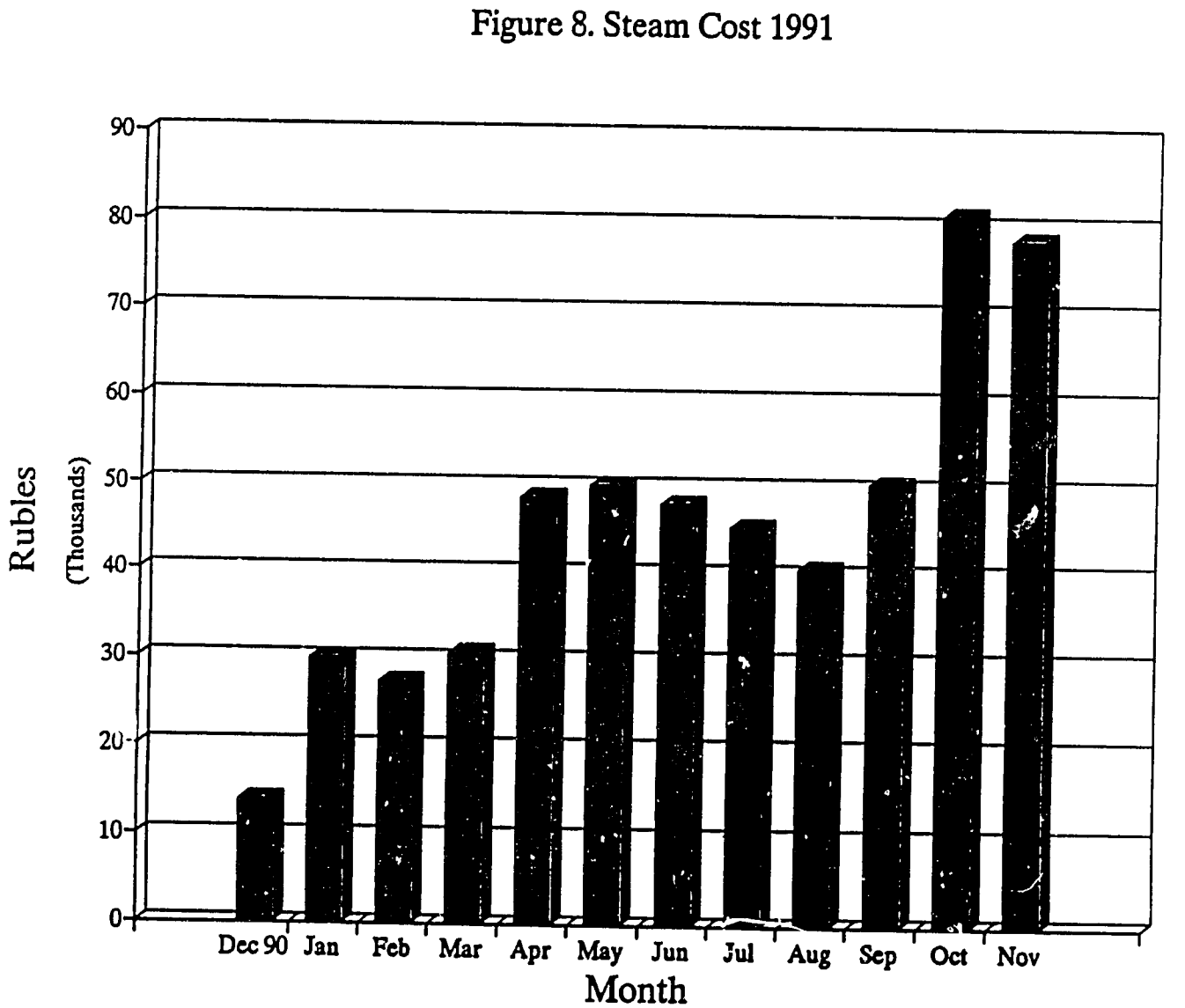


Figure 9. Thermal Water Consumption

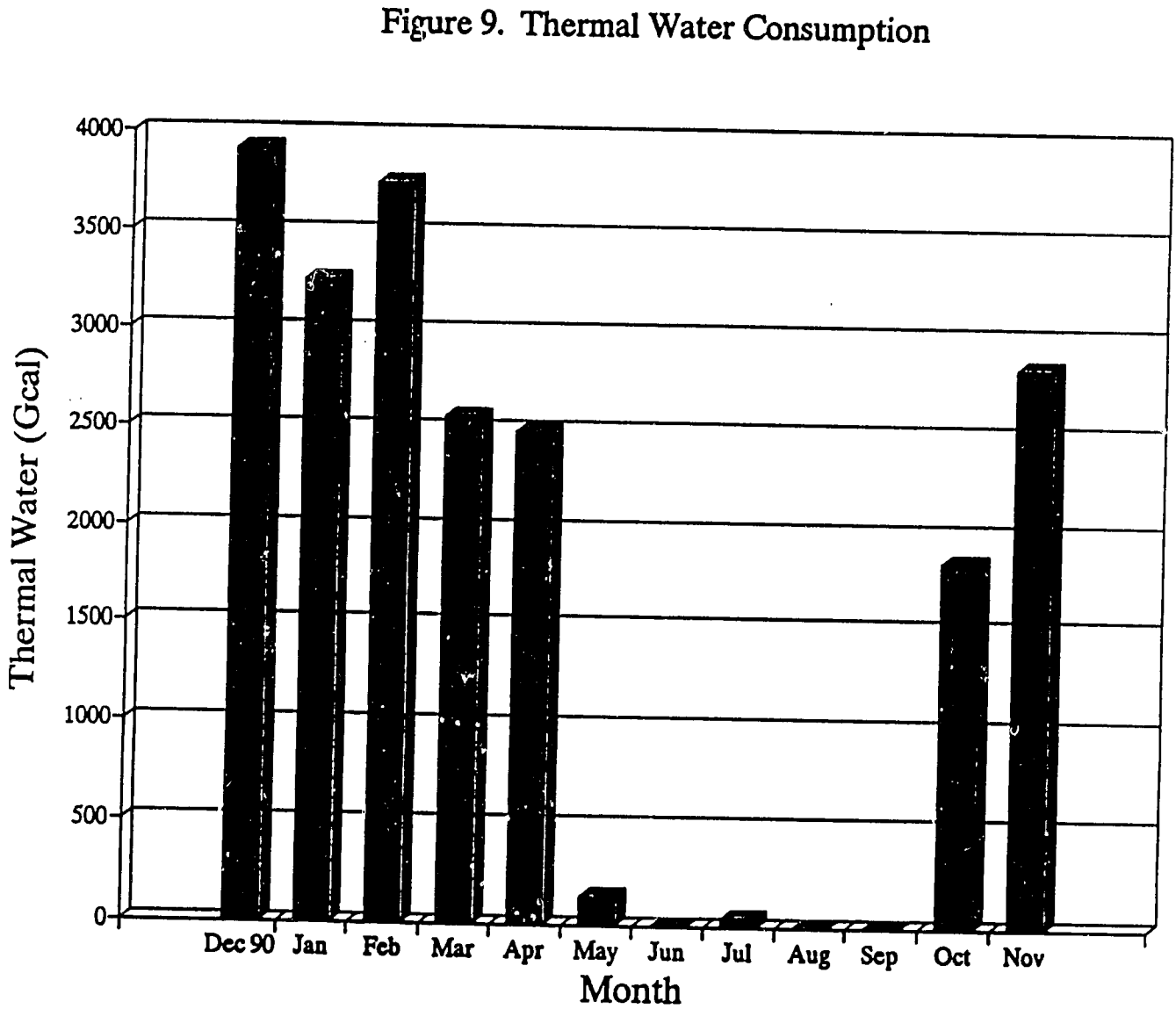


Figure 10: Thermal Water Cost 1991

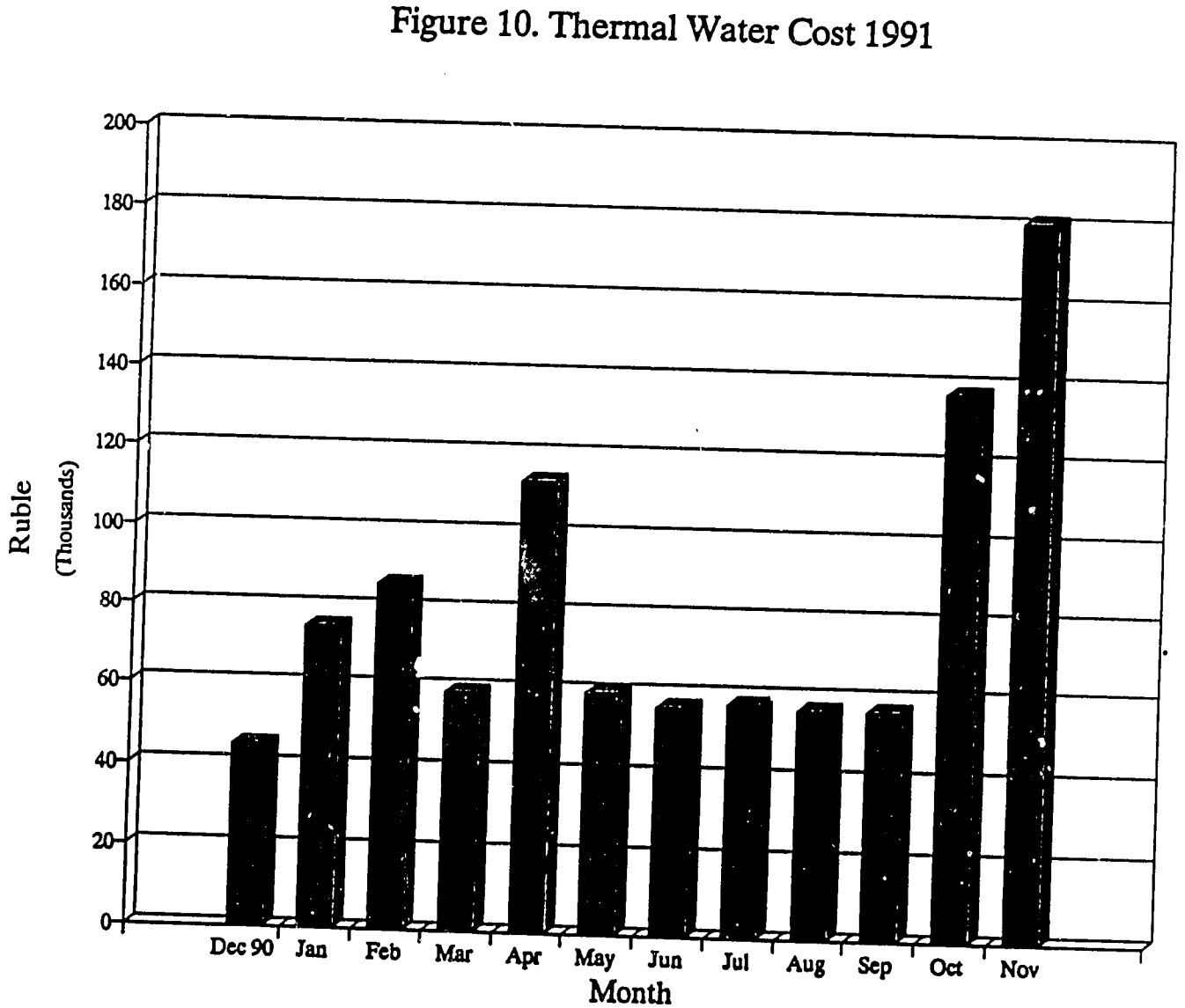


Figure 11. Total Energy Cost 1991

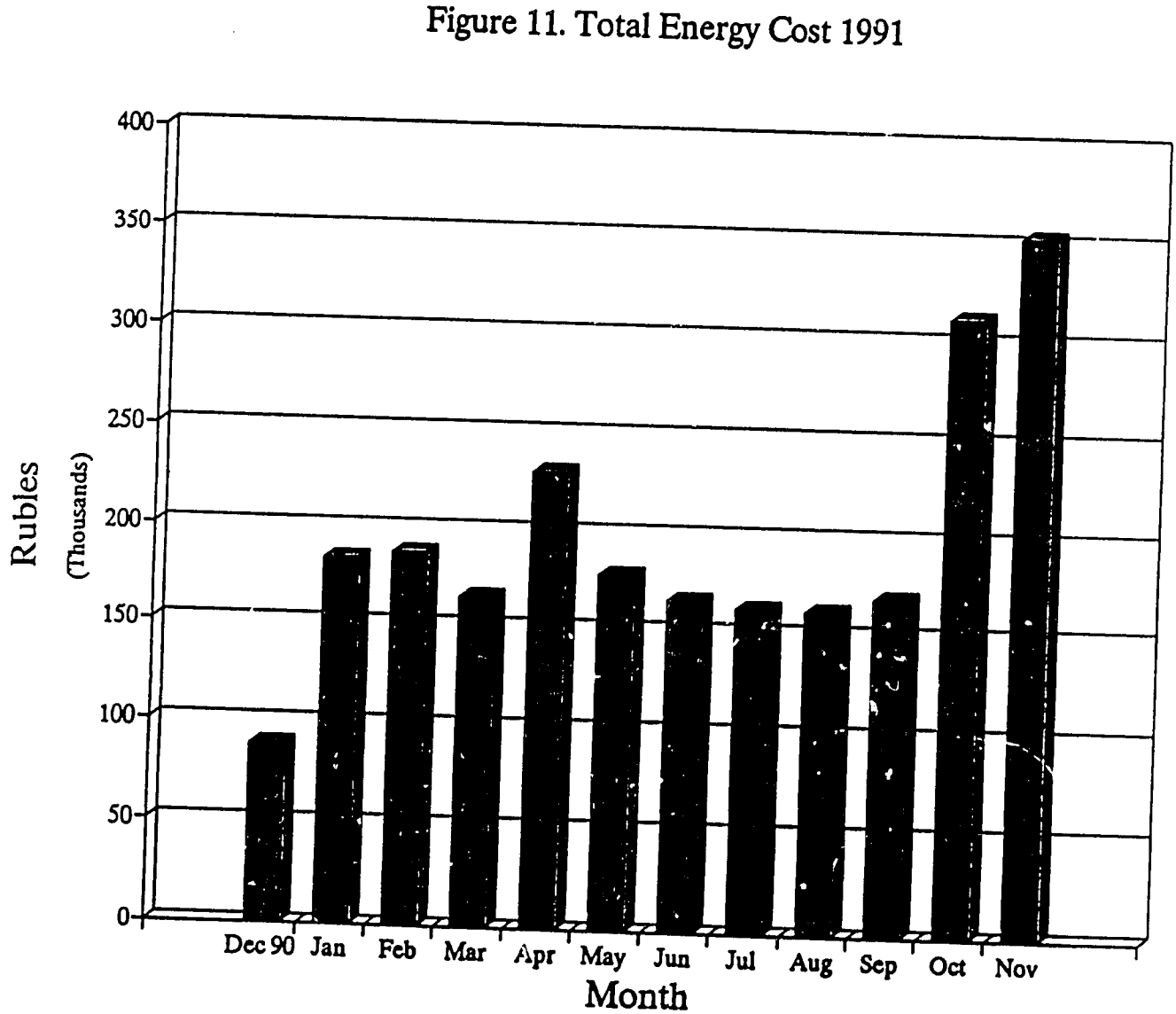


Table 4. Ventilation Air Motors

Dust Collection		Exhaust Fans		Make-up Air Fans	
Number	Capacity (kW)	Number	Capacity (kW)	Number	Capacity (kW)
1	18.5	2	1.5	1	0.75
3	22	1	1.9	1	1.50
4	28	3	2.2	1	2.2
12	30	2	3.0	2	2.80
4	30X2	1	5.5	1	4.5
8	37	16	7.5	21	7.5
2	37X2	3	13	1	10
30	40	1	17	1	15
4	40X2	4	30	4	17
				2	20
				9	22
				2	28
				1	30
TOTALS:					
68	2760.5	33	319	47	598.05

Connected electric load of the dust collection and exhaust fan motors totals 3079.5 kW, while connected electric load of the make-up air fan motors is 598.05 kW. Power to draw air out of the building far exceeds the power to push air into the building. The result is that there is a large negative pressure in the building relative to the outside pressure. This negative pressure gradient "pulls" large amounts of outdoor air into the building through open doors, broken windows, and cracks around doors and windows. This infiltration of outdoor air significantly increases the heating load on the building. The X sign indicates two motors operated simultaneously.

