BNL-52479

KRAKÓW CLEAN FOSSIL FUELS AND ENERGY EFFICIENCY PROGRAM

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PHASE I REPORT

T. Butcher and B. Pierce, Eds.

June 1995

Prepared for:
Office of Fossil Energy
U.S. Department of Energy
Washington, D.C. 20585

Under Contract No. DE-AC02-76CH00016 with the
UNITED STATES DEPARTMENT OF ENERGY

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ENERGY EFFICIENCY AND CONSERVATION DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, LONG ISLAND, NEW YORK 11973

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes:
Printed Copy: A16; Microfiche Copy: A01

ACKNOWLEDGMENTS

The work summarized in this report represents the combined efforts of many organizations both in Poland and the United States. Because of the project's size and complex relationships between participating organizations, it is very difficult to give proper credit to all of the participants. The following organizations participated directly in the work described in this report:

Polish Organizations:

- Academy of Mining and Metallurgy
- Ekopol
- FEWE-Kraków
- Kraków Development Office (Biuro Rozwoju Krakowa, BRK)
- Kraków Polytechnic Institute
- National Business Services Holding of Poland Ltd.
- Polinvest Ltd.
- VRG Strategy Company Ltd.

U.S. Organizations:

- About Saving Heat Co.
- Brookhaven National Laboratory
- Burns and Roe Company
- Burns and Roe Services Corp.
- Electrotek Concepts, Inc.
- G. Reeves Associates
- Pacific Northwest Laboratories
- Pittsburgh Energy Technology Center
- R.D.A. Engineering

Most of the project activities undertaken in Poland were done under direction of Biuro Rozwoju Krakowa, BRK. Director Jan Bieda of BRK played a key role in managing these effort.

The first version of most of the sections of this report were prepared by BRK with assistance from their subcontractors, based upon numerous project reports prepared by project participants during the course of the work. An important exception to this is Chapter 7, on Energy Conservation, which was prepared by Lawrence Markel of Electrotek Concepts under contract to Pacific Northwest Laboratories.

In the U.S., Douglas Gyorke of the U.S. Department of Energy's Pittsburgh Energy Technology Center served as project manager for this work.

As discussed in Chapter 1 of this report, a Bilateral Steering Committee was organized to oversee all of these efforts. Members of this committee during the project period include:

Dr. Howard Feibus, U.S. Department of Energy
Jan Friedberg, Deputy Mayor, City of Kraków
Dr. Krzysztof Görlich, Deputy Mayor, City of Kraków
Robert Ichord, U.S. Agency for International Development
Stanisław Kaminski, Deputy Director, Ministry of Environmental Protection, Natural Resources and Forestry
James Lacey, U.S. Department of Energy, Pittsburgh Energy Technology Center
Leonard Rogers, U.S. Agency for International Development
Joseph Strakey, U.S. Department of Energy, Pittsburgh Energy Technology Center
Jerzy Wertz, Director, Kraków Office of Environmental Protection

Funding for this project was provided by the U.S. Agency for International Development (AID), through the U.S. Department of Energy (DOE) under Interagency Agreement. Mr. Leonard Rogers and Mr. Robert Ichord of AID and Dr. Howard Feibus of DOE provided overall program management.

As discussed in Chapter 1, work in energy conservation was done through Pacific Northwest Laboratories. William Chandler and Thomas Secrest at PNL managed this work. Assistance in this area was provided by Elaine Guthrie of DOE.

The editors would also like to acknowledge contributions made by the Kraków district heat distribution utility Miejskie Przedsiębiorstwo Energetyki Cieplnej w Krakowie (MPEC) which acted as host site for the boiler testing and provided great assistance in many parts of the Engineering Analyses. The editors would also like to thank the Spółdzielnia Mieszkaniowa "Krowodrza" housing cooperative which acted as host site for the energy conservation demonstration.

Translation services provided by Letterman Professional Translators and Interpreters and by Zub Lido, both of Kraków, significantly eased the task of the editors.

Preparation of this report would not have been possible without the timely and caring efforts of Arlene Waltz and Francine Donnelly. The contribution of Avril Woodhead is also gratefully acknowledged. Any questions or comments should be directed to the editors.

NOTE ON FUEL HEATING VALUES AND THE THERMAL EFFICIENCY OF BOILERS AND STOVES

In the U.S. it is customary to use the higher heating value (HHV) of a fuel, while in Poland (and Europe, generally) lower heating value (LHV) is used. The difference between these is the latent heat of water vapor in the products of combustion. The HHV credits the fuel with this latent heat, while the LHV does not. These two heating values can be related by:

$$LHV = HHV - 10.30\ (H_2 \times 8.94)$$

where H_2 is the total percent hydrogen in the fuel.

In this report, in various places, the efficiency of boilers and furnaces is discussed. In the test program conducted as part of this work, these efficiencies were determined using a heat-loss method. When LHV is used for fuel heating value energy loss due to the latent heat of water vapor in combustion products is not considered in the efficiency calculation. This is the normal Polish procedure and was used for all efficiency calculations included in this report. The customary U.S. procedure uses HHV and includes the latent heat loss. Efficiencies listed in this report are higher than would be realized with the customary U.S. method. The magnitude of the difference depends on the fuel but for most solid fuels described here, it can be estimated at 3 efficiency percentage points.

NOTE ON SOME CONVENTIONS USED IN THE REPORT

In some cases, amounts of fuels or pollutants are presented in this report in units of tons (or "T"). In all cases, this refers to metric tons.

In 1995, the Polish currency was changed with the Old Zloty replaced by a new Zloty with a value of 10,000 greater. The new Zloty is used in a few places throughout this report and is given the symbol zł PLN or PLN zł. The old Zloty is used in most of the report.

1 PLN zł = 10,000 PL zł or zl or PLZ

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EXECUTIVE SUMMARY

INTRODUCTION

Almost half of the heating energy used in the historic city of Kraków, Poland is supplied by low-efficiency boiler houses and home coal stoves. There are more than 1,300 local boiler houses and 100,000 home stoves. These are collectively referred to as "low emission sources" and they are important sources of particulates and hydrocarbon emissions in the City and major contributors of sulfur dioxide and carbon monoxide. This report presents results of Phase 1 of the "Kraków Clean Fossil Fuels and Energy Efficiency Program," designed to reduce pollution from low emission sources in Kraków.

Funding for this program has been provided by the U.S. Agency for International Development (USAID). In 1991, USAID and USDOE signed an interagency agreement to conduct the project. Representatives from both organizations worked with Polish officials to establish an eight-member Bilateral Steering Committee (BSC) to plan and oversee the Program. In 1991, U.S. and Polish officials signed a Memorandum of Understanding formally initiating and directing the Kraków Clean Fossil Fuels and Energy Efficiency Program.

The BSC defined the three phases for the program. Phase 1 was to gather more information, primarily on emissions and costs, to verify assumptions on existing heating methods and their alternatives. Phase 2 was planned to inform Polish and U.S. companies of the Program, the results of Phase 1, and the opportunities available in Phase 3. Phase 3 was to solicit U.S. firms to participate in cost-shared projects to demonstrate and market energy efficiency and clean fossil fuel technologies in the Kraków area to alleviate the problems of air pollution caused by low emission sources. Presently, these projects are in progress.

For the information-gathering of Phase 1, funding was provided by USDOE to Pacific Northwest Laboratories (PNL) and to Brookhaven National Laboratory (BNL). The BSC designated the Pittsburgh Energy Technology Center (PETC) to manage all fossil energy-related work in the Program, including the BNL effort. The BSC also designated the Biuro Rozwoju Krakówa (BRK, the Kraków Development Office) to manage all Phase 1 studies in Poland. PNL and BNL negotiated contracts with BRK to conduct their portions of Phase 1.

The BSC defined five subprojects or areas of interest around which all of the Phase 1 work was developed. These subprojects were based on approaches towards addressing low emission sources under consideration by the city. The subprojects are:

1. Apartment building energy conservation and extension of the district heating system to allow small, local boiler rooms to be closed.

2. Replacement of small, hand-fired boilers which currently burn coal and/or coke with natural gas-fired boilers.

3. Replacement of coal-fired home stoves with electric heating appliances.

4. Reduction of emissions from stoker-fired boiler houses - either by boiler replacement or improved performance of existing boilers.

5. Reduction of emissions from coal-fired home heating stoves.

Work during Phase 1 included: source performance testing, a building energy conservation demonstration, engineering analysis, a public opinion survey, incentives analysis, and options comparison.

Testing measured emissions and performance from equipment and fuels that are presently used, as well as alternative equipment and fuels considered as potential improvements. Engineering analysis estimated costs for promising alternatives and conducted feasibility studies and conceptual designs for implementing these alternatives. As part of the engineering analysis, the impact was studied of selected options on air quality in the city. The incentives analysis tasks recommended financial incentives or regulatory changes necessary to convince residents and boiler owners to invest in alternatives that will reduce emissions. These incentives were based on detailed analyses of the economics of specific options to energy users. Complimenting these economic studies, public opinion was surveyed to evaluate the willingness and ability of residents to contribute to the costs of reduced pollution.

CHARACTERISTICS OF THE LOW EMISSION SOURCES

Low emission sources in Kraków include 100,000 home stoves, 227 traveling grate ("stoker-fired") boilers and more than 2,000 hand-fired boilers. The traveling grate boilers burn low cost, fine coal, and are the largest sources. Hand-fired boilers burn coal and/or coke depending upon the type. The source testing program was designed to obtain performance data on the most important source types to allow the relative importance of each to be weighed.

Home Stoves

The coal stove tested during this program is a traditional storage stove built of brick and covered with ornate ceramic tiles. It has been reported that there are seven million such stoves in Poland. These stoves are fired once or twice daily during Winter. Each firing period lasts about 1 1/2 hours, and during this time the stove's mass is heated. After the burning period is over, the room is heated as the masonry slowly cools.

Testing was done at the Academy of Mining and Metallurgy (AGH) in Kraków with a test stove built in place by local craftsmen. The test protocol used was based on U.S. standard methods for testing wood stoves and allowed continuous measurement of emissions and efficiency during burn cycles.

A range of fuels were tested, including coal typically used (10-20% ash, 30% volatiles) and low volatile, smokeless briquettes. The briquettes are being considered for future use and are not yet available on the fuel market. In tests with normal operating procedures, thermal efficiency of the stoves was found to be considerably higher than expected (60-70%). Emission factors for particulates were found to be very high with coal firing. With the low volatile briquettes, particulates were reduced by more than an order of magnitude. Similar results were obtained with use of low volatile coke.

The work at AGH included tests with a wide range of operating conditions. During the course of this work a new operating procedure was developed which can produce efficiency levels of 72-75% consistently.

Hand-Fired Boilers

There are two major types of hand-fired boilers in Kraków; steel boilers designed for coal firing and cast iron, designed for coke firing. Coal is considerably less expensive and produces greater levels of particulate emissions. Steel boilers generally cannot burn coke and in many cases coal/coke mixtures are used.

Efficiency for the hand-fired boilers ranges from 60-73%. As in the case of the home stoves, particulate emissions increase with increasing fuel volatiles content and wherever possible, coke or coal/coke mixtures should be substituted for coal. CO emissions are very high from the hand-fired boilers and this is not greatly affected by fuel type. CO can be reduced by careful use of overfire air, particularly during the time immediately following the addition of fresh fuel to the bed.

Stoker-Fired Boilers

Two stoker-fired boilers were tested during this program. The first is a 20 year-old hot-water boiler which provides heat to a local part of the district heating system and is rated at 11.6 MW thermal output. The second is a 40 year-old boiler which provides process steam to local factories and is rated at 2.9 MW output.

In both cases, boiler excess air is controlled manually and operators do not have instrumentation which allows excess air to be properly adjusted. The result is very low thermal efficiencies, 55-60%, particularly at low load.

These stokers are designed to use pea-size coal. The fuel actually fired has much more fines than is considered optimal. Tests showed performance can be improved significantly through a combination of improved fuel and better excess air control.

ENGINEERING STUDIES

Detailed studies were done to develop costs for implementing selected options. In many cases, capital conversion costs are highly site-specific. For example, costs to eliminate local boiler rooms which contain hand-fired boilers by connection to the district heating system ranged from $90 to $598/kW. The unit capital cost (per kW of thermal capacity) required to implement various options, averaged for the area of the whole city are as follows:

• Connect boiler-houses to the municipal district heating network	US$ 90 kW
• Convert coal-fired home stoves to gas boilers	US$ 120 kW
• Convert coal- and coke-fired DH boilers to gas-fired boilers	US$ 125 kW
• Convert coal-fired stoves to electric heating	US$ 150 kW
• Modernize stoker-fired boiler houses fully	US$ 245 kW
• Convert coal-fired home stoves to gas heating	US$ 320 kW

AIR QUALITY IMPACTS

Air quality in Kraków is affected by local power plants, local industry, pollutants carried into Kraków from other regions, and the low emission sources. Ambient air quality standards are generally exceeded and pollutants of primary concern include particulates and sulfur dioxide. During this program, pollutant modeling dispersion simulation studies were done to determine: 1) the contribution made by the low emissions sources to the air quality in Kraków, and 2) the impact of selected options on air quality.

It is concluded that the low emission sources contribute 35-40% of the total pollution and full elimination of the low sources would result in considerable, though not complete, improvement in the air quality in Kraków. For dispersed sources, such as home stoves and smaller hand-fired boilers, the greatest air quality impacts can be obtained in areas where source density is high, for example the Old Town part of the City. For larger, point sources, effects will be very significant only in a limited area surrounding the source.

PUBLIC OPINION

A public opinion survey was conducted as part of this project to study attitudes on air pollution, willingness to contribute to measures for improving air quality, and heating system preferences. About 70% of the group studied indicated that Kraków is one of the most polluted cities in Poland, and that living in the city is very dangerous to health. However, almost half of the group (46%) indicated they would not be willing to participate in the cost of reducing pollution. When stove owners were asked if they planned to change to a cleaner heating system in the future, 20% answered that they do plan to change. The main obstacle to conversion is lack of funds.

Following the public opinion survey, public relations activities were undertaken to inform Kraków residents and encourage municipal institutions, companies, and residents to adopt options developed under this program. This effort included press releases, brochures, seminars, and a film.

ANALYSIS OF INCENTIVES

Recognizing a limited willingness and/or ability to pay for reduced emissions, a study was done to identify and compare incentives programs which the City might implement to promote options for the low emission sources. This was done for specific options, consistent with the five subprojects identified for the program and included:

- Replacement of hand-fired boilers in the Old-Town part of Kraków with new gas-fired boilers.
- Elimination of local boiler houses by connection to the district heating system in selected parts of the city.
- Conversion of small coal stoves to electric heating in the Łobzow part of Kraków.
- Use of smokeless briquettes in small coal stoves.

In each case, a study was done to evaluate the cost impact of conversion on the user. A twenty year cash flow analysis was prepared based on two different assumptions about energy prices over the period. In the first energy price scenario, current prices in Poland were escalated over time. In the second scenario, estimated free market prices were used to eliminate price distortions caused by current subsidy policies in Poland.

In each case, options for incentives programs were identified. Legal and institutional barriers to the implementation of incentives programs were studied. In cases where financial incentives were considered (direct conversion assistance, heat cost subsidies, tax relief) the level of incentive was set to eliminate cost burdens to the users.

With current price trends of energy carriers and the operating and capital costs, conversion of heating systems imposes high cost burdens on users. The City will need to implement some type of incentives program for almost all those who change their heating system. In the case of direct financial assistance, it will be necessary to change some legal regulations so that such assistance can be given to individuals. Currently, prices of gas and electric heat are considered low in Poland. If conversions are delayed and future prices come in line with Western European (free market) prices, the subsidy levels required will increase significantly.

BUILDING ENERGY CONSERVATION

During this program, a demonstration of low-cost weatherization and other conservation techniques was done on four two-story buildings in a Kraków cooperative. The four identical buildings have 66 apartments each and are connected to the district heating system.

Different combinations of energy efficiency measures were tried in each building over 2 heating seasons:

- Baseline building (no improvements)
- Regulated hydroelevator
- Regulated heat exchanger
- Thermostatic valves on radiators and chemical cleaning of pipes in the building
- Fiberglass insulation of air space under the roof
- Fiberglass insulation of air channels in the concrete slab of the basement ceiling
- Weatherization package consisting of
  - Caulking interior cracks and around door and window frames
  - Weatherstripping all doors and windows
  - Installing door sweeps and thresholds on all entry and balcony doors
  - Sealing infiltration bypasses around electrical and pipe openings in the basement
  - Suggesting to residents that they not block radiators with furniture or curtains
- External polystyrene insulation applied either to all walls or to flat (no windows or balconies) walls only

The demonstration showed that the weatherization package (cost $45 US per apartment) and roof insulation (cost $37 US per apartment) were cost-effective, with simple paybacks of less than four years at current energy prices.

Some form of control was needed to reduce the amount of heat delivered to the building; otherwise the weatherization will just make it overheat. The demonstration used thermostatic valves on radiators, as well as temperature reset controls on building hydroelevators or heat exchangers. The district heat utility, MPEC, feels that comparable savings can be obtained by installing heat exchangers and air temperature-based controls in the network substation nodes, each of which serves from 5 to 25 buildings. This would lower the cost of controls to about $80 per apartment.

The building receiving the control, weatherization, and attic insulation measures reduced its seasonal heat energy consumption by over 21% (640 GJ, or almost 10 GJ per apartment). The other measures tested, external insulation and basement insulation, did reduce energy consumption, but were not cost-effective and, in the case of external insulation,were prohibitively expensive for widespread implementation.

In summary, the demonstration project identified affordable weatherization measures which could reduce heating energy by over 20% in all types of Kraków's older, un- or under-insulated buildings. The measures improved comfort, reduced energy bills, and were well received by the housing cooperative residents, cooperative management, and MPEC.

COMPARISON OF OPTIONS

The objective of options comparison is to identify those actions which provide the greatest pollution reduction for the lowest cost. The approach used in the project is based on a spreadsheet program written under the sponsorship of the U.S. Department of Energy. This program was written as a screening tool, providing a rapid method of analyzing options primarily to aid policy decisions on a city-wide scale.

In the spreadsheet, all of the low emission sources in the city are placed into categories based on physical characteristics and type of fuel used. In the application to Kraków, the low emission sources have been divided into 25 categories.

In evaluating options using the spreadsheet there are several choices:

- Heating capacity can be changed from one category to another (for example, from hand-fired boilers to gas-fired boilers.
- The efficiency of boilers or stoves in a category can be increased (by adding economizers to boilers, for example).
- Heat demand and fuel use in a specific category can be reduced through building energy-conservation measures.
- Pollution controls can be added or upgraded in a specific source category.

For each of these choices, the capital costs of the modifications must be input as well as the operating, fuel, and maintenance costs.

Output from a spreadsheet run includes the total emissions for each pollutant and total annual "user" costs (TAUC) before and after the option is implemented. The latter include energy, operating, and maintenance costs.

The spreadsheet program provides details of costs and emissions of specific pollutants before and after conversion in tabular and graphical form. It is useful, also, to have a single number which indicates the cost effectiveness of each case being evaluated. To do this, emissions of specific pollutants are first combined into a single "Equivalent Emission" Conversion or upgrade capital costs then are annualized. This annualized capital cost then is added to the annual user cost and the result is termed the "user combined cost" (UCC). Finally, for any specific options implemented, the change in user combined cost is calculated per ton of reduction of equivalent emissions:

> $UCC/\Delta EE = -((0.1523*CC + \Delta TAUC)/\Delta EE)$, where Δ means difference of results after and before conversion.

This user combined cost-per-ton of EE reduction is taken as a primary basis for comparing options. The most cost-effective options were those which involved improved coal-based fuels, operations improvements, and minimal capital investments. This includes using better coal at stoker-fired boiler houses in combination with efficiency improvements, and switching home stoves and hand-fired boilers to briquettes. The highest cost options included major reconstruction of the stoker-fired boiler houses including the installation of new boilers, conversion to gas, and conversion to electric heating. Elimination of local boiler houses by connection to the district heating system is somewhat difficult to evaluate generally using this spreadsheet because connection costs are very site-specific. On average, however, district heating connection is relatively attractive.

CONCLUSIONS

1. While the low emission sources are important contributors to air pollution problems in Kraków, even their complete elimination will not bring pollution levels below those set by current ambient air quality standards. The most significant effects of the low sources are in the central part of the city.

2. Coal-fired stoves constitute the most noxious component of the low emission sources. They generate over 1,000 Mg of particulates each season (over 43% of total emissions). These emissions can be reduced dramatically through the use of upgraded fuels.

3. The entire elimination of home stoves is not possible in the near term and temporary solutions, such as fuel switching, should be implemented.

4. Emission of pollutants from Kraków's boiler houses can be reduced by:

    - connection to the district heating system;
    - conversion to natural gas;
    - use of improved fuels, and
    - improving operations (stoker-fired boilers).

5. Heat energy conservation is possible in all part of heat distribution systems and at the end consumers. The highest and most distinct energy savings can be achieved at the heat consumers by means of weatherization of the buildings, assembling the measurement equipment and devices which make possible controlling temperature in rooms, and as a consequence, billing for actual heat consumption.

6. Excess capacity in the district heating system would allow more than half of the existing boiler houses to be eliminated by connecting them to the municipal district heating network.

7. In order to eliminate or significantly reduce low emission in Kraków, it is possible to undertake various actions, for example:

   - application of improved operating procedures for tile stoves and boilers;
   - use of improved fuel in tile stoves and boilers;
   - connection of boiler houses fired with coke and coal to the municipal district heating network;
   - replacement of coke- and coal-fired boiler houses with gas-fired units;
   - modernization of boiler houses, especially the mechanical stoker boilers houses, using various technically feasible methods in order to increase efficiency of the units and to reduce emission, and
   - elimination of coal-fired tile stove heating by replacement with electric or gas heating.

8. Using the spreadsheet program, the relative effectiveness of a wide range of options has been studied. The most cost-effective include improvements in operations, fuel upgrading, and connection to the district heating system in selected areas. The least cost-effective include conversion to gas and comprehensive modernization of stoker-fired boiler houses.

1.0 INTRODUCTION

1.1 BACKGROUND

Kraków is one of the largest and oldest cities in Poland. It is situated in the south of the country on the banks of the Vistula River. From the 11th until the 17th centuries, it was the capital of Poland. Today, Kraków is a city of 750,000 residents, one of the largest centers of higher education, an important industrial center, and is of particular importance because of the number and kinds of historic buildings and sites. For this reason, Kraków was included by the UNESCO in the list of the world's cultural heritages.

For about three decades, significant air pollution has been one of Kraków's most serious problems. Because the city is situated in the Vistula River valley, it is poorly ventilated and experiences a high concentration of air pollutants. The quality of air in Kraków is affected mainly by industry (Sendzimir Steelworks, energy industry, chemical plants), influx from the Silesian industrial region (power plants, metallurgy), transboundary pollution (Ostrava - Czech Republic), and local sources of low pollution, i.e. more than 1,000 boiler houses using solid fuels and more than 100,000 coal-fired home stoves. These local sources, with low stacks and almost no pollution-control equipment, are responsible for about 35-40% of the air pollution; they cause the highest concentration of air pollutants within the historic center of Kraków. This has had a significant effect on accelerated deterioration of historic buildings, as well as on the health of residents (respiratory tract disorders) and the condition of green areas and soil.

In a speech before the Polish Parliament on July 10, 1989, U.S. President George Bush pledged that the Unites States would assist Poland, and Kraków in particular, in the fight against pollution. Later that year, the U.S. Congress passed the Support for Eastern European Democracy (SEED) Act. Part of this legislation directed the U.S. Department of Energy (USDOE) to cooperate with U.S. and Polish experts to undertake an assessment program in Poland to use fossil fuels cleanly in small-scale combustion equipment. This program became specifically directed toward the emissions problems of low emissions sources in Kraków.

Funding for this program has been provided by the U.S. Agency for International Development (USAID). In 1991, USAID and USDOE signed an interagency agreement to conduct the project. Representatives from both organizations worked with Polish officials to establish an eight-member Bilateral Steering Committee (BSC) to plan and oversee the Program. In 1991, U.S. and Polish officials signed a Memorandum of Understanding formally initiating and directing the Kraków Clean Fossil Fuels and Energy Efficiency Program.

1.2 DESCRIPTION OF HEATING SYSTEMS IN KRAKÓW

Many centuries of town development, with a rapid acceleration in housing construction after WW II (threefold increase in the city's resident population), brought in many different heating systems. These include primitive coal-fired stoves in the old part of the city, boiler rooms in buildings, boiler houses serving multi-family housing and whole housing estates - which use mostly solid fuel (coke, coal), and district heating systems supplied from public central combined heat and power (CHP) plants. When the program began, the structure of heat sources in the city was as follows:

• Kraków CHP, KZS (soda factory), HTS (steelworks) combined heat and power plants	1465 MW -	52.4%
• Skawina CHP	13 MW -	0.4%
• Boiler Houses	999 MW -	35.7%
• Coal Home Stoves	240 MW -	8.6%
• Natural Gas	44 MW -	1.6%
• Electricity	36 MW -	1.3%

At present the situation is different, as the share of Skawina CHP has increased to about 220 MW, while Kraków CHP dropped to about 1210 MW, and the CHP in the soda factory was shut down; the share of other media, such as electricity and natural gas, has more than doubled (e.g. electricity reached 90-100 MW). Thus, the entire district heating system in Kraków operates by using two principal sources, i.e. Kraków and Skawina CHPs, with a minimum share for steelworks CHP of about 30 MW. The systems supplied from the two major CHPs were connected by a link between the Skawina pipeline and the western main pipeline of the municipal system; the CHPs now compete in some parts of the city. The heat distribution company (MPEC) distributes energy purchased from the above sources and supplies it to end users. Apart from this, MPEC operates its own boiler houses (about 170 of them) at sites not connected to the district heating network.

A 1991 inventory of low emissions sources in Kraków recorded 1,344 boiler houses, including 1,134 using solid fuel, with a total design output of 964.7 MW. There also were 100,000 coal-fired home stoves and an additional 17,000 rooms heated by small, individual boilers using solid fuel. The boiler houses consume approximately 375,000 Mg of solid fuels annually; the home stoves and small individual boilers use an additional 100,000 Mg. The boilers and stoves use 230,000 Mg of coal fines, 88,000 Mg of coke, and 157,000 Mg of coal.

The total number of boilers is 2,920, including:

- 2,262 boilers using solid fuel,
- 664 boilers using natural gas, and
- 14 boilers using fuel oil.

The solid fuel-fired boilers include:

- 229 boilers with travelling grates, and
- 2,033 boilers with fixed grates.

Pollution control devices are installed in 81% of boilers with travelling grates and in 4.6% of fixed-grate boilers.

Most of the boiler houses are located in the central part of the city. The Old Town District has 114 boiler houses with a total output of 52 MW, including 66 natural gas-fired boiler houses with 33 MW of combined output.

1.3 AREAS OF INTEREST

Phase I of the Program was designed to identify practical ways to reduce emissions from the low emission sources in Kraków. Based on surveys of existing equipment, the Bilateral Steering Committee approved five areas of interest (sometimes called "pilot projects" or "subprojects") for studies in the Program. Each focuses on specific alternatives to eliminate boilers or stoves, or to improve their performance. The five subprojects are briefly described below.

1) Energy Conservation and Extension of Central Station District Heating. Conserving energy and installing energy-efficiency measures would reduce the load and emissions from boiler houses or make more heat available for expanding the district heating system. Extending the central station district heating system would eliminate local boiler houses in favor of heat supplied by more efficient, less-polluting co-generation plants.

2) Replacement of Coal- and Coke-Fired Boilers with Natural Gas-Fired Boilers. The feasibility of such replacements is limited to areas of the city where natural gas is available and the infrastructure can handle the additional load. This is presently the case, for example, in the center city Old Town area, where low emission sources, boilers and home stoves, are concentrated. In Phase I, gas conversion was studied in Old Town and also in other parts of the city. Some consideration also was given to installing very small gas boilers in individual apartments currently heated with home stoves.

3) Replacement of Coal-Fired Home Stoves with Electric Heating Appliances. This involves installing electric thermal storage heaters or refitting home stoves with heating coils (a popular option in the city) . Such conversions are feasible in areas of the city where there is excess electrical capacity, but requires extensive rewiring of apartments and the use of day/night electric rates. One area northwest of the city center was identified as a strong potential site for conversion to electric heating appliances.

4) Reduction of Emissions from Stoker-Fired Boiler Houses. Many local boiler houses are relatively new or are far from existing district heating lines. These boiler houses will not be replaced or eliminated, but there are numerous alternatives to increase their efficiency and reduce their emissions. Extensive modernization of these boiler houses has been considered including new boilers, new particulate-control equipment, and possibly, sulfur-dioxide control equipment. Also considered were alternatives to replacing the boilers. The existing boilers could be modernized by adding economizers or pulverized coal-firing systems. Efficiency also can be improved by installing automatic combustion controls or by using coal that is cleaned and properly sized for stoker firing. Emissions from these boilers can be reduced by upgrading existing cyclones or incorporating other flue gas cleanup techniques.

5) Reduction of Emissions from Coal-Fired Home Heating Stoves. Due to the historical significance and esthetics of the tile home stoves, it is doubtful that these stoves will be replaced by other stoves or significantly modified, while still firing coal. Reducing emissions from home stoves is possible through operating them properly and using smokeless fuels, such as certain briquettes.

1.4 PROGRAM ORGANIZATION

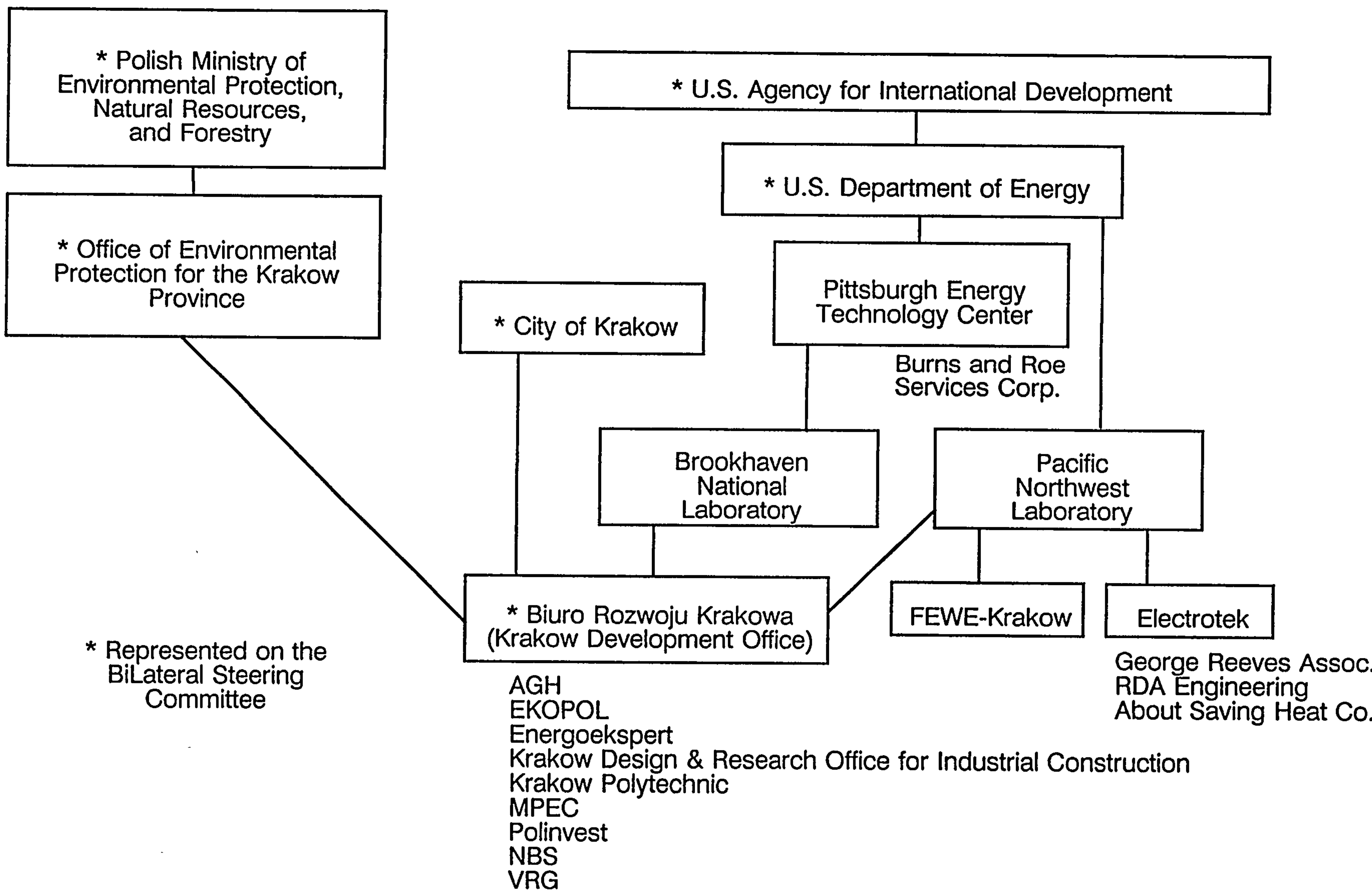
The BSC identified three phases for the program. Phase 1 was to gather more information, primarily on emissions and costs, to verify assumptions on existing heating methods and their alternatives. This report describes the results of Phase 1. Phase 2 was planned to inform Polish and U.S. companies of the Program, the results of Phase 1, and the opportunities available in Phase 3. Phase 3 was to solicit U.S. firms to participate in cost-shared projects to demonstrate and market energy efficiency and clean fossil fuel technologies in the Kraków area to alleviate the problems of air pollution caused by low emission sources. Presently, these projects are in progress.

For the information-gathering of Phase 1, funding was provided by USDOE to Pacific Northwest Laboratories (PNL) to study the first area of interest (energy efficiency and district heat extension), and to Brookhaven National Laboratory (BNL) for the remaining four areas of interest. The BSC designated the Pittsburgh Energy Technology Center (PETC) to manage all fossil energy-related work in the Program, including the BNL effort. The BSC also designated the Biuro Rozwoju Krakówa (BRK, the Kraków Development Office) to manage all Phase 1 studies in Poland. PNL and BNL negotiated contracts with BRK to conduct their portions of Phase 1.

Figure 1-1 shows the organization of the Kraków Clean Fossil Fuels and Energy Efficiency Program for the Phase 1 effort and the international cooperation at work in the Program. The eight-member BSC that directs the Program includes representatives of USAID, USDOE, the City of Kraków, the Office of Environmental Protection for the Kraków Province, and the Polish Ministry of Environmental Protection, Natural Resources, and Forestry.

The effort at BRK emphasized the performance, cost, and feasibility of heating methods in three major tasks: testing, engineering analysis, and incentives analysis. These tasks were conducted by BRK for each of the five areas of interest. Testing measured emissions and performance from equipment and fuels that are presently used, as well as alternative equipment and fuels considered as potential improvements. Engineering analysis estimated costs for promising alternatives and conducted feasibility studies and conceptual designs for implementing these alternatives. As part of the engineering analysis, the impact was studied of selected options on air quality in the city. The incentives analysis tasks recommended financial incentives or regulatory changes necessary to convince residents and boiler owners to invest in alternatives that will reduce emissions. These incentives were based on detailed analyses of the economics

Figure 1-1. Organization of Phase 1 of the Krakow Clean Fossil Fuels and Energy Efficiency Program



of specific options to energy users. Complementing these economic studies, public opinion was surveyed to evaluate the willingness and ability of residents to contribute to the costs of reduced pollution.

Table 1-1 lists the major Phase 1 participants, including the principal BRK subcontractors, and their areas of responsibility.

1.5 REPORT ORGANIZATION

The rest of this report presents detailed results from all of the Phase I activities. Chapter 2 discusses existing home-heating equipment. Equipment types, operating habits, and fuel use are discussed for home stoves, hand-fired boilers, and stoker-fired boilers. Test procedures and results are described, including emission factors and efficiencies.

Chapter 3 presents results from the engineering studies for each of the alternatives considered in the Program, including technical requirements for implementing each option and associated costs. Chapter 3 also discusses the possibility for supplying improved solid fuel to Kraków.

Chapter 4 gives the results from air-quality analyses. In the context of current air quality and pollution loads in Kraków, studies show the improvements to be expected if each of the options were implemented.

Chapter 5 describes public relations activities associated with the program. Focus groups were conducted to determine residents' level of knowledge about pollution sources and to identify their concerns. A public opinion survey was administered to a subset of Kraków's population to explore issues identified in the focus groups and to evaluate residents' ability and willingness to pay to reduce emissions from home heating sources. Some of the outreach and education activities also are described.

Economic feasibility and incentives analyses conducted for the program are discussed in Chapter 6. For each subproject, economic analyses used conversion costs developed in the engineering studies and two fuel price forecasts to determine whether the various alternatives would be justified on their own. For those cases where life-cycle costs would increase, various legal and economic ways the City could encourage conversions are explored.

Chapter 7 describes the conservation activities that were undertaken to support extending the district heating system. Four apartment buildings received various levels of conservation measures (caulking, insulation, new heat exchangers), and energy savings were measured over several heating seasons.