Steam enters the plant at 10 bar, 160 °C and is distributed through the plant to meet process energy requirements and to provide preheat for service hot water.

3.0 Audit Description

The audit began with a meeting at the plant on December 2, 1991, attended by Mr. Tchepas, plant General Director; Mr. Slankunas, Chief Energy Engineer; Mr. Radzius, Technical Director and the audit team. Specific areas of the plant to be audited in detail were selected. These areas/items included: piping insulation; uncontrolled building heating; temperature and flow measurements of exhaust air from the sawdust collection system motors; and window construction in building areas. Audit data collection and measurements were started on Wednesday and completed on Thursday (see Appendix B).

The plant technical director and power engineer also were present to answer questions and provide guidance. Mr. Slankunas and his staff furnished information about the energy usage of various buildings from a report completed in 1990. Additional plant personnel furnished information as requested by the audit team. Virginijus Buciunas of NEGA W, a private contractor, assisted with equipment selection during the audit and will continue to assist with the audits as necessary regarding further equipment selection and compatibility.

- The uninsulated pipe surface temperature was measured with an infrared digital non-contact pyrometer and pipe dimensions were recorded.

- Power consumption measurements were made at one of the dust collection fans in order to determine the power used by the fan under varying loads due to change in the number of dampers open for dust collection.

- The infrared temperature instrument was used to measure temperatures of the windows for single pane and double pane glass.

- Air curtains and/or the lack of air curtains at the doors between heated and unheated spaces were noted.

- Saw dust and the wood waste collection system was inspected and costs of scrap wood sales and wood and sawdust waste disposal costs were evaluated.

On Friday, the audit team presented its recommendations at a meeting attended by Mr. Tchepas, Mr. Slankunas, and Mr. Radzius. The energy audit presentation was well received and included an explanation of the funds available to implement the recommendations. The recommendations and schedule for implementation were discussed.

The plant management personnel concurred with the recommendations and agreed that it should be possible for them to have better control over the energy system with improved instrumentation. They also agreed that the projected savings needed to justify these recommendations were reasonable.