Chapter 8 then presents results of a screening analysis of the alternatives, using a spreadsheet developed by the BSC. The chapter includes detailed input assumptions for each option, and compares the attractiveness of the various options in terms of costs and emission reductions. Finally, in Chapter 9 the conclusions and recommendations from Phase I activities are presented.

Table 1-1. Major Phase 1 Participants

Organization	Responsibility
Pacific Northwest Laboratories (PNL)	Lead for Area of Interest #1
Brookhaven National Laboratory (BNL)	Lead for Areas of Interest #2 through #5
Electrotek	PNL Contractor to direct BRK in tests conducted for energy efficiency/conservation
Burns and Roe Services Corporation	PETC Support Contractor
Miejskie Przedsiebiorstwo Energetyki Cieplnej (MPEC)	Host for boiler combustion testing
Biuro Rozwoju Krakowa (BRK)	Prime Contractor (to BNL and PNL) for all Phase 1 work
BRK Subcontractors:	
Ekopol	Analysis of emissions, air quality, and associated fees and penalties
Polinvest, Ltd.	Legal and economic analysis of options and incentives
Academy of Mining and Metallurgy	Home stove combustion tests
Energoekspert	Boiler combustion tests
NBS	Public relations/public information
FEWE - Kraków	Installation of energy efficiency measures
Kraków Design and Research Office of Industrial Construction	Engineering analysis of options for boiler modernization

2.0 CHARACTERISTICS OF THE LOW EMISSIONS SOURCES

2.1 HOME STOVES

2.1.1 Description of the Polish Tile Stoves

The coal stove tested during this program is a traditional storage stove built of brick and covered with ornate ceramic tiles. Lipka et al. (1991) stated that there are seven million such stoves in Poland. These stoves are fired once or twice daily during Winter. Each firing period lasts about 1 1/2 hours, and during this time the stove's mass is heated. After the burning period is over, the room is heated as the masonry slowly cools.

Figure 2-1 shows a vertical cross-section of the tested stove. There are three vertical "channels" or flue gas passages. The first is directly above the firing grate and extends across the full width of the front part of the stove. The bottom half of this channel serves as the combustion chamber. The second and third channels are each a half-width across the back of the stove. Combustion products travel down through the second channel, cross over to the third channel at the bottom of the stove, and then travel up through the third channel and finally out into the flue. The air flow for combustion is regulated by positioning access doors above and below the firing grate.

2.1.2 Details of the Test Program

The type of ceramic home stove tested has long been used in Poland. The technical literature on stoves dates back several decades. According to these reports, the efficiency of a ceramic-tile stove ranges between 65 and 70%. Emissions of pollutants from such stoves have not been measured previously. According to current popular opinion, the efficiency of these stoves actually is much lower, in the 25 - 40% range, and such values have been adopted in various comparisons.

The following specific objectives were set for this program:

- To determine the efficiency of the stove with various fuels.
- To establish pollutant-emission factors with various fuels.
- To evaluate selected modifications of the combustion process which might increase its efficiency or reduce emissions without modifying the stove's construction (to determine an optimum procedure of firing).
- To evaluate if small changes in construction might improve the combustion process.

The test stove was built at the laboratory of the Academy of Mining and Metallurgy (AGH) in Kraków, after consultation with experts from the Brookhaven National Laboratory (BNL) using measuring equipment supplied by the U. S. project participants. A dilution tunnel method was used to continuously determine the emission rates of gaseous pollutant and the energy loss from

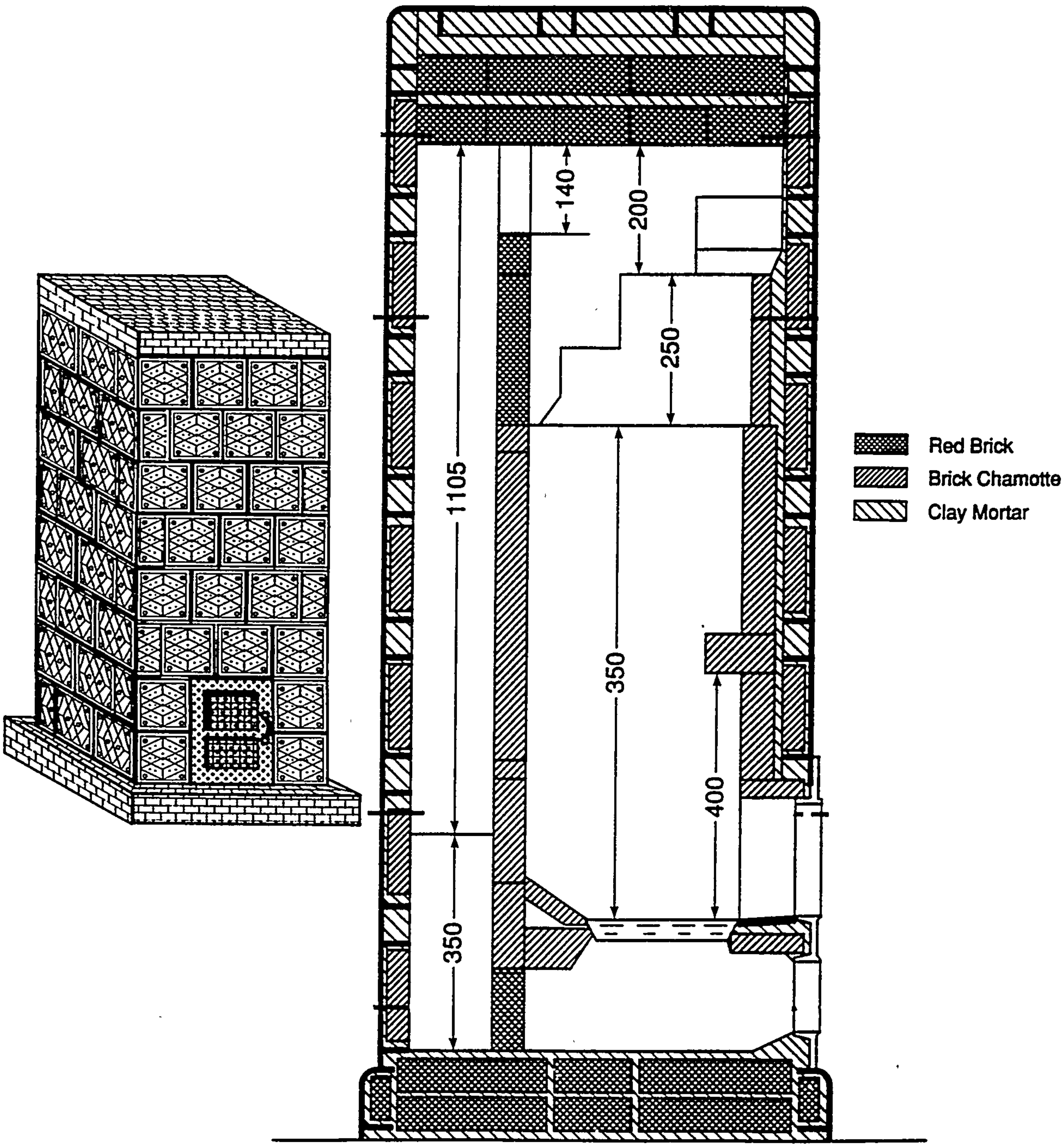


Figure 2-1. Illustration of Polish tile stove showing first and second passes.
(all dimensions are in millimeters)

the flue gas during the firing cycle. This test was adapted from U. S. standard methods for testing wood-fired stoves (Macumber 1981; U. S. Code of federal Regulations, 1990).

The measurement system is illustrated in Figure 2-2. All of the combustion products leaving the stove enter the dilution tunnel, along with air from the room. The flow of flue gases at the stove's exit varies greatly during a firing cycle, and often is too low to measure practically. In contrast, the flow in the dilution tunnel is steady and can be easily measured. The emission rate of any gaseous pollutant is simply the product of the concentration and the flow rate in the dilution tunnel.

The thermal efficiency of the stove is determined by integrating the rate of energy loss from the stove over the firing cycle. The assessment requires measurements of the mass flow rate of flue gas from the stove. Infrared analyzers are used to monitor CO_2 both in the stove exhaust and the dilution tunnel continuously. These measurements, along with the flow rate in the dilution tunnel, allow calculation of the stove's mass flow. Knowing mass flow rate of the flue gases, the dilution ratio, and the composition of gas in the dilution tunnel, the composition of flue gas at the stove's exit can be calculated for any time during the combustion process. To complete the determination of heat loss, the ultimate analysis of the as-fired fuel and the heat loss due to unburned carbon must be known. In normal cyclic operation, char remaining on the grate after each cycle is left to be burned during the following firing cycle. However, all ash and char passing through the grate is removed. This procedure was followed during these tests, and efficiency was determined in tests involving multiple cycles.

In the test arrangement, a data logger was used to record temperatures and pressures throughout the stove and dilution tunnel system, and also output from the CO_2 and hydrocarbon analyzers. Concentrations of O_2, CO, NO_x, and SO_2 in the dilution tunnel were measured using an analyzer with electrochemical-type cells. Data from both the logger and the gas analyzer were downloaded to a computer during the tests for analysis later.

The following elements are marked on the illustration of the test arrangement (Figure 2-2):

1. Stove
2. Diluted flue gas
3. Flue gas exhaust fan
4. Air/flue gas mixing element
5. Damper controlling dilution ratio and draft
6. Flue gas sample conditioner

7.,8. Analyzer for CO_2 in flue gas before and after dilution, respectively

9. Analyzer for volatile hydrocarbons in flue gas (readings given as methane equivalent)
10. Programmable multichannel data logger
11. Gas analyzer
12. Particulate-sampling train

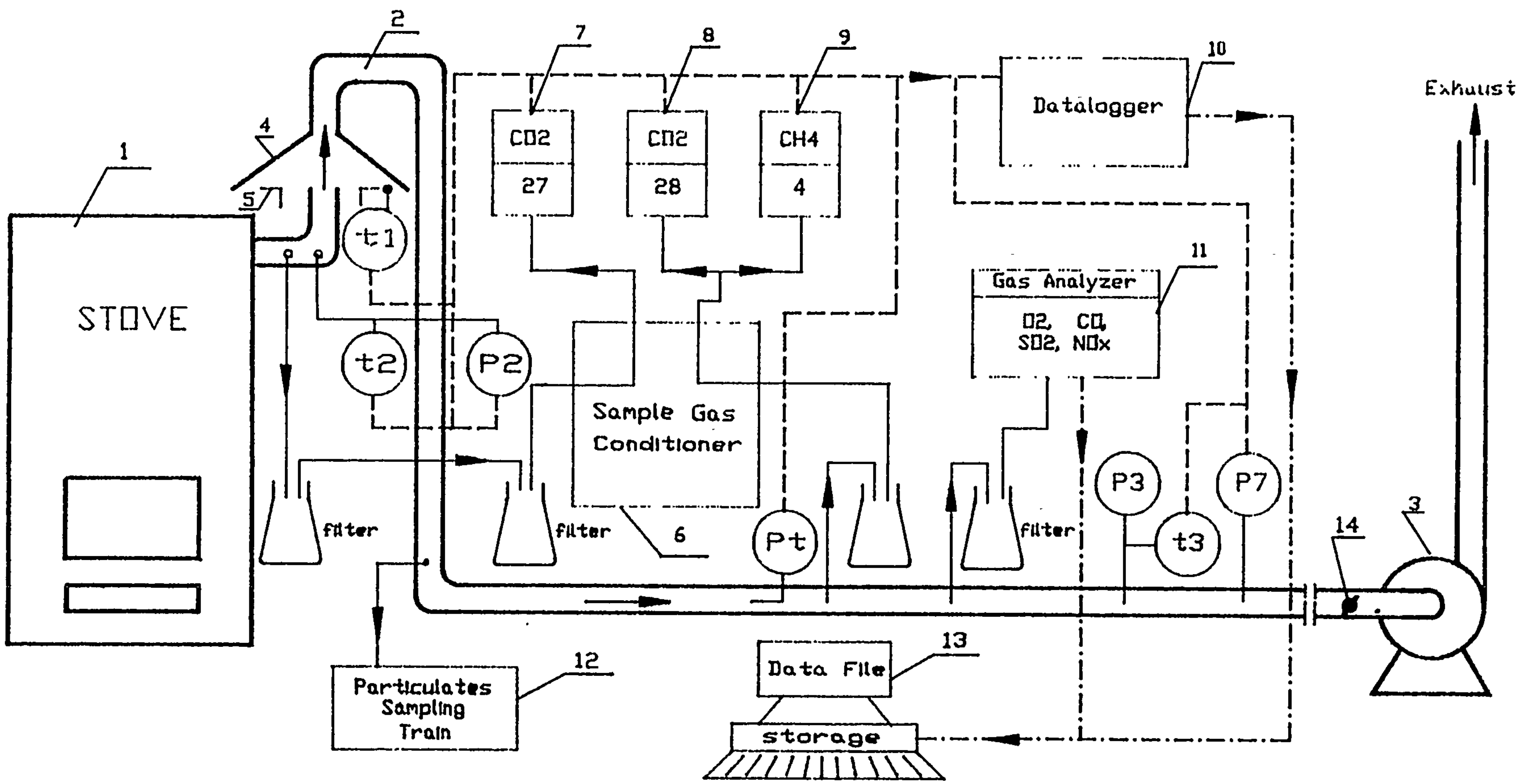


Figure 2-2. Stove test arrangement

13. Computer controlling the measurements and recording of data
14. Damper regulating the flow rate in the dilution tunnel

The operating procedure was designed to closely reflect the typical way of firing a home stove. Each test cycle lasted around 24 hours. On average, three cycles were conducted to evaluate each kind of fuel or operating procedure. Before each series of tests, the combustion chamber, ash-pit, and dilution tunnel were carefully cleaned of all residues from the previous tests. At the end of each firing cycle, after poking the grate, slag was separated manually from the coke and removed, along with the contents of the ash-pit. The char was left to be burned with the charge of fuel during the next test. The contents of the ash-pit and the slag were weighed and analyzed to determine their carbon content. After the series of tests, the last portion of char also was analyzed for combustible parts.

In the test arrangement, the draft on the stove was controlled using a damper at the inlet to the dilution tunnel's exhaust fan and also a damper at the dilution hood (5 in Figure 2-2). Before starting tests, measurements were made in the field to establish realistic draft/time profiles, and during testing the dampers were carefully controlled to reproduce a typical draft/time profile.

The following fuels were used in testing:

1. High-quality hard coal from the Wujek Coal Mine, 1992 supply
2. High-quality hard coal from the Wujek Coal Mine, 1993 supply
3. Low-quality hard coal from Bolesław Śmiały Coal Mine, 1992 supply
4. Smokeless briquettes manufactured by IChPW Zabrze, 1992 supply
5. Smokeless briquettes manufactured by IChPW Zabrze, 1993 supply
6. Dry-quenched coke from Przyjaźń cokery, 1994 supply
7. Wood-waste briquettes from Eko-Tes Tartak

Table 2-1 lists the properties of all these fuels.

NOTE: Results of the tests with coke and wood are included in this report although they were conducted outside the formal scope of the U. S. - Polish Program.

Coal from Wujek mine in Katowice has a high-heating value and is relatively low in sulfur and ash content. Coal from Bolesław Śmiały mine in Łaziska also is a low-sulfur coal but is very high in ash. Smokeless briquettes are manufactured by the Institute for the Chemical Processing of Coal (IChPW) in Zabrze, using its own technology (Zielinski et al. 1991). The briquettes are produced in a hot process in which a caking coal and char obtained from the pyrolysis of steam coal are combined; the latter serves as the binder. Pyrolysis takes place in a circulating fluid-bed gasifier, at about 800°C, where volatiles are removed. To plasticize the caking coal, it is mixed with hot char at about 450°C. The mixture then is fed into a roll press, forming briquettes. The briquettes supplied by IChPW Zabrze in 1992 and in 1993 had comparable characteristics.

Dry-quenched coke, 20-40 mm grain size, was produced and supplied by Przyjaźń cokery in Dąbrowa Górnicza. This fuel is produced by a dry-quenching in which the energy of the hot coke is removed by inert gas and used to generate steam. This procedure improves the efficiency of the coking process as well as lessening pollution (by much more than wet quenching), and the coke obtained this way has better strength characteristics. A 1994 supply from Przyjaźń cokery was used in testing. It is a fuel of high heating value, slightly higher in sulfur than Zabrze briquettes but lower in ash content.

Briquettes made of sawdust (sawmill waste) were supplied by the producer, Eko-Tes Tartak. The cylindrical briquettes are formed in punch presses. The production of the briquettes begins with a pneumatic installation that carries sawdust from the sawmill to a drum-drier heated by flue gases from a furnace burning waste wood. After being heated and dried, the sawdust is pneumatically transported to a cyclone separator and directly fed to lines of punch presses. No binder is used. It is a fuel with low heating value but practically sulfur-free and ash-free.

2.1.3 Description of the Operating Procedures Tested

The tile stove was tested under various operational procedures. The baseline tests were called **"normal (average user) operating procedure"**, reflecting the behavior of the majority of users and their ideas about the correct operation of the home stove. Next, the effect of the most frequent faults in the stove's operation were studied, and also frequently occurring leaks in the stove. These tests were called **"poor operating procedure"**. An attempt also was made to introduce slight modifications in the stove's construction, without basic design. The testing conducted after these changes was called **"modified operating procedure"**.

The experience gathered in the testing program allowed us to develop an optimum procedure for operating tile stoves; this procedure was called **"improved procedure."**

Table 2-1. Test Fuel Properties

FUEL	Sample Year	Qi [kJ/kg]	St [%]	V [%]	Ultimate analysis (weight %) C	H	S	N	O	W	A
Zabrze briquettes	1993	27611	0.60	10.3	77.90	2.25	0.34	1.35	3.16	3.7	11.3
	1992	27619	0.62	8.14	78.44	1.58	0.22	1.15	4.42	3.3	10.9
Wujek Mine Coal	1993	28226	0.94	30.9	75.10	4.45	0.59	1.24	6.92	4.4	7.3
	1992	31324	0.85	32.1	79.55	4.78	0.28	1.18	8.17	2.7	3.3
Boleslaw Smialy Mine Coal	1992	24605	0.65	30.3	60.91	4.13	0.29	0.98	9.54	2.5	21.6
Przyjazn coke	1994	30280	0.59	1.0	88.50	0.10	0.50	1.40	0.70	0.10	8.70
Sawdust briquettes	1993	17916	0.00	72.6	46.61	5.85	0.00	1.08	39.0	5.6	1.81

Qi - lower heating value as-fired
St - total sulfur
S - combustible sulfur
V - volatiles content
W - water content

Normal Operating Procedure

The process of firing under this procedure involved the following steps:

1. Lighting a small quantity of kindling wood (around 200 g) and about one-third of the total fuel charge to be tested.

2. When the initial charge starts to burn well, loading the remaining fuel (on average, 5 to 15 minutes later).

3. Burning the fuel charge with the doors in positions adopted by the majority of users i.e.:

   - top inner (screen) door closed,
   - top outer door left ajar as little as allowed by their construction, but not full closed,
   - ash-pit door slightly ajar.