4.0 Summary of Results and Recommendations

As a result of the energy audit, several short and long-term energy conservation opportunities (ECOs) were identified. Short-term opportunities are characterized by low or no cost implementation and payback periods of two years or less. These projects could be implemented within six months. Long-term projects are characterized by higher implementation costs and longer payback periods. The emphasis of the short-term measures is to reduce the heating requirements of make-up air required to balance the large amount of air exhausted by the dust collection systems. Once the heating requirements of make-up air is reduced, increased control of the make-up air, exhaust air, and dust collection system can be justified.

The costs of natural gas, steam, thermal water, electricity and the exchange rate are changing so rapidly that it is not possible to predict the cost of fuel savings in rubles. Therefore, the energy savings are calculated based on nominal world prices. Lithuania is in the process of trying to bring fuel prices in line with world prices. For the purpose of this analysis, a cost of natural gas is assumed to be US$3.00 per million BTU or US$105.00 per 1,000 normal cubic meters, the cost of electricity is assumed to be US$0.05/kWh and US$10/kW/month, and the cost of steam and thermal water is assumed to be US$6/Gcal.

4.1 Short-Term Energy Conservation Opportunities

Filter and Return Dust Collection Air

About 50% of the space heating requirement is for heating make-up air to replace the air exhausted by the various dust collection systems. The existing systems use cyclones to remove some of the dust and then exhaust the air to the atmosphere. The air could be brought through a baghouse filter system to sufficiently clean the air and reintroduce it to the building. This will save US$5,500/year and cost US$11,792.

Installation of Curtains on Presses

The continuous and batch presses require ventilation air to exhaust fumes. The hoods for the continuous presses are located at the exit of the press and are about two meters above the conveying belt that moves and stacks the boards. This height above the belt results in a less effective capture of fumes. In addition, the stacked boards are located outside of the hood. The team recommends installing strip curtains on the side of the hood to more effectively capture the fumes from the pressed boards. The plant had curtains on the side of the press in the past and they were removed by the employees. Using strip curtains may increase the accessibility to the press conveyor and reduce the chance that the employees will remove the curtain.

Implementation of this measure would result in both thermal and electric energy savings. Adding the curtain will reduce the air flow by an estimated 25%. This will reduce the power requirements by about 30%, resulting in an annual electrical savings of 7,200 kWh.

The reduction in thermal energy for make-up air would be 25.6 Gcal/yr. The total cost savings would therefore be 7,200 * .05 + 25.6 * 6 = US$514.00.

The estimated cost of the measure for one press is US$240. This would result in a payback of .5 years. The total energy savings for the plant to use curtains for 30 hoods is 768 Gcal and 216,000 kWh. This is about 2% of the electric use and about 3.7% of the thermal water energy consumption.

Installation of Strip Curtains on Large Doorways

During the audit it was observed that some of the large entrance doors were completely open to the outside. This was due to either a door that was left open or air curtains that were not working. In addition, the air curtains that are used push air from both sides of the door and do not effectively form an air wall across the door entrance. Some of the air curtains force the heated air out of the building.

The team recommends the addition of strip curtains to the entrance door of the dryer area. This will allow fork lifts to enter and exit, but greatly reduce the loss of air and heat through the door. The strip curtains could be applied to other doors that do not have an effective air curtain and/or a closed door, such as the entrance to the battery charging warehouse.

The team also recommends retrofitting the existing air curtains to make them more effective. The existing air curtains could be retrofitted with additional ducting to push air from one side of the door and pull air from the other. This would create a more effective barrier to air flow leaving through the doorway.

The savings from this measure includes both thermal and electric energy savings. The electric savings will occur by reducing the make-up air flow required by an estimated 4,000 m^3/hr. This will reduce the power requirements by about 2 kW. The annual electric savings, as calculated, would be 8,000 kWh. The reduction in thermal energy for make-up air would be 51.2 Gcal per year. The total cost savings would therefore be US$707.00. The cost of the measure is estimated to be US$225. Therefore the payback is .32 years.

Installation of Steam Meters

The steam meters that are used to bill the facility are not considered accurate. Because of this, the plant personnel are unsure of how much condensate they are really losing. The installation of new, more accurate steam meters would allow the plant to track steam losses more accurately and provide hard data to justify projects to reduce the loss of condensate. In addition, a more accurate measure of condensate will give the factory some leverage with which to negotiate an improved contract with the utility. By knowing exactly the amount of condensate they return, the factory can approach the utility to have their steam and condensate rate structure reflect their actual use. The factory will have an incentive to return as much condensate as possible to keep costs down and the utilities will not have to heat and chemically treat as much make-up water, thereby keeping their costs minimized.

The team recommends installing steam meters at the inlet and outlet of steam to the wood dryer system. This will allow the operating staff to accurately know the amount of steam they are injecting into the dryers, and may be used to more effectively control the steam use.

Each month the plant loses about 500 metric tons of steam, which results in annual costs of about US$3,067. This is about 15% of the overall steam cost. The estimated cost of two steam meters is US$8,000. By installing meters, it is assumed that 25% of the condensate losses can be eliminated. This would result in a payback of 2.6 years with world energy prices.

Insulation of Steam Pipes

The majority of the plant piping is adequately insulated. However, uninsulated heating water supply and return lines, steam supply lines and condensate return lines in some spaces contribute to overheating. Ventilation air is required during parts of the year to maintain worker minimum comfort. This compounds an inefficient situation by using energy to mitigate the impacts of energy loss. Using pipe surface temperature measurements and unit pipe surface area, the heat loss from the uninsulated pipe was estimated. Insulation of all types of lines pays back in less than 1.6 years except for heating water return. All heating water piping and heating water control valves should be insulated to minimize heat loss. Reinstallation of insulation after piping repairs should be part of maintenance activities.

The plant personnel alleviate the overheating by opening windows. This results in an additional source for heat loss. The existing plant pipe insulation, which consists of fiber-glass wrapped with aluminum foil and chicken wire, is an acceptable insulation system. Additional measurements of exposed lines will be needed to determine the total annual cost and savings to the plant.

Repair of Compressed Air Leaks

During the plant audit many compressed air leaks were observed. Compressed air is sometimes treated as a free commodity without regard to the electric power it represents. Although not every air leak can be eliminated, in this plant it is estimated that at least 5% of the compressed air is wasted. The team recommends no capital cost measure but encourages a more diligent maintenance program to identify and rectify air leaks in the system.