   This is the principal stage in the combustion process, during which the bed is poked at least once (the frequency of poking depends on type of fuel).

4. Closing tightly the top outer door after the process of degasifying fuel is over (marked by the disppearance of "long flames").

5. Closing the stove completely i.e. by closing tightly both doors, when the temperature of the fuel bed begins to drop (based on visual observation - "a darkening of the glow").

In addition, it was assumed that the user will not remove the char left after firing but, after poking and possibly taking out only larger pieces of slag, will leave it to be burned with the next charge of fuel.

Poor Operating Procedure

The most typical faults in operating the stoves were firing with both top and bottom doors full open, and leaving them open for longer than the time necessary for combustion of the fuel charge. Another important condition evaluated during these tests was a leaky stove door. Over the years, the masonry which surrounds the metal door-frames deteriorates and opens cracks and holes. If these are large, they can lead to significant leakage of air into the stove during the second part of the cycle - when combustion has stopped and the room is being warmed by stored heat. This air would be warmed in the stove and lost through the chimney. To evaluate the effects of air leaks, the doors were left open a very small and carefully set amount after normal combustion ended. The extent of opening adopted was determined through a set of field tests in which actual leakage rates with older stoves were carefully measured and then used in the tests.

Four test series were carried out to check the effects of these faults on combustion in the stove:

1. Following the "**normal operating procedure**" except that both top and bottom doors were left completely open.

2. Following the "**normal operating procedure**" except that closing the doors was delayed by about an hour.

3. Following the "**normal operating procedure**" except that after the firing the doors were not tightly closed.

4. Conditions of combustion process as described under 1 and 3.

Modified Procedure

Slight modifications of the tile stove were made to test whether its emissions could be reduced or its efficiency improved. The assumption was that these modifications may not require any essential alterations or rebuilding of the stove.

The following modifications were tested:

1. Burning the fuel charge in a cylindrical metal insert placed in the combustion chamber. The insert was designed and produced by BNL.

   Because of the results, only two tests were completed, one with Zabrze briquettes, the other with Wujek coal.

2. Burning the fuel charge in an insert with a removable drawer placed in the combustion chamber. The insert was designed and produced by BNL. Three 24 hr-tests were completed for each kind of fuel.

3. Burning the fuel charge with the top inner (screen) door replaced by specially designed door meant tc pre-heat air before it entered the combustion chamber. This door was designed and manufactured by AGH. Because of the results, only one test was completed, using Zabrze briquettes.

4. Burning the fuel charge in a combustible container. The container was manufactured by AGH. Because of the results, only one test was completed, using Zabrze briquettes.

Improved Operating Procedure

The experience gathered in the testing program allowed us to develop an improved operating procedure which leads to higher efficiency and, most importantly, reduced CO emissions with some fuels. This procedure involves:

- Using the correct amount of the fuel charge in a single firing.

- Reducing overall excess air in the combustion chamber and, at the same time, supplying all of the combustion air through the grate (by closing the top door tightly and leaving the bottom, ash pit, door open).

- Poking the bed with the correct frequency and timing.

- Closing the stove, i.e. completing the active stage of the firing cycle, when the temperature of flue gas begins to drop after poking the bed for the last time.

Taking into account these conditions, a procedure for burning fuels called **"improved operating procedure"** was developed, although there were still with some variations depending on the kind of fuel used. This procedure is described as follows:

1. Loading into the stove about 150-200 g of kindling wood in the case of Zabrze briquettes and coal (while coke requires 300-350 g) and about one-third of the fuel charge planned for a given test. For coke, the whole charge should be loaded at once. Also, the char left from previous firing should be loaded if removed earlier from the combustion chamber.

2. Lighting the fire and then, closing the top door tightly after no more than several minutes, but leaving open the bottom door.

3. After the initial charge is burning well, loading the next portion of fuel; this will be the next one-third for Zabrze briquettes, or the remaining part of Wujek coal. This step does not apply to coke.

4. Adding the remaining one-third of Zabrze briquettes about 15 minutes after loading the previous portion.

5. Poking the bed during firing. For Zabrze briquettes this is to be done three times, the first time about 20 minutes after the last fuel addition, the second and third times in about 15-minute intervals. For Wujek coal, there should be only one poking about 40 minutes after lighting. For coke, there may be also three pokings and intervals may be the same as smokeless briquettes from Zabrze. After each poking, the top door should be closed as soon as possible. Under testing conditions, the fire was probed when CO emissions started to rise. In operating a home stove, given good repeatability of the course of firing, the timing may be determined by following the measured times, according to the schedule presented above.

6. Closing the stove (i.e. closing tightly the ash-pit door) when the temperature of flue gas at the stove exhaust begins to decrease. This means that the stove should be closed, 10 to 15 minutes after last the poking in the case of burning Zabrze briquettes and coke, and 10 minutes after the last poking for Wujek coal.

2.1.4 Test Results

General Behavior

Figures 2-3 to 2-8 show the general behavior of a stove during a typical firing cycle, with gas temperatures, internal-masonry temperatures, and emission rates of some flue gas components over time. These graphs were prepared for: Wujek coal and the smokeless briquettes. The level of CO_2 emissions and temperature of flue gas can be used as measures of the combustion rate. For about the first 20 minutes, most of the fuel volatiles burn off, with high levels of CO_2 and CO emissions. After this, the combustion rate remains fairly high, but the emission rate of CO decreases. It seems likely that the reduced CO emissions between 20 and 55 minutes result not only from the burning out of volatiles, but also from the higher temperature inside the stove. After about 55 minutes, the top door was closed causing a gradual decrease in combustion rate but, at the same time, a rapid increase in CO emissions. A significant portion of the overall CO emissions occurs after the top door is closed. After about 75 minutes, the bottom door is closed and combustion ceases. A similar course of the events occurred with Zabrze briquettes. Figure 2-8 shows temperature changes at the stove's inner roof as a function of time, where 24-hr cycles of storing and giving up heat are clearly marked.

Results with the Normal Operating Procedure

Table 2-2 provides values of gas and particulate emissions and stove efficiencies obtained in baseline tests with normal operating procedures. These values are calculated per 1 kg of fuel; per 1 MJ of heat input with fuel; and per 1 MJ of effective energy (taking the stove's efficiency into account). The tests were completed for coals from Wujek and Bolesław Śmiały coal mines and briquettes from Zabrze, 1992 supply.

Results with Poor Operating Procedure

Table 2-3 has values of gas and particulate emissions and stove efficiency in tests simulating common flaws in operating procedures. As for normal operating procedures, the results are calculated per kg of fuel; per MJ of heat input; and per MJ of heat output. The following codes are used in these tables:

TP Tests in which the stove doors were left open for an extra hour (a common operating error).

TZN Tests simulating air leaks into the combustion chamber after the doors are closed (a stove in poor condition).

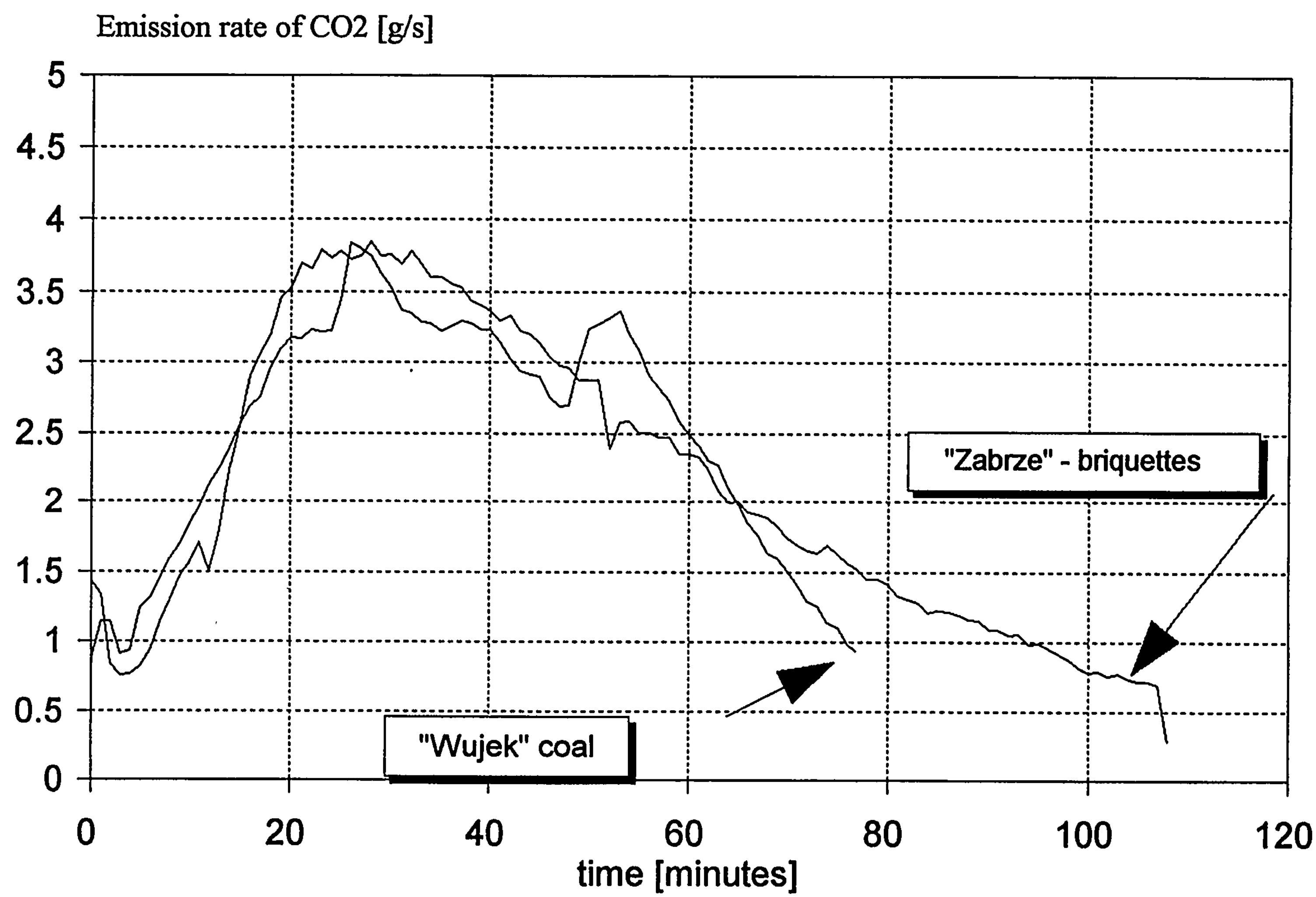


Figure 2-3. Example of stove operating behavior - CO_2 emission rate during firing cycle. Wujek coal and Zabrze briquettes with normal operating procedures.

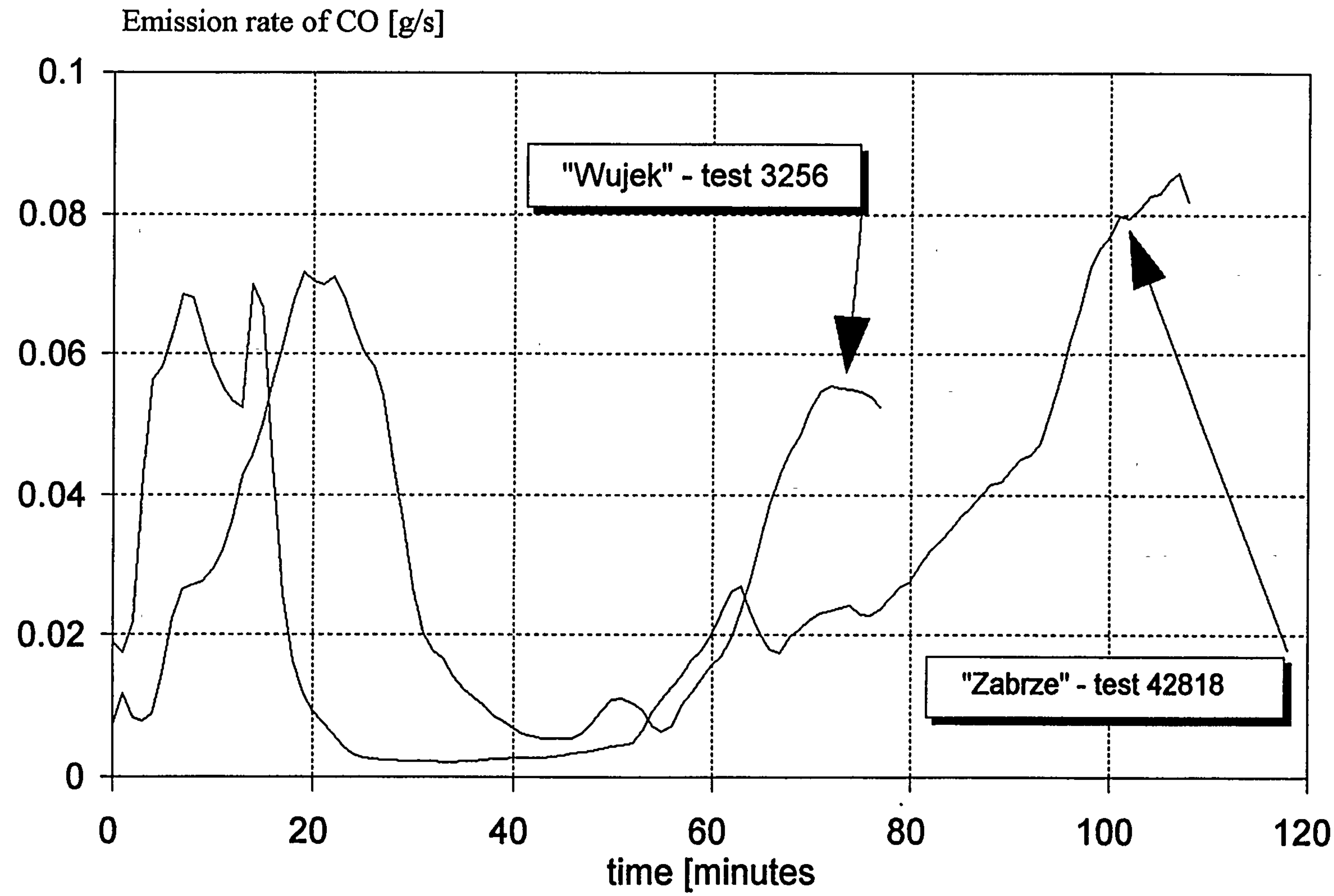


Figure 2-4. Example of stove operating behavior - CO emission rate during firing cycle. Wujek coal and Zabrze briquettes with normal operation procedure

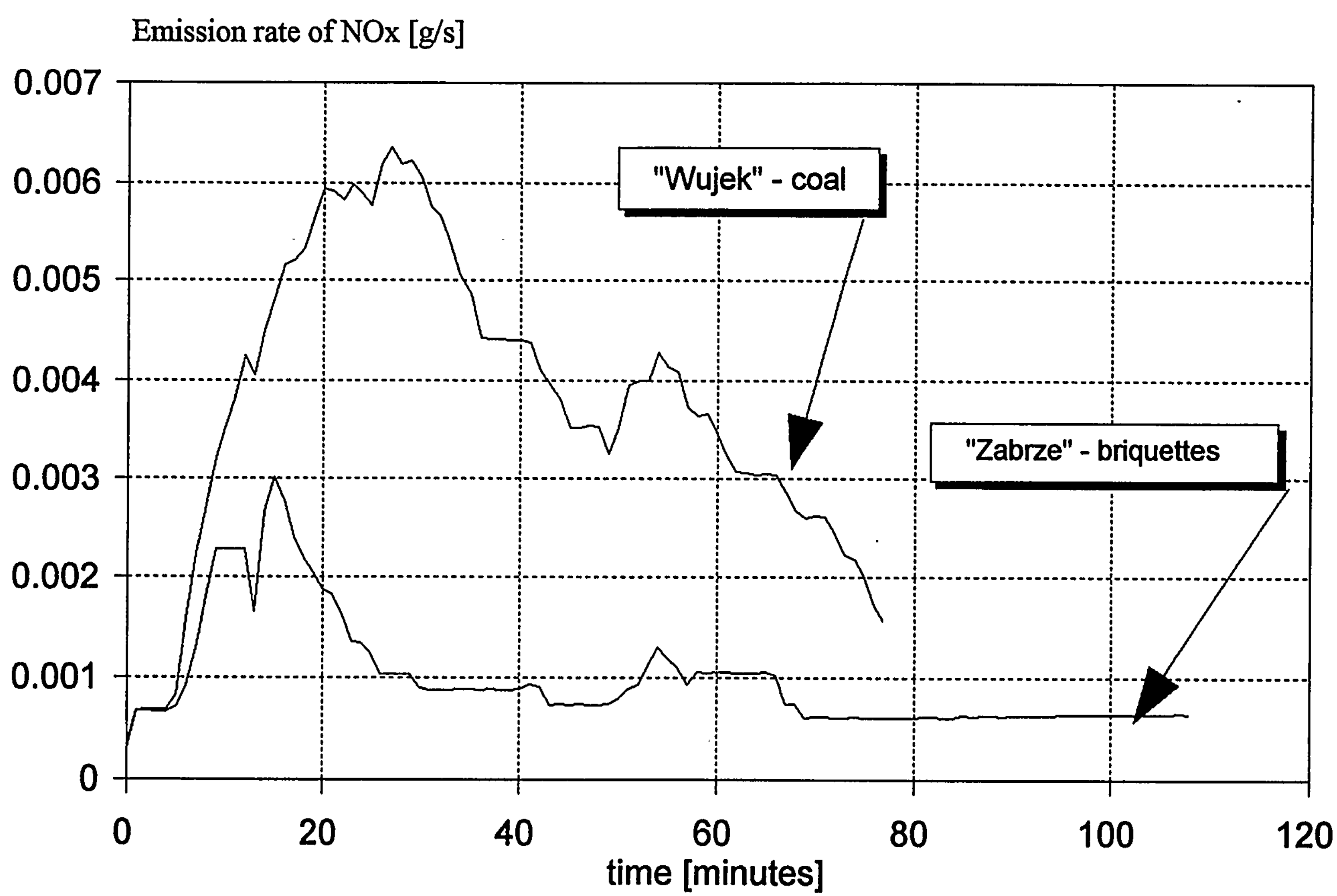


Figure 2-5. Example of stove operating behavior - NOx emission rate during firing cycle. Wujek coal and Zabrze briquettes with normal operating procedure.