The energy savings conservatively assumes that 25% of the existing air leaks can be eliminated with increased inspection. The annual energy savings would be about 15,600 kWh which results in a cost savings of 1,045 rubles. For a 50% return on the labor time invested, the increase in maintenance time would be 9 hours/month. This should be enough time to realize the reduced air leakage and energy savings.

4.2 Long-Term Energy Conservation Opportunities

The long-term ECO's require larger capital investments than the short-term investments and have longer payback periods. Therefore, these measures should be performed after the short term ECO's and should be investigated further by the plant staff.

Heat Recovery from Air Compressors

The two stage air compressors require cooling water to cool the air between stages. This heated water is then sent to a cooling pond and the heat released to the atmosphere. This heat could be used to heat make-up air and reduce the thermal water requirements for the facility.

Replace Incandescent with Fluorescent Lights

There are a number of areas that use incandescent lighting. Many of these areas could use fluorescent lighting and reduce the electric energy consumed considerably.

Demand Control During Peak Hours

By installing a demand controller, the plant could reduce the demand that it pays for and more accurately estimate its maximum demand, thereby reducing its chance of paying a penalty for exceeding the estimated maximum demand. The demand controller may be linked to the "transport fans" that move dust to the briquette area. The demand period is only for a total of five hours per day and saw dust storage is enough to interrupt the transport system. These fans could then be turned off when necessary to reduce the electric demand.

Repair Windows to Reduce Leakage

After the ventilation system is brought into balance, and the make-up air is sufficient to meet the exhaust air, window maintenance will reduce infiltration and reduce heating energy. Reparation of the windows could include complete replacement or maintenance of the windows to ensure a snug fit with the frame.

Controls for Steam and Dryer System

The steam and dryer systems are not effectively controlled to minimize the waste of steam from the system. It is difficult to maintain the proper pressure in all parts of the system and condensate tank. Automatic controls could significantly reduce losses and optimize the use of the steam in the dryer operation.

4.3 Justification of Recommend Energy Conservation Opportunities

Filter and Return Dust Collection Air

About 50% of the heating requirements are due to the removal of air by the dust collection system. This system consists of fan systems with many multiple "branches" to various cutting equipment to collect the dust. Most of the branches of ducting have metal dampers that slide in and out of the duct. The dampers are moved manually to cut off the air flow. It was observed during the audit that the dampers were often left open, drawing air flow, while there was no work being done on the equipment. In addition, it was observed that some of the duct branches had no dampers. During the audit, a Dranetz power analyzer was connected to the fan motor. While the analyzer was connected, the dampers were opened one-by-one and the power associated with different air flow conditions was recorded. *Figure 12* shows the relationship between the number of open dampers and the power consumed.

Limited savings could be achieved by fostering increased awareness and incentives for the workers to be more conscientious in closing the dampers when they leave their cutting equipment. However, shutting down a large number of the dampers may reduce air flow in the main dust lines enough to interfere with efficient dust transport.

More substantial energy savings may be achieved by improving the removal end of the dust collection system. The ducts deliver the dust to cyclone units on the outside of the building. These units separate most of the dust from the airstream, but both the air and the dust are discarded outside the building. In cold climates such as the Northern U.S.A., it is very common for facilities like this to filter the air thoroughly and then return it to the building. This substantially reduces the heating load, because the air loses only a fraction of its heat during its transit time through the filtration system and therefore needs substantially less heating than the equivalent volume of make-up air.

It is recommended that two pulse-jet baghouses be installed next to two of the existing cyclone units, to be used as after-filters. The air which has passed through the cyclones and has had most of the dust removed will be ducted through the baghouses to remove the rest of the dust and then into the building. In order to reduce shipping costs and permit the systems to be air-freighted, only the inner workings of the baghouses will be supplied from the U.S.A. The housing, hopper, ducting and support structure for each unit will all be constructed by the plant personnel. The U.S. supplier has agreed to supply the complete shop drawings for this work, because they will be in an optimal position to bid on the supply of baghouses to be used as after-filters for all the other cyclones at the plant. This follow-on work will be strongly recommended to the plant, provided the demonstration systems function as well as expected.

Energy Savings

The baghouses that are to be installed will be attached to cyclones with a capacity of 18,500 m^3/nr each. Thermal energy will be saved though return of the air to the plant, and

electrical energy will be saved through reduction of the make-up air required. During the audit of the plants, the Dranetz AC Power Analyzer was used to measure the electric power used by the fans (see *Figure 12*). It was found that the fans consume an additional 1 kW for an airflow of 1,800 m^3/hr. The electric and thermal energy savings can be calculated as follows:

Assume:

- One shift operation for area served by this system or 2,000 hours per year. The heating system is approximately 6 months/year. Therefore, the thermal savings are based on 1,000 hours during the heating season. The electrical energy for the make-up fans will be saved year-round.

  Energy content of air: 0.24 kcal/(kg °C)
  Density of air: 1.2 kg/m^3

  Therefore: 1.2 * .24 = 0.29 kcal/(m^3 °C)

- Assume that the average difference in temperature is 22 °C during the heating season. Air passing through the filter system could be expected to drop in temperature by approximately 6 °C before being returned to the building. Calculations are based on two baghouses.

  Electric energy saved: 2 * (1 kW/1,800 m^3/hr) * (18,500 m^3/hr) * 2,000 hr
  = 41,200 kWh

  Thermal energy saved: 2 * 0.29 kcal * (22 °C - 6 °C) * 18,500 m^3/hr * 1,000 hr
  = 172,000,000 kcal
  = 172 Gcal