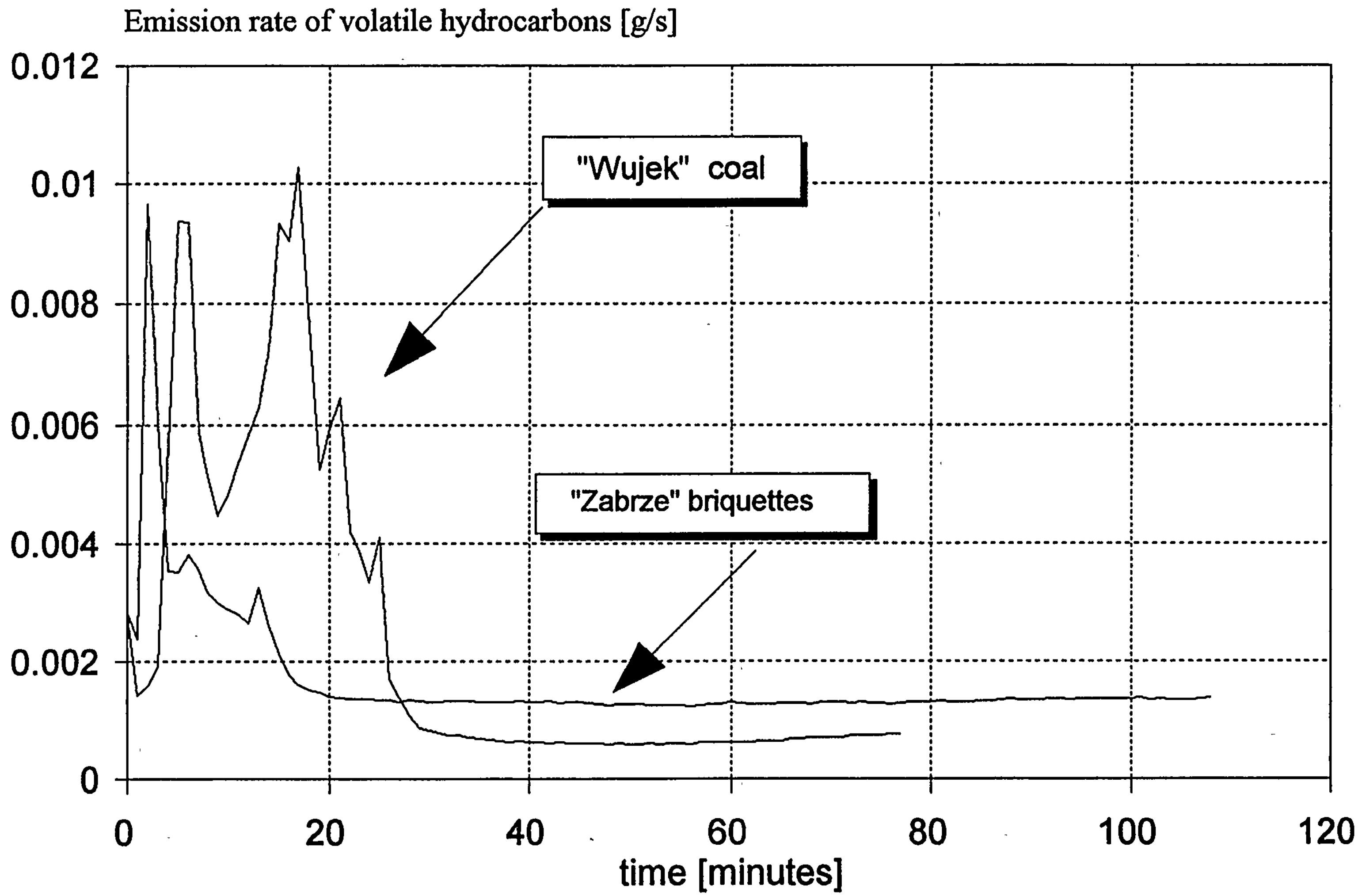


Figure 2-6. Example of stove operating behavior - volatile hydrocarbon emission rate during firing cycle. Wujek coal and Zabrze briquettes with normal operating procedure.

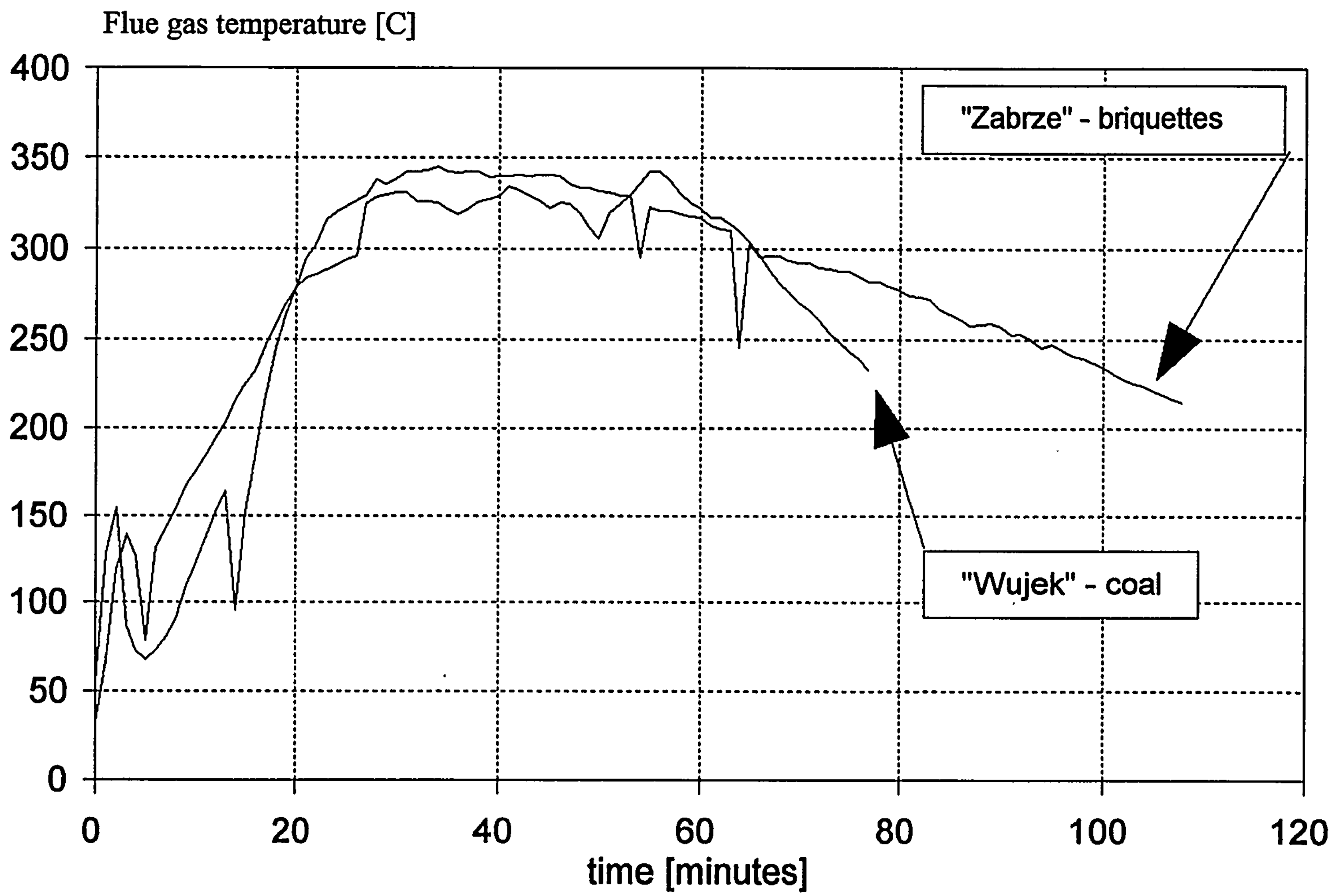


Figure 2-7. Example of stove operating behavior - temperature of gas at stove exit. Wujek coal and Zabrze briquettes with normal operating procedures.

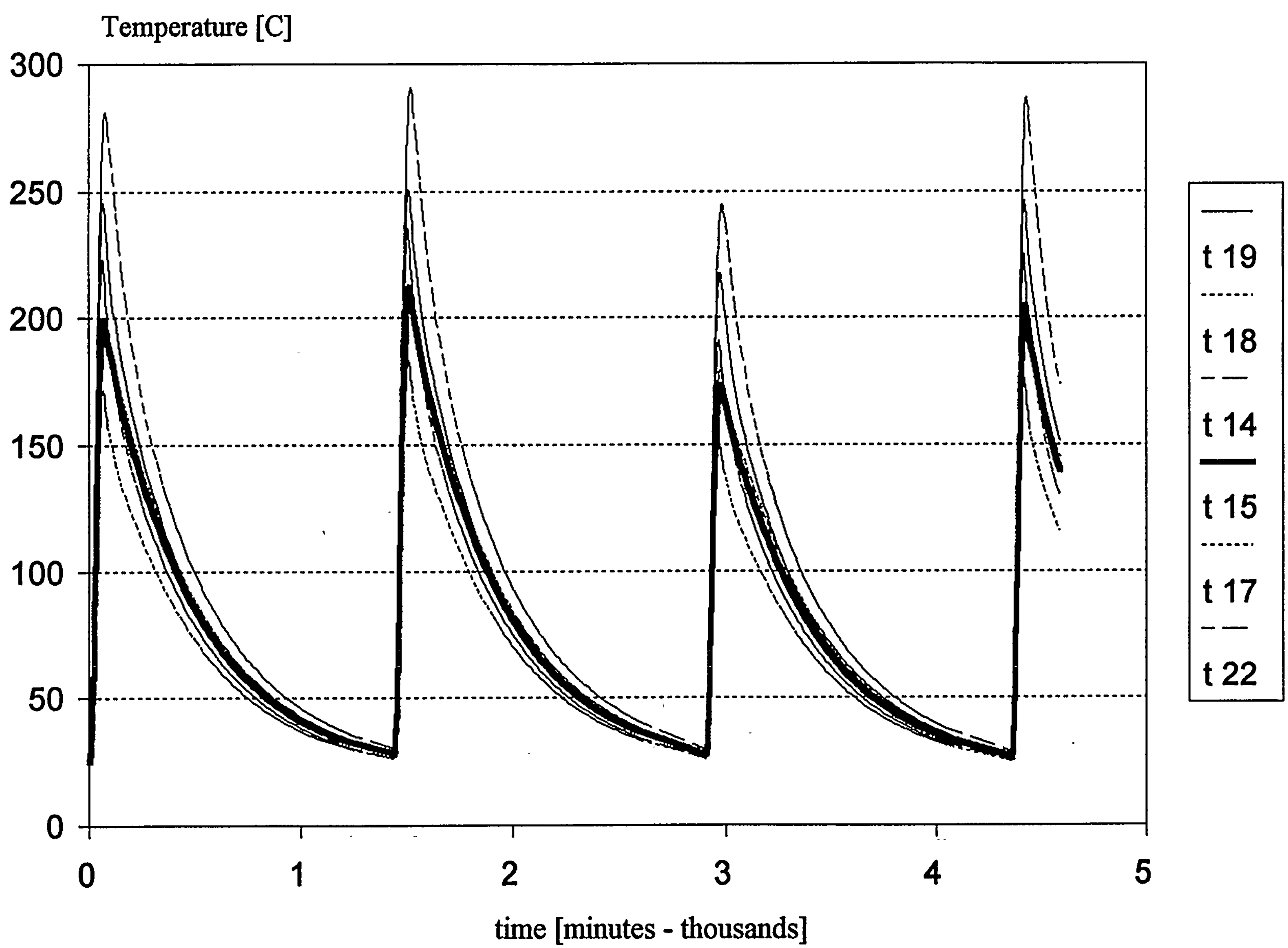


Figure 2-8. Example of stove operating behavior. Variation in selected stove internal temperatures during several firing cycles.

DO Tests simulating faults in which fuel is burnt with excess air (both doors fully open for the entire firing cycle).

DON Tests simulating combustion with too much air and then leaks after closing (combined DO and TZN tests).

All these tests were completed for Wujek coal and briquettes manufactured by Zabrze.

Results with Modified Procedures

The results of the tests using modified procedures showed that practically none of them increased the stove's efficiency or reduced emissions of pollutants:

- When briquettes were burned in a cylindrical metal container inserted into the combustion chamber, the efficiency was 19%. In addition, an enormous amount of char was left (2.6 kg).

- Burning fuel in a metal container with movable drawer, gave a slight increase in efficiency (from 56.9 to 60%) for briquettes but a decrease (from 68.5 to 56.7%) for Wujek coal. Practically all emissions of pollutants were higher for both fuels. CO emissions from burning briquettes were only slightly higher, but, in the case of Wujek coals, they were higher by a factor of 2.7. Only NO_x emissions were reduced, resulting from lower rate of combustion and resultant lower temperatures in the combustion chamber. In addition, after burning briquettes, a considerable amount of char was left.

- Applying specially designed doors which pre-heat combustion air gave 49.2% efficiency; this is less than in tests with normal operating procedures. CO emissions doubled.

- Burning briquettes in a combustible container gave a short burning period, (53 minutes), and relatively low emissions. However a large amount of char (1.9 kg) was left at the end of combustion, indicating the necessity to prolong the time for combustion. It is likely that this would increase emissions and this approach does not appear to be technically attractive.

The reasons for such adverse results were described in detail in a special report (see Appendix I). As these modifications did not yield the expected results, tables are not included in this report.

Results with The Improved Operating Procedure

Table 2-4 shows the values of gas and particulate emissions and stove efficiency in tests carried out with the improved operating procedure. The following codes are used in these tables:

PP	Tests with improved operating procedure, using Wujek coal and Zabrze briquettes.
K	Tests with improved operating procedure, using dry-quenched coke from Przyjaźń cokery.
TR	Tests with improved operating procedure, using sawdust briquettes.

Table 2-2. Summary of Stove Test Results with Normal Operating Procedures

Emissions per kg of fuel and efficiency (g/kg)										
Fuel	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	η(%)[5]
Zabrze Briquettes	2794.9	49.3	2.42	3.33	2.41	0.795	0.44	1.45	105	56.9
Bolesław Śmiały Coal	1968.3	20.0	3.35	5.60	3.31	13.75	0.89	1.43	265	61.8
Wujek Coal	2789.3	27.1	1.77	5.11	6.87	16.62	0.94	3.10	65	68.5
Emissions per MJ of heat input (fuel lower heating value)										
Fuel	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	101.2	1.79	0.088	0.121	0.087	0.029	0.016	0.053	3.8	
Bolesław Śmiały Coal	80.0	0.81	0.136	0.228	0.135	0.559	0.036	0.058	10.8	
Wujek Coal	89.0	0.87	0.057	0.163	0.219	0.531	0.03	0.099	2.1	
Emissions per MJ of heat output (heat input X efficiency)										
Fuel	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	177.9	3.14	0.155	0.213	0.153	0.051	0.028	0.091	6.7	
Bolesław Śmiały Coal	129.4	1.32	0.22	0.367	0.217	0.906	0.058	0.094	17.4	
Wujek Coal	130	1.26	0.082	0.238	0.32	0.774	0.044	0.145	3.0	

[1]Ms = particulates captured in sampling train filter, nozzle, and probe
[2]Meo = organic material extracted from sampling train impingers
[3]Men = non-organic material extracted from sampling train impingers
[4]Ma = ash removed from stove
[5]All efficiency values in this report are based on the lower heating value and the customary European calculation method. Efficiencies based on customary U.S. calculation methods are about three percentage points lower.

Table 2.3. Summary of Stove Test Results with Poor Operating Conditions

Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	η%[5]
Emissions per kg of fuel and efficiency											
Zabrze Briquettes	TP	2730.5	80.7	3.42	2.69	2.71	1.195	0.80	1.373	103	49.1
	TZN	26990.0	48.8	3.32	3.68	2.73	1.36	1.49	1.908	102	63.6
	DO	2646.4	88.5	2.74	2.93	2.64	0.726	0.69	1.208	96	56.7
	DON	2813.0	87.1	2.29	3.77	3.64	1.604	1.90	2.819	103	56.3
Wujek Coal	TP	2676.5	24.5	3.13	5.50	4.13	20.00	0.62	1.91	53	47.2
	TZN	2759.7	28.7	2.68	4.42	4.42	16.92	0.54	2.26	53	54.2
	DO	2694.3	19.7	2.61	5.06	4.16	17.08	0.69	2.077	555	55.0
	DON	2731.4	26.7	2.84	4.87	4.97	14.49	0.73	2.12	46	53.3
Emissions per MJ of heat input (fuel lower heating value)											
Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	TP	98.863	2.922	0.124	0.097	0.098	0.043	0.029	0.05	3.729	
	TZN	97.723	1.767	0.12	0.133	0.099	0.049	0.054	0.069	3.693	
	DO	95.818	3.204	0.099	0.106	0.096	0.026	0.025	0.044	3.476	
	DON	101.85	3.154	0.083	0.137	0.132	0.058	0.069	0.102	3.729	
Wujek Coal	TP	85.446	0.782	0.1	0.176	0.132	0.638	0.02	0.061	1.692	
	TZN	88.102	0.916	0.086	0.141	0.141	0.54	0.017	0.072	1.692	
	DO	86.014	0.629	0.083	0.162	0.133	0.545	0.022	0.066	1.756	
	DON	87.198	0.852	0.091	0.155	0.159	0.463	0.023	0.068	1.469	
Emissions per MJ of heat output (heat input X efficiency)											
Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	TP	201.35	5.95	0.252	0.198	0.199	0.088	0.059	0.101	7.6	
	TZN	153.65	2.78	0.198	0.21	0.155	0.077	0.085	0.109	5.8	
	DO	169	5.65	0.175	0.187	0.179	0.047	0.044	0.077	6.1	
	DON	180.9	5.6	0.147	0.242	0.234	0.103	0.122	0.2	6.6	
Wujek Coal	TP	181.03	1.654	0.211	0.372	0.279	1.35	0.042	0.129	3.6	
	TZN	162.55	1.688	0.158	0.26	0.26	0.977	0.032	0.133	3.1	
	DO	156.39	1.146	0.151	0.294	0.241	0.99	0.04	0.12	3.2	
	DON	163.6	1.601	0.17	0.292	0.298	0.852	0.043	0.125	2.8	

[1]Ms = particulates captured in sampling train filter, nozzle, and probe
[2]Meo = organic material extracted from sampling train impingers
[3]Men = non-organic material extracted from sampling train impingers
[4]Ma = ash removed from stove
[5]All efficiency values in this report are based on the lower heating value and the customary European calculation method. Efficiencies based on customary U.S. calculation methods are about three percentage points lower.

Table 2-4. Summary of Stove Test Results with Improved Combustion Procedures

Emissions per kg of fuel and efficiency											
Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	$\eta(\%)$[5]
Zabrze Briquettes	PP	2825.3	20.8	1.37	4.12	1.79	1.19	0.54	1.12	118.	73.6
Wujek Coal	PP	2507.3	32.2	3.87	2.74	2.78	15.0	1.90	1.99	67.2	75.1
Coke	K	2916.5	28.1	1.75	2.83	1.57	1.75	0.55	1.23	135.	73.1
Sawdust Briquettes	TR	1720.1	48.4	6.03	0.07	0.51	6.43	2.05	1.36	17.4	74.0
Emissions per MJ of heat input (fuel lower heating value)											
Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	PP	102.3	0.75	0.050	0.149	0.065	0.043	0.02	0.041	4.274	
Wujek Coal	PP	88.8	1.14	0.137	0.097	0.098	0.53	0.067	0.071	2.381	
Coke	K	96.3	0.93	0.058	0.093	0.052	0.058	0.018	0.041	4.445	
Sawdust Briquettes	TR	96.0	2.70	.337	0.004	0.028	0.359	0.114	0.076	0.971	
Emissions per MJ of heat output (heat input x efficiency)											
Fuel	Test	CO2	CO	CH_4	SO_2	NO_x	Ms[1]	Meo[2]	Men[3]	Ma[4]	
Zabrze Briquettes	PP	139.1	1.02	0.067	0.203	0.088	0.059	0.027	0.055	5.81	
Wujek Coal	PP	118.3	1.52	0.183	0.129	0.131	0.706	0.091	0.094	3.17	
Coke	K	131.8	1.27	0.079	0.128	0.079	0.079	0.025	0.056	6.08	
Sawdust Briquettes	TR	127.1	3.58	0.446	0.005	0.038	0.475	0.152	0.100	1.29	

[1]Ms = particulates captured in sampling train filter, nozzle, and probe
[2]Meo = organic material extracted from sampling train impingers
[3]Men = non-organic material extracted from sampling train impingers
[4]Ma = ash removed from stove
[5]All efficiency values in this report are based on the lower heating value and the customary European calculation method. Efficiencies based on customary U.S. calculation methods are about three percentage points lower.

2.2 DISCUSSION OF RESULTS

Efficiency

Table 2-5 summarizes selected results on efficiency, including the results with normal operating procedures, with "poor operating procedure" in which the doors were left open for an extra hour (the worst of the poor procedures), and the improved procedure. The data with normal and poor procedures can provide the upper and lower limits on the range of efficiency which should be applied to existing stoves in the city. Results with the improved procedure can be used as a measure of the highest efficiency which can be achieved in the stoves.

Table 2-5. Summary of Measured Efficiencies

Fuel	Test Procedure	Efficiency (%)[1]
Zabrze Briquettes	Normal (TZ)	56.9
	Door open for prolonged period (TP)	49.1
Wujek Coal	Normal (TZ)	68.5
	Door open for prolonged period (TP)	47.2
Bolesław Śmialy Coal	Normal	61.8
Przyjaźń Coke	Improved (K)	73.1
Zabrze Briquettes	Improved (PP)	73.6
Wujek Coal	Improved (PP)	75.1
Sawdust Briquettes	Improved (TR)	74.0

[1]All efficiency values in this report are based on the lower heating value and the customary European calculation method. Efficiencies based on customary U.S. calculation methods are about three percentage points lower.

The data presented indicate that the widespread belief that the efficiency of the ceramic tile stoves is poor are not correct. The efficiency varied between 47 - 68%, with the upper values indicating proper operational procedures, and the lower ones representing poor operational procedures with major faults. It may be assumed that an average efficiency for the population of stoves in the city is 55%, much higher than commonly believed. The strongest adverse effect on the efficiency is exerted by prolonged time of combustion i.e. closing the stove door too late; reduces efficiency to 47 - 49%. The impact of other faults in operating procedure, such as too much air (combustion with top and bottom doors fully open), and leaks after the stove is closed is much smaller. In tests simulating these faults, the efficiencies obtained fell in to the 53 -56% range. Introducing the improved operating procedures developed during this program would increase efficiency to about 73 - 75%.

Generally, if the correct operating procedure is used, which is somewhat fuel-specific, then all fuels can achieve about the same high level of efficiency. The duration of the combustion process, controlled by the time at which the doors are closed, is a decisive factor. Any extension of combustion time always entails a drop in efficiency. Figure 2-9 shows the relationship between measured efficiency and the duration of the combustion period; this includes each of the three operating procedures of Table 2-5.

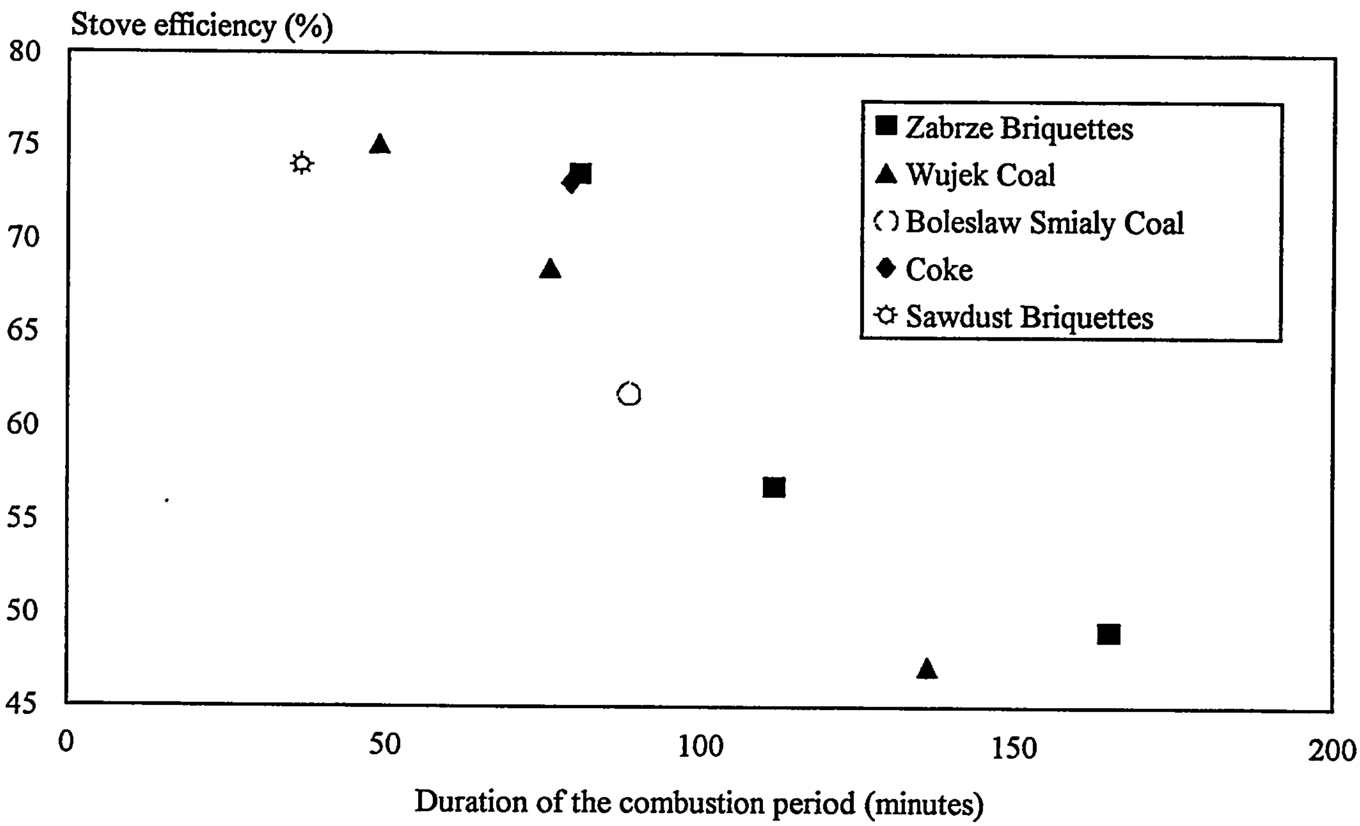


Figure 2-9. Relationship between efficiency of a stove over repeated cycles and the duration of the period of combustion

The temperature of the exhaust flue gas can be used to indicate the correct time for closing the doors and ending active combustion; the stove should be tightly closed when the temperature is at its maximum. The following optimum times of combustion were determined for various fuels:

- smokeless Zabrze briquettes - approx. 80 minutes
- coke - approx. 80 minutes
- Wujek coal - approx. 50 minutes
- sawdust briquettes - approx. 35 minutes

Generally, the higher the volatiles content, the shorter should be the time of combustion.

Pollutant Emissions

Pollutant emissions may be considered individually or together, using some criteria for weighing each pollutant. The discussion in this section covers both approaches. In this section, all values are presented as emissions per unit of heat input in fuel.

For the individual pollutants, the following general conclusions can be made:

CO:

The maximum CO emission rate of 2922 g/GJ occurs with the improper combustion of Zabrze briquettes. The minimum emissions of 752 g/GJ also occurs with these briquettes after adopting the improved operating procedure. In burning coals, the emissions were similar using different procedures and fall between 782 - 1140 g/GJ. The emissions from burning coke, 929 g/GJ, are similar to those with coal. Burning wood briquettes was a very significant source of CO emissions, at 2704 g/GJ.

Volatile Hydrocarbons (CH_4):

The maximum emissions, 337 g/GJ occur with wood briquettes. The lowest emissions, 50 g/GJ, are obtained with the Zabrze briquettes with the improved operating procedure. For Bolesław Śmiały coal burned with the normal operating procedure, the emissions are high, 136 g/GJ. Burning Wujek coal with the normal procedure produced emissions ranging from 57 - 137 g/GJ while Zabrze briquettes yielded emissions similar to those for coals; 88 - 124 g/GJ. The level of emissions from burning coke was not much higher than for Zabrze briquettes - 58 g/GJ.

SO_2:

The maximum emissions (228 g/GJ) occur when Bolesław Śmiały coal is burned with the normal operating procedure; emissions also are high from burning Wujek coal (163 - 176 g/GJ) with the normal procedures. Burning Zabrze briquettes with the normal procedure gives emissions between 97 to 121 g/GJ; using the improved operating procedure raises them to 149 g/GJ.

However, this may have reflected the slightly different composition of the second supply of briquettes with lower sulfur content. Burning coke from Przjaźń gave the lowest emissions, 93 g/GJ, among the coal-based fuels. Undoubtedly, wood briquettes, with negligible emissions are the best fuel with regard to SO_2.

NO_x:

The coals were found to have the highest emission factors for nitrogen oxides. The maximum value (per unit of heat input in fuel) was caused by burning Wujek coal, 219 g/GJ, with the general range for both coals being 98 - 219 g/GJ. Zabrze briquettes give emissions between 87 and 98 g/GJ with the normal operating procedure, and 65 g/GJ with the improved procedure. Emissions from burning coke were lower at 52 g/GJ. The best fuel is wood briquettes with emissions at only 28 g/GJ.

Particulate Emissions:

The highest particulate emissions occur in burning Wujek coal where the doors were left open for a prolonged period (Test "TP"), reaching 638 g/GJ. In general fuels with high volatiles content produced emissions exceeding by many times the figures for smokeless fuels. Nevertheless, it is interesting to note that emissions from the hard coals used in these tests (with volatiles contents between 30 and 32%), ranging between 530 - 638 g/GJ, are higher than those from wood briquettes, 359 g/GJ, having volatiles content (72.6%) almost twice as much as coals. The lowest emissions, 29 g/GJ, were obtained with Zabrze briquettes with values ranging 29 - 43 g/GJ range. Burning coke gives slightly higher emissions of 58 g/GJ.

Combined Measures of Emissions:

The results show that emissions of individual substances differ significantly (sometimes even by an order of magnitude) and the alterations obtained by using various procedures for firing the same fuel might show opposite tendencies. Improvements in operating procedures may suppress the emissions of some substances while increasing others. These effects may impede comparing fuels and the efficacy of procedures for their combustion. For assessing the effects of combining emissions, two different methods were used. The first is "Equivalent Emissions" defined as:

$$\mathbf{Ee = 2.9 \times Mg + 0.5(CO + CH_4) + 2.9 \times NO_x + SO_2} \qquad \mathbf{[g/GJ]}$$

Where:

CO, CH_4, SO_2, NO_x are the respective emissions of carbon monoxide, hydrocarbons, sulfur dioxide, and nitrogen oxides (calculated as NO_2) expressed in g/GJ of heat input in fuel.

Ms - particulate emissions expressed in g/GJ.

The criterion of equivalent emissions is based on so-called toxicity coefficients for individual substances taken from 1981/1983 guidelines of the Polish Ministry of Administration, Local Management and Environmental Protection.

The second method of combining pollutants is termed "Cost Criterion" and is defined as:

$$KK = [800 \times Mg + 400(CO + CO_4) + 1500(NO_x + SO_2) \times 10^{-3} \qquad [zł/GJ]$$

Where the parameters are the same as those defined above.

The Cost Criterion is in units of Zloties/GJ and it represents a sum of pollution emission fees, according to the Ordinance of the Council of Ministers of December 27, 1993. This is the fee boiler owners now must pay for their emissions. Where the Cost Criterion is included in tables in this report, it has been converted to $/MJ using a currency conversion rate of 22,000 Zl/$.

Table 2-6 lists values for Ee and KK calculated for various fuels and operating procedures (related to unit for energy input in fuels). Several conclusions can be drawn from these results. Certainly the low volatiles content fuels, the briquettes, and coke have the best environmental performance. With the briquettes, performance strongly depends upon operating procedure, and the improved operating procedure sharply reduced the combined emissions. With a higher volatiles-content fuel, such as the Wujek mine coal, emissions performance is much less dependent upon the operating procedure. Generally, fuels with the highest volatiles content produce the highest emissions during the initial, devolatilization stage of combustion, and changes in operating procedures which affect the later stages of combustion have little effect on overall emissions. However, with low volatile fuels the emission rates are more uniform over the entire combustion period, and changes made during the later stages of combustion can affect total emissions during the firing cycle.

Note: The Equivalent Emission calculation appears in several sections of this report. In Section 2, CH_4 is included in Ee and in other sections it is not. This is a result of these sections representing the work of completely different organizations. The contribution of CH_4 to Ee is, in all cases, very small and for practical purposes it can be ignored.

Table 2-6. Equivalent Emissions (Ee) and Cost Criterion (KK) for Different Fuels and Operation Procedures. Emissions per GJ of Energy Supplied in the Fuel.

Fuel	Test Code	Ee [g/GJ]	KK [$/MJ]	η [%]
Zabrze briquettes	TZ	1394	49.3	56.9
	TP	2028	70.2	49.1
	PP	863	30.7	73.6
Wujek Mine Coal	TZ	2799	62.1	68.5
	TZ	2850	60.2	47.2
	PP	2557	55.8	75.1
Bolesław Śmiały Mine Coal	TZ	2715	62.3	61.8
Przyjazn Coke	K	906	30.0	73.1
Sawdust Briquettes	TR	2647	70.5	74.0

Estimates of Performance for the Lowest-Quality Coal Available in Kraków

During this program, two kinds of coal from those available on the Kraków market were tested: Wujek coal which is considered to be the best-quality coal, and Bolesław Śmiały coal, at that time considered to be of the lowest quality available. The main shortcoming of the Bolesław Śmiały coal is its high ash content, reaching 21%. Recently, hard coal from Siersza mine has appeared in the Kraków fuel market and can now be considered the worst available to individual consumers. This coal has a high sulfur content and low heating value. The results of analysis of a sample of this fuel is given below:

lower heating value	Qi[kJ/kg]	23 918
volatiles	Vi[%]	32.33
total sulfur	S_t[%]	1.27

coal composition (elemental analysis) %

carbon	58.50
hydrogen	4.23
combustible sulfur	1.04
nitrogen	6.03
oxygen	5.46
moisture	12.42
ash	12.32

On the basis of the results for Wujek and Bolesław Śmiały coals, and taking into account differences in chemical composition, the emissions of pollutants were estimated for Siersza coal; this allows emission factors to be developed for the home stoves in Kraków. These emission factors, are used in evaluating the relative importance of different emission sources in the city, and also in comparing options. Table 2-7 shows the results expressed in units of heat input in fuel. Also, the expected values of equivalent emissions and cost criterion have been calculated.

The values of equivalent emissions for Wujek and Bolesław Śmiały coals ranged from 2,715 - 2,850 g/GJ. For Siersza coal, Ee is higher by 30-80%. The values of cost criterion for Wujek and Bolesław Śmiały coals range from 60.2 - 62.3 $/MJ; for Siersza coal, KK is higher by 80 to 120%.

Table 2-7. Estimated Emissions for Siersza Coal Fired in Kraków Home Stoves

Pollutant				**Range of emission rates:**		
		[g/kg]			**[g/GJ]**	
	from		**to**	**from**		**to**
CO	**20.0**		**32.0**	**836**		**1338**
CH_4	**1.8**		**3.9**	**75**		**163**
SO_2	**-**	**20.8**	**-**	**-**	**870**	**-**
NO_x	**4.1**		**6.9**	**171**		**288**
Ms	**14.5**		**20.0**	**606**		**836**
Ee [g/GJ] (Equivalent Emissions)				**3,578.8**		**4,880.1**
KK [$/MJ] (Cost Criterion)				**109.6**		**136.6**

Emission Levels and Stove Efficiency Suggested for Use Comparing Alternatives for Kraków

On the basis of sales figures of Kraków fuel marketers, it was estimated that high-quality coal (with characteristics similar to Wujek coal) represents 75% of the market, while about 25% is the lowest-quality coal (similar to Siersza class). A weighed average of the measured performance of the Wujek coal and the estimated performance of the Siersza coal then was adopted to arrive at a "model coal" for the city. Another assumption was that only some of users fired coal in their stoves correctly, (similar to the normal operational procedure), causing emissions similar to those obtained in tests with prolonged combustion time. Using these assumptions, weighted averages were calculated for efficiency and pollutant emission factors. These factors, shown in Table 2-8, are suggested as a basis for calculating total emissions from the stoves in Kraków. In other regions of Poland, these values may differ, depending on the local fuel mix.