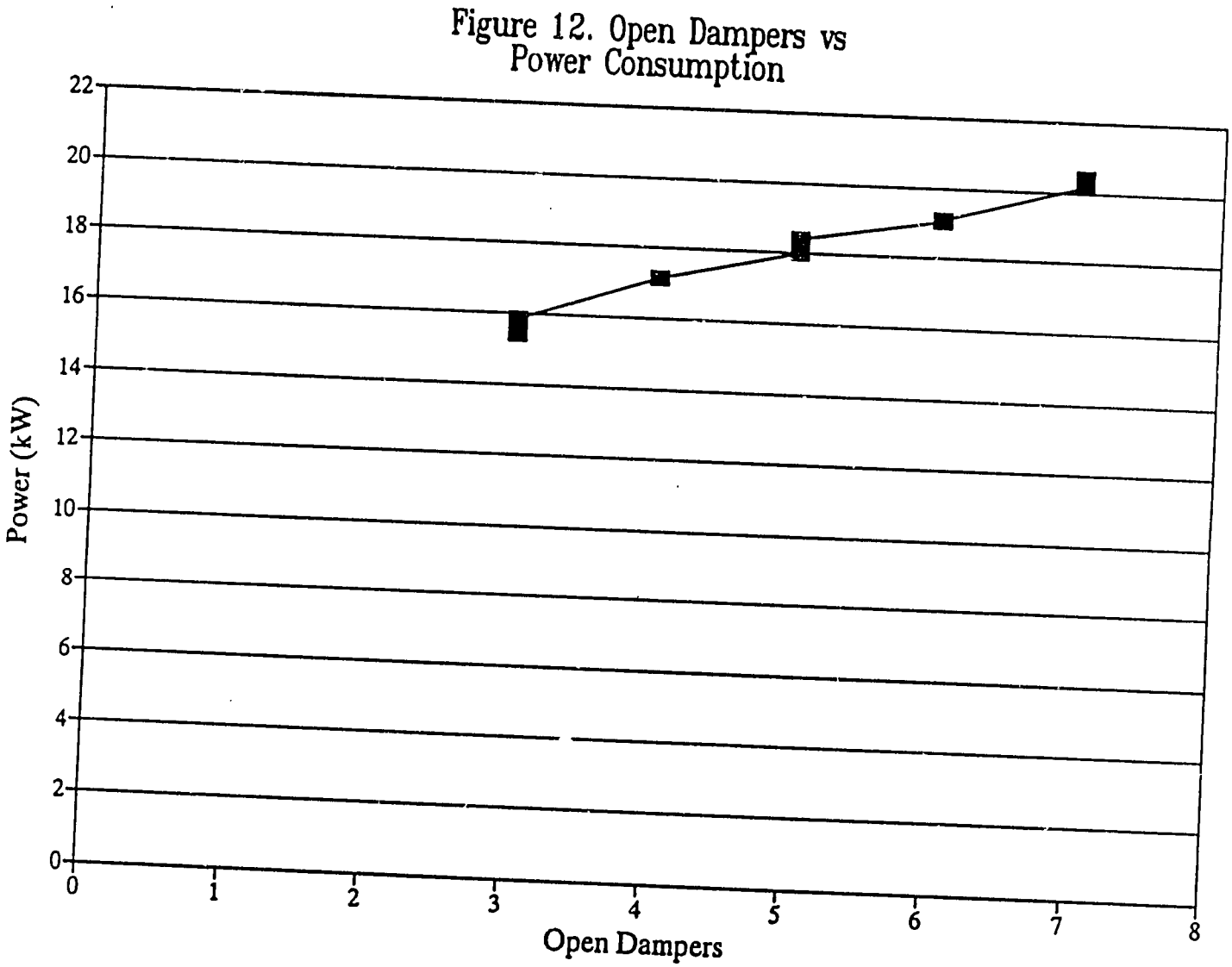
Annual Energy Cost Savings are based on the following assumed costs:

- Thermal energy costs: US$20/Gcal
- Electric energy costs: US$0.05/kWh

The cost of the dust collection system will be US$4,496 per baghouse, plus some additional materials purchased locally for ducting, housing and support structure. The latter materials are estimated at US$1,400 per baghouse. Note that approval is being sought only for the U.S. materials in this request. Approval for the locally purchased materials will be sought at a later date.

Estimated annual energy savings (steam):	172 Gcal/yr
Estimated annual energy savings (electricity):	41,200 kWh
Estimated annual cost savings:	US$5,500/yr
Estimated cost:	US$11,792
Estimated payback:	2.1 years

Figure 12. Open Dampers vs. Power Consumption



Installation of Strip Curtains on Large Doorways

During the audit it was observed that some of the large entrance doors were completely open to the outside. This was due to either a door that was left open or air curtains that were not working. In addition, the air curtains push air from both sides of the door and do not effectively form an air wall across the door entrance. Some of the air curtains force the heated air out of the building.

The team recommends the addition of strip curtains on the entrance door to the dryer area. This allows fork lifts to enter and exit, but greatly reduces the loss of air and heat through the door.

Energy Savings

Installing strip curtains will save energy by reducing the quantity of make-up air that is heated. Both electric and thermal energy will be saved. It is estimated that at least 4,000 m^3/hr can be reduced from leaving the facility.

- Reducing the air flow by 4,000 m^3/hr will reduce the make-up air power requirements by at least 2 kW.

- Two shift operation - 4,000 hours/year

- Energy content of air = .24 BTU/(lb*°F) = 1,003.2 J/kg °C

- Density of air = .075 lb/ft^3 = 2.65 lb/m^3 = 1.202 kg/m^3

- Therefore: 2.65 * .24 = .636 BTU/(m^3*°F) = .160 kcal/(m^3*°F)
  = .288 kcal/m^3 °C

- Assume that the average difference in temperature is 40 °F (22.2 °C) during the heating season, which is about 6 months/year. Therefore, the operation is performed 2,000 hours during the heating season.

- Electric energy saved = 2 kW * 4,000 hr = 8,000 kWh

- Thermal energy saved = H
  H = m^3/h * .288 kcal/m^3 °C * ΔT °C * hr/yr/1 * 10^6 kcal/Gcal = Gcal/yr
  H = 4,000 * .288 * 22.2 * 2,000/1 * 10^6 = 51.2 Gcal/yr

- Annual Energy Cost Savings:
  - Thermal energy costs = US$6.00/Gcal (44 R/Gcal)
  - Electric energy costs = US$.05/kWh (.067 R/kWh)

  Savings = 6 * 51.2 + .05 * 8,000 = US$707

- Cost of installing the air curtains is estimated to be US$1/ft^2 and an estimated 225 ft^2 will be required. Therefore, the cost is US$225.

- Simple Payback for press curtain installation:
  US$225/US$707 = .32 years = 4 months

Installation of Steam Meters

The steam meters that are used to bill the facility are not considered accurate. This has caused the plant to be unsure of how much condensate they are really losing. The installation of new, more accurate steam meters would allow the plant to track steam losses more accurately and provide data to justify projects to reduce the loss of condensate.

This ECO recommends the installation of steam meters at the inlet and outlet of the steam pipe to the dryer system. This will provide an accurate measure of the amount of steam used in the drying process and allow more efficient steam use.