Total Emissions from the Kraków Home Stoves

The global emissions from all stoves in Kraków were calculated using these average values for emissions, representing the current situation. The total number of stoves was assumed to be 100,000. Based upon an average heat loss calculated from a room heated with a ceramic stove, the annual fuel consumption was set equal to 850 kg of "model fuel" per stove. For comparison, pollution emissions also were calculated for cases of changing fuels or operating procedures. The results are shown in Table 2-9. Calculations were made for the following hypothetical cases:

- Wujek coal is used in all stoves with 55% efficiency.
- Zabrze smokeless briquettes are used in all stoves with 55% efficiency.
- "Model coal" is used in all stoves with the improved combustion procedure developed during this program, with 75% efficiency.
- Wujek coal is used in all stoves with the improved procedure and 74% efficiency.
- Zabrze smokeless briquettes are used in all stoves with the improved procedure and 74% efficiency.

Table 2-8. Averaged Values of Emission Factors Suggested for Use in Calculating Total Emissions in Kraków

Pollutant	Averaged Values of Emissions per unit of:		
	mass of fuel	heat input	heat output
	g/kg	g/GJ	g/GJ
CO	25.9	889.4	1,617.1
CH_4	2.6	88.6	161.1
SO_2	9.2	344.6	626.5
NO_x	5.5	189.0	343.6
Ms	18.0	618.6	1,124.7
Ee [g/GJ]	3,175.6		
KK [zł/GJ]	76.7		

The calculations indicate that a 72% reduction in equivalent emissions would be achieved by changing the fuel currently used to Zabrze smokeless briquettes or a similar improved fuel without changing the operating procedures. Equivalent emissions could be reduced by 26% if the present coal mix ("model fuel") is used but with improved operating procedure which will raise efficiency to 74%. A simultaneous change to briquettes and the improved operating procedure would reduce the equivalent emissions by as much as 79%.

Other Home Heating Devices Using Solid Fuel

So far, there is nothing available to replace the ceramic tile stoves. During this program, one other stove was tested which now is used in Poland to a very limited degree. This is a cast iron stove (ŻAR 1.2 "Bartek" type) which operates in a continuous, slow-burning mode. Generally, stoves of this type provide better, more uniform thermal comfort than a ceramic tile stove, but this comfort is achieved at the cost of almost doubled fuel consumption and with significantly higher emission of pollutants. Imported fireplaces also are appearing on the market with heating elements, closed or open, as well as small-size stoves using prepackaged coal charges, with controlled combustion process. Their availability is limited, and combined with a lack of any technical data, high prices and lack of experience in operating such devices, limits their market potential. They are not considered as serious alternatives to the present Polish tile-stoves.

Table 2-9. Hypothetical Calculations of the Total Emission from the Coal Stoves in Kraków

Fuel	Efficiency	Fuel Use [mt/year]	Pollutant Emissions [mt/year]					
			CO	CH_4	SO_2	NO_x	Ms	Ee
"Model Coal"	55	85,000	2,202	221	782	468	1,530	7,786
			100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Wujek Coal	55	88,800	2,857	344	243	247	1,328	6,412
			129.7%	155.5%	31.1%	52.8%	86.8%	82.3%
Smokeless Briquettes	55	90,800	1,885	124	374	163	1,081	2,164
			85.6%	56.3%	47.8%	34.8%	70.7%	27.8%
"Model Coal"	74	63,176	1,637	164	581	348	1,137	5,787
			74.3%	74.3%	74.3%	74.3%	74.3%	74.3%
Wujek Coal	74	66,000	2,123	256	181	184	987	4,766
			96.4%	115.6%	23.1%	39.3%	64.5%	61.2%
Smokeless Briquettes	74	67,486	1,400.	92.5	278	121	80.3	1,610.
			63.6%	41.9%	35.5%	25.8%	5.2%	20.7%

2.3. DESCRIPTION OF KRAKÓW BOILER POPULATION

In advance of the start of this program the Kraków Voivodship Department of Environmental Protection commissioned the Kraków Development Office (BRK) in 1990 to conduct an inventory of Kraków boiler houses. The inventory was done in the fourth quarter of 1990 and the first quarter of 1991.

During the inventory, the following data were collected:

- administrative data about boiler houses (address, owner, user)
- purpose of boiler house (size of apartment, commercial or industrial space heated, process heat provided)
- number of boilers, pollution control devices, emissions sources within boiler house
- technical data (type, rating, age, energy medium, degree of utilization, seasonality of use)
- type and amount of fuel used (annual figures)

- number of boilers, pollution control devices, emissions sources within boiler house
- technical data (type, rating, age, energy medium, degree of utilization, seasonality of use)
- type and amount of fuel used (annual figures)

In total, 1,344 boiler houses were registered, with total rating of 1,050.4 MW. This number includes:

- 1,133 solid fuel-fired boiler houses - total rated capacity of 963.5 MW
- 3 coal/natural gas boiler houses - total rated capacity of 1.1 MW
- 1 coke/natural gas-fired boiler house - total rated capacity 0.2 MW
- 202 natural gas-fired boiler houses - total rated capacity 76.7 MW
- 5 oil-fired boiler houses - total rating of 8.9 MW

These boiler houses can be grouped according to their ratings:

- up to 200 kW - 549 boiler houses (40.8%) with rating of 53.7 MW (5.1%)
- 200 - 500 kW - 413 boiler houses (30.7%) with rating of 131.1 MW (12.5%)
- 500 - 1,000 kW - 181 boiler houses (13.5%) with rating of 126.0 MW (12.0%)
- over 1,000 kW - 201 boiler houses (15.0%) with rating of 739.6 MW (70.4%)

These boiler houses have 2,920 boilers installed, including:

- 2,262 solid fuel-fired boilers (77.5%)
- 644 natural gas-fired boilers (22.0%)
- 14 oil-fired boilers (0.5%)

Solid fuel-fired boilers include:

- 229 stoker-fired boilers with mechanical grates
- 2,033 fixed grate boilers, including:
  1,118 coke-fired boilers
  685 coke/coal mix-fired boilers
  230 coal-fired boilers

A significant majority, i.e., (185 or 80.5%) of the boilers with mechanical grates, have air pollution control devices, mostly cyclones or multicyclones. Only 94 fixed-grate boilers (4.6%) have pollution control devices.

In Kraków, the most common among stoker-fired boilers are WCO, PCO and KCO (together 52% of all boilers), WLM and PLM type boilers (20%) and WR type boilers (9%).

Fixed-grate boilers are manufactured as either cast-iron or steel boilers. Among the cast-iron boilers designed to burn coke, ECA and KZ-5 types dominate. There are also KZ-3, Strebel and Camino types. Among steel boilers designed to burn coal the most common types are ES-KA Rumia, ES-ŻET, RSW and RSP. Where cyclone particulate collectors are used with hand-fired boilers these are generally with steel boilers, firing coal.

Stoker-fired boilers are designed to use hard coal fines (size 5 to 10 mm). In fixed grate cast-iron boilers the recommended fuel is coke, and for steel boilers, the larger-size classes such as cobble and pea-size coal. Monitoring of the coal market in Kraków shows substantial changes which have occurred in recent years. In the eighties there was a deficit of fuels in Poland. There were some problems with purchasing fuels. Particularly dramatic was the shortage of coke. All this led to administrative attempts to regulate the market, e.g., by limiting quotas for coke purchase and directing low-sulfur coal to be sold in some areas under particular threat of air pollution, such as the Kraków region. On the other hand, there was a widespread practice of burning fuels with much worse properties than the specification fuel for a given type of boiler. For instance, in cast-iron boilers there was a coal/coke mix used instead of coke. This led to troubles in operation, lower combustion efficiency and increased pollutant emissions as well as a shorter operational life of operation of the boilers.

At the beginning of the nineties, as a result of economic reform, the availability of fuels gradually increased, as well as their quality. The phenomenon of using substitute fuels such as the coke/coal mix in cast iron boilers disappeared. These mixtures are still used in steel boilers which cannot burn coke alone. Now fuels of required quality are commonly available. Increasingly, coal mines are offering to supply washed and graded coal.

2.4 TESTING OF FIXED-GRATE BOILERS

2.4.1 Description of the Boilers Tested

Two of the most commonly used types of fixed-grate boilers were chosen for testing:

- cast-iron boilers ECA-IV installed in a boiler room at 28 Rydla Street
- steel boilers ES-ŻET installed in a boiler room at an army facility on Ułanów Street

ECA IV Boiler

The ECA IV boiler is a sectional, cast-iron boiler with a horizontal grate, hand fired from the front or top. These boilers have slag wool (silicate cotton) insulation and a steel-sheet jacket. The boiler is adapted to burn coke with grain size of 25-125 mm. These boilers are used in water- and steam-heating systems. Assembling segments allows application of boilers of variable

Table 2-10. Technical Parameters of the Tested ECA IV Boilers

BOILER TYPE	UNIT	ECA IV	ECA IV	ECA IV
MANUFACTURER'S NUMBER	-	01025	01024	35783
HEATED SURFACE	[m^2]	44	44	47
THERMAL OUTPUT	[kW]	409	409	437
MAXIMUM PRESSURE	[MPa]	0.5	0.5	0.7
MAXIMUM TEMPERATURE	[°C]	100	100	100
YEAR OF MANUFACTURE	-	1992	1992	1976
REQUIRED STACK DRAFT	Pa	60	60	60

These are natural draft boilers, and the flow of combustion air into the furnace is regulated by two doors on the boiler's front face. A lower door allows air to feed under the fuel grate; this is the primary supply. The position of this door is regulated manually or automatically to control firing rate and the boiler's output. The second air opening is smaller and is located above the combustion zone; this introduces air into the region of hot combustion products, reducing emissions of unburned gases. In normal practice, this door is kept closed.

All three boilers exhaust flue gas into a common breaching ("settling") chamber and steel chimney - diameter = 0.9 m, height approx. 30 m ECA boilers are manufactured by Dolnośląskie Zakłady Metalurgiczne, Nowa Sól.

ES - ŻET Boiler

The ES-ŻET is a steel, fire-tube boiler (Table 2-11). It is assembled as a detached unit, set on a brick base. The grate is made of cast iron, is flat, and is not cooled. The furnace has a back ridge in form of a water-cooled threshold marking the back extent of the furnace. The boiler's jacket is thermally insulated. The boilers are designed to use coal of 16 -125 mm grain size. These boilers are used for steam- and water-heating systems, and come in sizes ranging from 6 to 65 m^2 of heated surface with 41 to 530 kW output. These are natural draft boilers, and the combustion air inlets are similar to those of the ECA-IV boiler. Flue gases pass twice through fire tubes and then go via a smoke-box and a metal smoke conduit to a chimney. These boilers have a single brick chimney, with a cross section of 0.5 x 0.6 m, and a height - 7 m.

Table 2-11. Technical Parameters of the Tested ES-ŻET Boilers

BOILER TYPE	STEEL WATER-BOILER
IDENTIFICATION	ES - ŻET
HEATED SURFACE OF THE BOILER	15 m^2
GRATE	FLAT
FUEL FEED	MANUAL

2.4.2 Normal Operational Procedure of Fixed-Grate Boilers

The normal operational procedure consists in starting-up the boiler and then spreading the required quantity of fuel on the grate surface. After this portion of fuel burns, the fire is not dumped, but again, the furnace is filled with fuel. The combustion rate and the boiler's output is regulated by operating the lower air-shutter in the furnace's front face, so controlling the entry of primary air. Combustion is evaluated by an operator, guided by observing the color of the flame in the furnace.

The only equipment for control and measurement on the boiler are thermometers and pressure gauges on the boiler's inlet and outlet. There are no devices for operation. Operators adjust the boiler's output to achieve a desired water temperature at the outlet based on outdoor temperature.

2.4.3 Testing Objective, Fuels Used, Testing Program

Because of the breaching arrangements at both of the boiler houses, the boiler's could not be tested individually but, rather, as a boiler system. During the testing program, boilerhouse load, which essentially is determined by outdoor temperature, was nearly constant. The load on individual boilers was varied by changing the number operating. With three boilers at the Rydla site, for example, this gave three possible levels for the average load on each boiler: high (one boiler operating to meet boiler house load), medium (two operating), and low (three operating).

The aim of testing was to determine the boiler system efficiency and particulate and gaseous emissions depending on:

- kind of fuel burnt,
- manner of combustion,
- thermal load, and
- quantity of air supplied during combustion.

Testing Program at Rydla Street Boiler House

Three kinds of fuel were tested:

- fuel normally used i.e. coke from Sendzimir Steelworks cokery,
- coke/coal, 1:1 mixture; coal from Ziemowit coal mine, and
- smokeless briquettes manufactured by Institute for the Chemical Processing of Coal in Zabrze.

The fuel's properties are given in Table 2-12.

The entire set of tests was completed for coke, which is the fuel normally used in cast iron boilers. For each of the three loads, the following operating procedures were tested:

- procedure normally applied,
- with introduction of secondary air, and
- with fuel fed in layers and secondary air introduced.

Feeding fuel in layers consisted of limiting the quantity of fuel fed at any time.
The remaining two fuels (coke/coal mixture and briquettes) were tested at medium load and under two operating procedures - normal, and with regulation of secondary air. In total, 13 tests were completed, each consisting of 1 to 3 charges of fuel.

Testing Program at Ułanów Street Boiler House

Three kinds of fuel were tested:

- fuel normally used i.e. coal from Halemba coal mine in Katowice,
- coke/coal, 7:3 mixture; coal from Ziemowit coal mine, and
- smokeless briquettes manufactured by Institute for the Chemical Processing of Coal in Zabrze.

Table 2-12. Quality Data for Fuels used in Testing of ECA-IV Boilers

Serial number	Fuel quality parameter	General designation acc. to G-04510[1]	Units	Coke	Mix of coke/coal 50%/50%	Briquettes
I. General properties						
1.	Total moisture content	w_t^r	%	3.13	10.20	3.34
2.	Unbound moisture content	w_{ex}^r	%	2.43	6.50	0.64
3.	Moisture content in test sample	w^a	%	0.7	3.70	2.70
4.	Ash content	A_r	%	11.10	8.42	11.20
5.	Volatile content	V^r	%	2.0	18.10	8.80
6.	High calorific value for air-dry sample	Q_s^r	J/g	28,299	27,836	28,186
7.	Heating value of fuel as-fired	Q_i^r	J/g	27,490	25,224	27,498
II. Chemical compounds						
8.	Total carbon	C_t^a	%	81.20	75.90	79.90
9.	Total hydrogen	H_t^a	%	0.21	2.58	1.95
10.	Total nitrogen	N^a	%	0.89	1.02	1.43
11.	Oxygen content	O^a	%	5.10	7.60	2.30
12.	Total sulfur content	S_t^r	%	0.91	1.02	0.55
13.	Combustible sulfur content	S_c^r	%	0.82	0.76	0.52

[1]These symbols refer to Polish standard nomenclature.

The properties of the fuels are given in Table 2-13.

Each fuel underwent the same set of tests. Two levels of load were tested, represented by operating one or two boilers, and maintaining a constant load on the boiler system. For each of the two loads, the following operating procedures were tested:

- procedure normally applied,
- fuel fed in layers and secondary air introduced.

Twelve tests were completed, each consisting of 2 full charges of fuel.

Table 2-13. Quality Data for Fuels used in Testing of ES-ŻET Boilers

Serial number	Fuel quality parameter	General designation acc. to G-04510[1]	Units	Coke	Mix of coke/coal 70%/30%	Briquettes
			I. General properties			
1.	Total moisture content	w_t^r	%	2.20	3.32	4.40
2.	Unbound moisture content	w_{ex}^r	%	0.50	2.04	2.30
3.	Moisture content in test sample	w^a	%	1.70	1.28	2.10
4.	Ash content	A_r	%	9.20	9.62	13.10
5.	Volatile content	V^r	%	31.50	10.36	10.00
6.	High calorific value for air-dry sample	Q_s^r	J/g	30,255	28,830	28,018
7.	Heating value of fuel as-fired	Q_i^r	J/g	28,993	27,803	26,787
			II. Chemical compounds			
8.	Total carbon	C_t^a	%	76.00	82.72	76.50
9.	Total hydrogen	H_t^a	%	4.84	1.64	2.20
10.	Total nitrogen	N^a	%	1.46	1.01	1.07
11.	Oxygen content	O^a	%	6.00	3.09	4.76
12.	Total sulfur content	S_t^r	%	0.93	0.72	0.62
13.	Combustible sulfur content	S_c^r	%	0.80	0.61	0.27

[1] These symbols refer to Polish standard nomenclature.

Test Plan

The tests of the boilers was compiled with current Polish regulations, particularly BN86/1317-02 standard "Heating boilers. Thermal testing." Following these procedures, efficiency was measured by a direct input-output method. Energy input was determined by measuring the mass of fuel and ash and their properties. Energy output was measured using calibrated water-flow nozzles. The particulate emissions were measured according to the EPA-5 method of the U.S. Environmental Protection Agency. Semivolatile organics were extracted from the icebath impingers of the EPA-5 train. The physical and chemical analyses of the fuel and slag were completed in accordance with relevant Polish standards.

Throughout the program, the testing team undertook the following tasks:

- monitoring the course of combustion,
- measuring the thermal parameters of the boilers,
- measuring particulate and gaseous emissions,
- measuring the composition of flue gases,
- measuring the quantities of fuel, slag, and ash, and
- collecting samples of fuel, slag and ash for laboratory analyses.

The measurement of energy parameters i.e. temperatures, pressures, humidities were recorded by a multi-channel datalogger. The flue gas was analyzed continuously using a portable electrochemical cell type analyzer. and covered measurements of CO, SO_2, NO_x, O_2, "combustible gases", and the temperature of gases at the point where the samples were collected. Volatile hydrocarbons in the flue gas (reported as CH_4 equivalent) were measured using an FID type analyzer. Physical and chemical analyses of fuels and slags were completed in a laboratory.

Test Results

Characterization of the Combustion Process in Fixed-Grate Boilers

With hand-fired boilers, emissions of flue gas vary greatly with time. Emissions always are highest immediately following additions of fresh fuel as it is being devolatilized. The magnitude of these emissions depends upon the volatiles content of the fuel. Figure 2-10 shows examples of such changes. The graphs were made for test run No. 10 in the Rydla Street boiler house, with a coke/coal mixture as fuel, without secondary air regulation. The fluctuations of temperature result from continuous regulation by operators, adjusting the temperature of system water leaving the boiler to the test standards.

For comparison, the graphs in Figure 2-11 shows the changes of the parameters measured for the Ulanów Street boiler house. Test No. 2 included fuel fed in thinner layers, with precisely measured portions of fuel added after the preceding charge had burnt out.