Energy Savings

- The annual cost to the facility for condensate loss is 12,700 rubles. This is based on a charge by the utility of 2.4 rubles per metric ton. Each month they lose about 500 metric tons (at 70R/US$1.00 the penalty for not returning the condensate = US$181/year).

- The energy lost for 500 metric tons of lost condensate is:

  Estimated condensate exit temperature = 90 °C (195 °F)
  Estimated condensate temperature returned to boiler = 10 °C (50 °F)

  (1 BTU/lb-°F) * (500 metric tons)*(2,200 lb/metric ton) * (195 - 50) °F = 159 MMBTU = 40.1 Gcal

  40.1 Gcal/month * 12 months = 481 Gcal

- The energy cost using world energy prices of US$6.00/Gcal yields 6 * 481 = US$2,886.00

- Therefore, the total annual cost of lost condensate is: US$181 + US$2,886 = US$3,067/year

- Percentage of overall controllable steam costs:
  53,900/(345,000+12,704) = 15%

- Estimated cost of two steam meters = US$8,000

- Assume that the metering can help reduce by 25% the lost condensate.
- Simple payback at world prices = 8,000/3,067 = 2.6 years

Insulation of Steam Piping

A number of uninsulated pipes containing thermal water, steam, and condensate were observed. The majority of the plant piping is adequately insulated. However, several areas experience over heating due to large lengths of uninsulated piping. Ventilation air is required during parts of the years to maintain worker minimum comfort. This compounds an inefficient situation by using energy to mitigate the impacts of energy loss.

Energy Savings

Using pipe surface temperature measurements and unit pipe surface area, the heat loss from the uninsulated pipe was estimated. *Tables 5 and 6* present the results of a heat loss analysis for steam supply and condensate return. As can be seen from these Tables, steam supply line insulation of 2 inches of mineral wool insulation pays back in 4 months. Insulation of all types of lines pays back in less than 1.6 years, except for thermal water return. Piping such as hot water distribution to space heaters and hot water control valves should all be insulated to reduce heat loss. Reinstallation of insulation after piping repairs should be part of maintenance activities.

It is recommended that the factory make a determination of the necessary piping insulation lengths and obtain a bid from a local supplier for the insulation improvements to be covered by this project.

Repair Compressed Air Leaks

During the plant audit many compressed air leaks were observed. Compressed air is sometimes treated as a free commodity without regards to the electric power it represents. Although not every air leak can be eliminated, in this plant it is estimated that at least 5% of the compressed air is wasted. This ECO is basically a no cost measure that recommends a more diligent maintenance program to identify and rectify air leaks in the system.

Energy Savings

- This ECO uses local energy prices to calculate payback, because payback is based on the local wage rate.
- Assume 25% of the present air leaks can be eliminated by increased maintenance time to inspect piping and connections.

Table 5. Steam Supply

TABLE 5 STEAM SUPPLY LINE INSULATION ANALYSIS

....INSULATION ECONOMIC THICKNESS... DATE 03-16-1992 TIME 11:37:37

*** INPUTS ***

1. PROJECT NAME		FURNITURE
2. RUN IDENTIFICATION		STEAM
3. AMBIENT TEMP,	F	75
4. FLUID TEMP,	F	320
5. FUEL COST,	$/MILLION BTU	7.5
6. ANNUAL INFLATION, FUEL COST,	%	5
7. BOOK VALUE OF STEAM PLANT,	$	0
8. INTEREST RATE,	%	5
9. AVG HEAT TO PROCESS,	MMBTU/HR	6.5999
10. SCHEDULE,	HOURS PER YEAR	5200
11. REMAINING LIFE,	YEARS	10
12. INSULATION TYPE		MINERAL WOOL
13. CITY COST MULTIPLIER		1
14. SYSTEM COMPLEXITY		AVERAGE
15. 2''MTRL (2'' PIPE,$/FT) OR (FLAT,$/FT2)		3
16. INSTALLATION LABOR RATE,	$/HR	15
17. PIPE SIZE,	IN	3
18. BOILER EFFICIENCY,	%	100

....RESULTS.....

AVERAGE FUEL COST, $/MMBTU: HEAT @ 10.1 + COST PLANT @ 0

CONDUCTIVITY, BTU-IN/HR-SF-F: .321 AT AVG INSUL TEMP, F: 197.5F

CAPITAL RECOVERY FACTOR AND INFLATION AVERAGING FACTOR: 0.130 AND 1.233

NO OF LAYER	THCKNSS INCHES	MTRL $/FT	LABOR $/FT	TIC $/FT	TIC $/FTYR	HEATLOSS BTU/HR-FT	HEATLOSS $/FTYR	TOTAL $/FTYR	SURF TMP,F
0	0	0	0	0.0	0.0	643	34.0	34.0	
1	1	2	3	4.9	0.7	69	3.6	4.3	112
1	1.5	3	3	6.0	0.9	54	2.8	3.7	99
1	2	4	3	7.3	1.0	45	2.4	3.4	92
1	2.5	5	3	8.8	1.3	40	2.1	3.4	88
1	3	7	4	10.5	1.5	36	1.9	3.4	86
1	4	8	4	12.7	1.8	31	1.6	3.4	82
2	3	7	5	11.7	1.7	36	1.9	3.6	86
2	4	9	6	14.9	2.1	31	1.6	3.7	82
2	5	13	7	19.6	2.8	27	1.5	4.2	81
2	6	16	8	24.1	3.4	25	1.3	4.8	79

Table 6. Steam Condensate

TABLE 6 STEAM CONDENSATE LINE INSULATION ANALYSIS

..INSULATION ECONOMIC THICKNESS.. DATE 03-16-1992 TIME 11:41:49

*** INPUTS ***

1. PROJECT NAME		FURNITURE
2. RUN IDENTIFICATION		CONDENSATE
3. AMBIENT TEMP,	F	75
4. FLUID TEMP,	F	270
5. FUEL COST,	$/MILLION BTU	7.5
6. ANNUAL INFLATION, FUEL COST,	%	5
7. BOOK VALUE OF STEAM PLANT,	$	0
8. INTEREST RATE,	%	5
9. AVG HEAT TO PROCESS,	MMBTU/HR	6.5999
10. SCHEDULE,	HOURS PER YEAR	5200
11. REMAINING LIFE,	YEARS	10
12. INSULATION TYPE		MINERAL WOOL
13. CITY COST MULTIPLIER		1
14. SYSTEM COMPLEXITY		AVERAGE
15. 2''MTRL (2'' PIPE,$/FT) OR (FLAT,$/FT2)		3
16. INSTALLATION LABOR RATE,	$/HR	15
17. PIPE SIZE,	IN	3
18. BOILER EFFICIENCY,	%	100

....RESULTS.....

AVERAGE FUEL COST, $/MMBTU: HEAT @ 10.1 + COST PLANT @ 0

CONDUCTIVITY, BTU-IN/HR-SF-F: .304 AT AVG INSUL TEMP, F: 172.5

CAPITAL RECOVERY FACTOR AND INFLATION AVERAGING FACTOR: 0.130 AND 1.233

NO OF LAYER	THCKNSS INCHES	MTRL $/FT	LABOR $/FT	TIC $/FT	TIC $/FTYR	HEATLOSS BTU/HR-FT	HEATLOSS $/FTYR	TOTAL $/FTYR	SURF TMP,F
0	0	0	0	0.0	0.0	466	24.6	24.6	
1	1	2	3	4.9	0.7	52	2.8	3.5	103
1	1.5	3	3	6.0	0.9	41	2.2	3.0	93
1	2	4	3	7.3	1.0	34	1.8	2.9	88
1	2.5	5	3	8.8	1.3	30	1.6	2.9	85
1	3	7	4	10.5	1.5	27	1.4	2.9	83
1	4	8	4	12.7	1.8	23	1.2	3.0	81
2	3	7	5	11.7	1.7	27	1.4	3.1	83
2	4	9	6	14.9	2.1	23	1.2	3.3	81
2	5	13	7	19.6	2.8	21	1.1	3.9	79
2	6	16	8	24.1	3.4	19	1.0	4.4	78

- Air compressors:
  - five 125 kW with 20 m^3/min
  - one 160 kW with 24 m^3/min

- Typical use, 2 to 3 125 kW compressors

- Average power = 2.5 * 125 kW = 313 kW

- Power savings = (.05) * (.25) * (313) = 3.9 kW

- Operating hours = 4,000 hours/year

- Annual energy savings = 3.9 * 4,000 = 15,600 kWh

- Annual cost savings = 15,600 * .067 R/kWh = 1,045 R (US$.05/kWh yields US$780)

- Average wage is about 5 R/hr

- Number of maintenance hours that could be devoted to system inspection for a 50% return on invested time is:

  1,045 * .50 / 5 = 104 hours or 9 hours/month

- Which should be sufficient to achieve a 25% reduction in leaks.

APPENDIX A
List of Abbreviations

AC	= alternating current
amps	= amperes
atm	= atmosphere = 14.696 pounds per square inch
bar	= 100,000 pascals = 14.504 pounds per square inch
BTU	= British thermal unit
cfm	= cubic feet per minute
cm	= centimeter = 0.3937 inches
cm^2	= square centimeter = 0.155 square inches
CO	= carbon monoxide
CO_2	= carbon dioxide
DC	= direct current
°C	= degree Celsius T[°C] = 5/9*(T[°F] - 32)
°F	= degree Fahrenheit
°R	= degrees Rankine T[°R] = T[°F] + 460
eff	= efficiency
ex air	= excess air
ft^2	= square foot
ft^3	= cubic foot
Gcal	= gigacalorie = 1 billion calories = 3.968 million BTU
GJ	= gigajoules = 1 billion joules
gph	= U.S. gallons per hour
gpm	= U.S. gallons per minute
GWh	= gigawatt hours = 1 billion watt hours
H_2	= hydrogen
H_2O	= water
H_2SO_4	= sulfuric acid
hectare	= 10,000 square meters = 2.471 acres
hectoliter	= 100 liters = 26.42 U.S. gallons
Hg	= mercury
hr	= hour
Hz	= hertz = cycles per second
J	= joules
kcal	= kilocalories = 1 thousand calories = 3.968 BTU
kg	= kilogram = 2.2046 pounds
Kgcc	= 7,000 Kcal = 27,776 BTU
kJ	= kilojoules = 1 thousand joules = 0.947813 BTU
km	= kilometer = 0.621 miles
kN	= kilonewton = 1 thousand newtons
kp	= kopeck = 1/100 ruble
kPa	= kilo pascals = 1 thousand pascals = 0.14504 pounds per square inch
kV	= kilovolts = 1 thousand volts
kVA	= kilovolt-amperes
kVAr	= kilovars = 1 thousand volt-amperes (reactive)
kW	= kilowatt = 1 thousand watts
kWh	= kilowatt hour = 1 thousand watt hours
lbs	= pounds

liter	= 0.2642 U.S. gallons = 0.03531 cubic feet
m	= meter = 39.37 inches
m^2	= square meter = 10.76 square feet
m^3	= cubic meter = 35.31 cubic feet
mA	= milliampere = 0.001 amperes
MCal	= megacalorie = 1 million calories
metric ton	= 1 thousand kilograms = 1.1023 U.S. tons
mg	= milligrams
min	= minute
MJ	= megajoules
mm	= millimeter = 0.03937 inches
MM	= million
MPa	= 1 million pascals = 145.04 pounds per square inch
MVA	= megavolt-amperes
MW	= megawatt = 1 million watts
MWh	= megawatt hours = 1 million watt hours
NG	= natural gas
nm	= nanometer
Nm^3	= cubic meters at standard conditions of temperature and pressure (20°C and 1 atmosphere)
NO_X	= nitrogen oxide
O_2	= oxygen
P	= pressure
PC	= personal computer
ppm	= parts per million
psi	= pounds per square inch
psig	= pounds per square inch (gauge)
R	= ruble = 70R/US$1
s	= second
SO_2	= sulfur dioxide
sq ft	= square feet
Tcal	= teracalorie = 1 trillion calories = 3.968 billion BTU
T	= temperature
V	= volts
VArs	= volt-amps (reactive)
VSD	= variable speed drive
yr	= year

APPENDIX B
Photographs

1. Measuring the power of fans with the Dranetz. From left to right: Virginijus Buciunas (NEGA W), John Nicol (RMA), a plant worker and the plant electrician.

2. John Nicol of RMA uses the heat spy on the dust collection system.

3. Piping of the plant's dust collection system.

4. Cyclone separators as they currently exist at the plant.