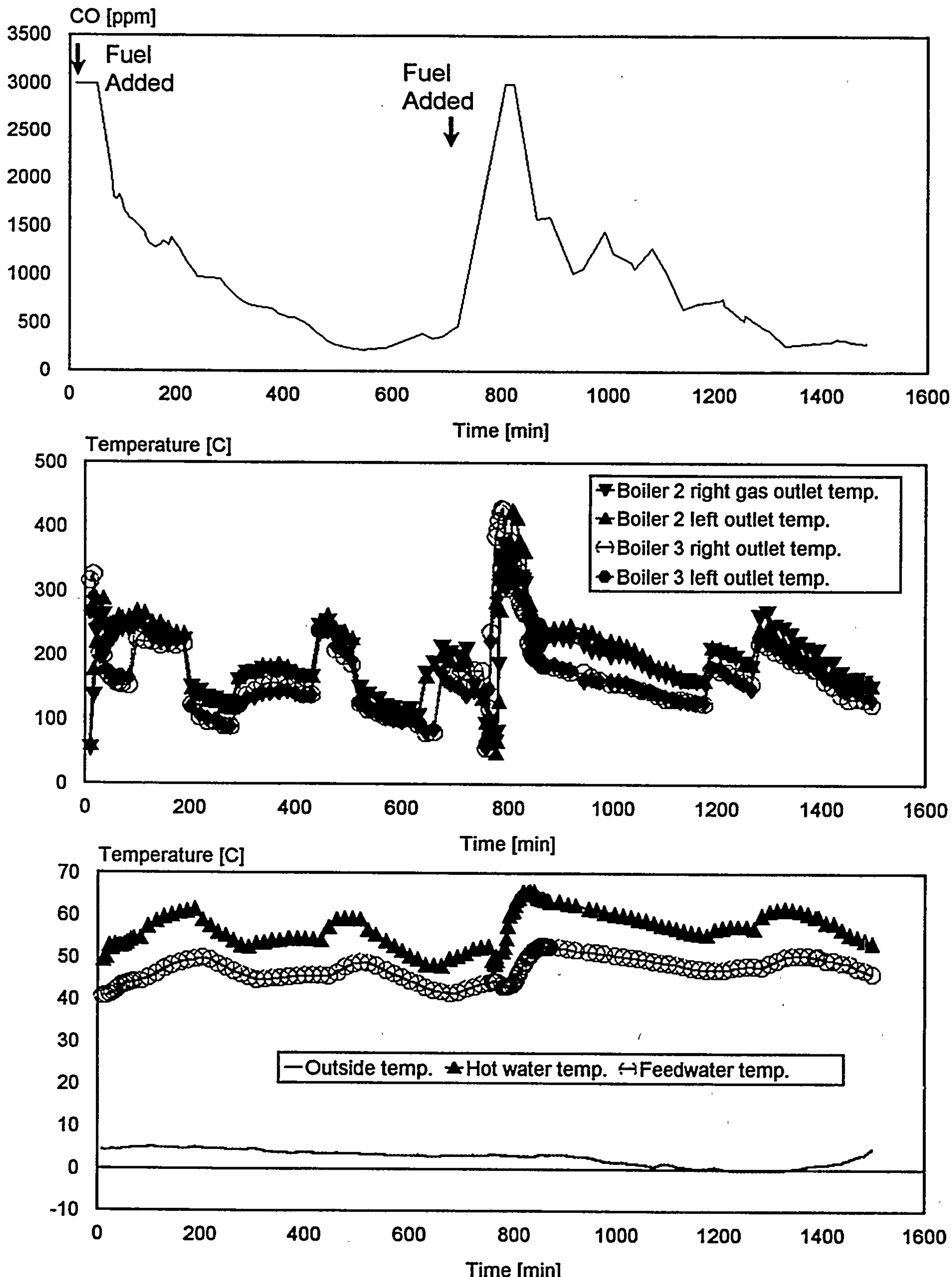


Figure 2-10. Example test results , hand-fired boiler at Rydla Street. CO emissions, boiler outlet gas temperature, outside temperature, and water temperature.

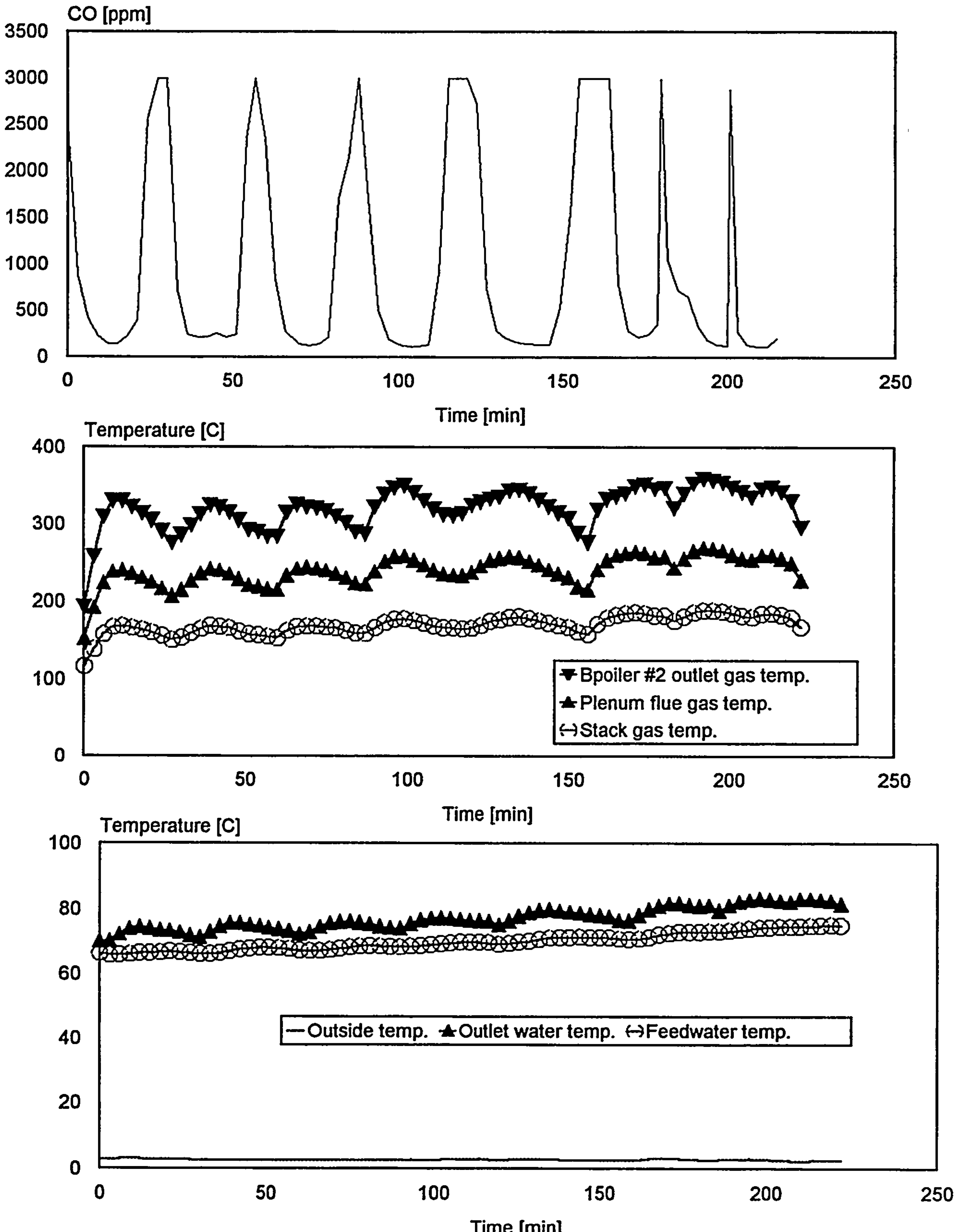


Figure 2-11. Example test results , hand-fired boiler at Ulanow Street with coal fed in small batches (layer feeding). CO emissions, boiler outlet gas temperature, outside temperature, and water temperature.

Results of Testing of ECA IV Boilers

Table 2-14 gives the results of testing ECA IV boilers at the Rydla Street boiler house, related to the amount of energy in the fuel. Efficiency was determined for the boiler system, and not for individual boilers. The highest efficiency of 73% was achieved at the medium load, i.e. with two boilers operated, using coke.

Applying secondary air, particularly at the beginning of the cycle, significantly improved combustion efficiency resulting from the complete combustion of CO and CH_4. Tests in which the fuel was fed in thinner layers were generally disappointing; particulate emissions related to the amount of energy supplied in the fuel increased significantly with the load. The emissions also rose with an increase in overfire air provided for combustion, giving high values when fuel was burnt in layers.

In all tests, the level of particulate emissions was significantly lower than the limit for this type of boiler, which is 720 g/GJ. The lowest emissions occurred when coke was burnt, regardless of the procedure applied. With all fuels introducing overfire air increased particulate emissions.

In all the tests (except briquettes), emissions of SO_2 were very high and exceeded the permissible standard i.e. 410 g/GJ; this reflected the high content of combustible sulfur in the fuel. The lowest SO_2 emissions were obtained in burning briquettes, slightly higher in burning coke/coal mixture, and the highest emissions were from coke. The SO_2 emissions are proportional to concentration of combustible sulfur in the fuel, and are practically independent of the combustion procedure.

The average CO emissions with all fuels were very high, particularly in measurements taken in runs without overfire air. At the beginning of the cycle, immediately after charge of fuel was placed in the furnace, the concentrations of CO, even though diluted in the chimney, were so high that they exceeded the scope of measurement of the instrument. Under normal operating procedures, CO concentrations are the lowest for coke, and the highest for briquettes.

The average NO_x emissions were high and fluctuated within the limit value of 35 g/GJ, in some cases exceeding it. The lowest emissions were obtained when coke was burnt in layers.

The average emissions of hydrocarbons, calculated as CH_4 were low for coke and briquettes, not exceeding 34 g/GJ; an increase was observed with an increased load on one boiler. Emissions of CH_4 were definitely the highest when burning the coke/coal mixture; they dropped significantly when secondary air was regulated.

Table 2-14. Results of Tests for ECA-IV Boilers at Rydla Street Boiler House

KIND OF FUEL AND MANNER OF PERFORMING TESTS	BOILER HOUSE EFFICIENCY [%]			PARTICULATE EMISSIONS [g/GJ]			CO EMISSIONS [g/GJ]			NO_x EMISSIONS [g/GJ]			SO_2 EMISSIONS [g/GJ]			CH_4 EMISSIONS [g/GJ]			ORGANICS EMISSION [g/GJ]			INORGANICS EMISSION [g/GJ]		
	LOAD			LOAD			LOAD			LOAD			LOAD			LOAD			LOAD			LOAD		
	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H
COKE α	67	72	66	68	55	80	3167	2546	2452	39	52	47	425	437	442	18	20	32	1.10	2.18	2.89	25.92	24.10	32.5
COKE β	72	73	71	49	75	149	1766	1684	1491	39	50	42	443	448	453	16	20	29	1.01	8.07	3.99	21.60	28.25	68.4
COKE γ	65	67	69	107	102	241	1736	1536	1436	29	36	32	444	446	448	14	20	29	1.53	6.42	5.57	43.43	35.08	71.4
COKE/COAL α		71			214			2950			47			413			248			44			67	
COKE/COAL β		66			456			1636			42			431			84			89			86	
BRIQUETTES α		65			150			3738			41			287			136			10			24	
BRIQUETTES β		69			636			1573			39			288			34			16			34	

Loads: L - Low α means a measurement under normal combustion procedure

A - Average β means a measurement with secondary air regulation

H - High γ means a measurement with fuel fed in layers

The emissions of organic substances increased generally with the amount of overfire air. They were at the lowest level in cases of low loads on a single boiler. Similarly, for all fuels the emissions of inorganics increased with loads, but remained at the lowest level when minimum amounts of overfire air were provided to combustion process.

The emissions of organics and inorganics were the lowest for the coke/coal mixture.

Test Results for ES-Źet Boilers

Table 2-15 shows the results obtained in testing the ES-Źet boilers at Ułanów Street related to the amount of energy provided in the fuel.

Because of testing arrangements, the efficiency of the boiler system was determined and not that of single boilers. The highest efficiencies were obtained in burning briquettes, the lowest in runs with coal fuel. Operating procedures did not affect the efficiency much. Although the particulate emissions were highest for coal fuel, they did not exceed the limit value of 1850 g/GJ; they were significantly lower in case of the coke/coal mix, and particularly low for briquettes. The SO_2 emissions did not exceed the limit value of 990 g/GJ; briquettes had the lowest emissions.

CO emissions were high throughout the testing. The highest levels were for the coke/coal mix, and the lowest ones for briquettes burnt in layers. NO_x emissions increased with both the heating value of the fuel, and the temperature of combustion. The level was high for all fuels, and as a rule exceeded the limit of 35 g/GJ.

The hydrocarbon emissions, calculated as CH_4, clearly were the largest when coal was burnt in two boilers. CH_4 concentrations depend strongly on the amount of overfire air provided for combustion, regulated by the operator to ensure the proper temperature of the water leaving the boiler.

The highest emissions of organics were noted in test runs including 2 boilers, and for the coke/coal mixture in single-boiler operations.

As for hydrocarbon emissions, they depend strongly on the overfire air; hence, a rather wide range of results was obtained.

On average, the highest inorganic emissions were found in runs burning coal, lower emissions were associated with the coke/coal mixture, while burning briquettes gave the lowest values

Discussion of Test Results for Fixed-Grate Boilers

Operating procedures and fuels used were compared using criteria jointly describing the emissions of different fuels, i.e. a "criterion of equivalent emission" E_e, and a "cost criterion"

Table 2-15. Results of Testing for ES-ŻET Boilers at Ułanów Street Boiler House

KIND OF FUEL AND MANNER OF PERFORMING TESTS	BOILER HOUSE EFFICIENCY [%]		PARTICULATE EMISSIONS [g/GJ]		CO EMISSIONS [g/GJ]		NO_x EMISSIONS [g/GJ]		SO_2 EMISSIONS [g/GJ]		CH_4 EMISSIONS [g/GJ]		ORGANICS EMISSIONS [g/GJ]		INORGANICS EMISSION [g/GJ]	
	BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]		BOILERS OPERATED [NUMBER]	
	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler	2 boilers	1 boiler
COAL α	60	53	650	706	1804	1278	76	85	195	295	141	43	86	25	77	28
COAL γ	59	56	874	927	1527	1202	78	95	272	391	142	23	40	36	133	35
BRIQUETTES α	71	67	69	282	1553	1459	37	20	95	136	71	89	10	25	17	29
BRIQUETTES γ	69	67	118	355	983	823	44	22	133	137	17	37	26	18	47	32
MIXTURE α	65	63	242	469	2097	2115	61	50	197	268	31	100	36	68	63	80
MIXTURE γ	62	61	112	233	2033	1154	64	24	188	240	24	23	25	41	18	49

α means a measurement under normal combustion procedure
γ means a measurement with fuel fed in layers

Table 2-16. The Values of Equivalent Emissions and Cost Criterion for ECA IV and ES-ŻET Boilers

BOILER	FUEL		EFFICIENCY [%]	EQUIVALENT EMISSION [g/GJ]	COST CRITERION [PLZ/GJ]
Eca-IV	COKE	α	72	2 030	1 804
	COKE	β	73	1 662	1 849
	COKE/COAL 1:1	α	71	2 769	2 140
	BRIQUETTES	β	69	3 049	1 640
Es-Żet	COAL	α	60	3 272	1 704
	COKE/COAL 7:4	α	65	2 110	1 387
	BRIQUETTES	α	71	1 214	903

α means a measurement under normal combustion conditions
β means a measurement with secondary air regulation

KK. Both criteria were described in detail in Section 2.1, Table 2-16 shows the values of both criteria related to the amount of energy provided in fuel for a medium load.

The results indicate that coke is the best fuel for cast-iron boilers of ECA IV type. Emissions can be significantly reduced by regulation of the input of overfire (secondary) air, particularly at the beginning of fire cycle.

Burning fuel in layers did not yield good results, neither in terms of efficiency nor emissions of pollutants.

One disadvantage of coke fuel is its high content of sulfur that causes high SO_2 emissions. Among the remaining fuels, briquettes could be a better option provided that special operational procedures are developed.

For ES-ŻET boilers, briquettes certainly are the best fuel showing the highest efficiencies with lowest emissions of particulates and gaseous pollutants. Comparing the two procedures, spreading fuel in layers give slightly inferior efficiencies, and, in case of coal, also increased the level of particulates and gaseous pollutants.

2.5 STOKER-FIRED BOILER TESTING

2.5.1 Description of the Boilers Tested

Two types of stoker-fired boilers were selected for testing:

- No. 2 WR 10-011 water boiler at the Balicka boiler house
- No. 3 PLM 2.5-1 steam boiler at the Krzesławice boiler house.

Both boilers are the La Mont type and have a very similar design. For many years, water boilers have been manufactured in Poland under designations WLM 1.25, WLM 2.5, and WLM 5 (numbers indicate the rated capacity in Gcal/h), and steam boilers are designated as PLM 1.25, and PLM 2.5. After minor alterations in design, these were replaced by the WR-series (water boilers with ratings of 1.25, 2.5, 5, and 10 Gcal/h) and CR-series (steam boilers with ratings of 1.25 and 2.5 Gcal/h).

La Mont type boilers are stoker-fired, water-tube, forced circulation boilers. Smaller boilers are designed as single-pass, and larger ones (with rated capacities of 5 and 10 Gcal/h) as two-pass boilers. The main components of the boiler are the heating system, mechanical grate, supporting structure with boiler casing, exhaust system for flue gases and a drum with steam boilers. The heating system consists of coils inside the boiler that are welded to the inlet part of the lower collector chamber (water boilers) or to the drum (steam boilers). The inlets to the coils have jets to ensure a balanced distribution of water. The heating system is attached to the supporting steel structure, standing on the concrete foundation of the boiler. Coal is fed to the boiler from the top by a bucket conveyor. The height of the coal bed on the grate is maintained by a coal gate. A scale-type (single or double) grate is powered by an electric motor. The speed of the grate is controlled by a four-speed (WR 10-011) or two-speed (PLM-2.5-1) mechanical gearbox. Under the grate, in the lower part of the structure, there are two steel-plate ash-pit chutes: at the front, for removal of material falling down through the grate, and at the back, removing slag falling off the end of the grate. The inside of the boiler is lined with chamotte bricks, and outside with regular bricks. The furnace chamber is additionally protected by thermal insulation and steel sheets. Air to the boiler is not pre-heated; primary air is fed under the grate by a forced-draft fan.

Behind the boiler there is a battery of six cyclones and an induced draft fan. Additionally, the WR 10-011 boiler has an overfire air fan blowing secondary air to the combustion chamber above the grate. Overfire air fans commonly are used with boilers of this type to promote mixing and complete combustion of volatile fuel components generated from the coal bed. Primary air is fed through the grate in zones and its distribution among the zones can be adjusted by manual dampers. These dampers match the distribution of air along the grate with the demand for air of the burning fuel bed. This type of adjustment is done very infrequently.

Table 2-17 gives the technical specifications of the boilers in the testing program.

Table 2-17. Technical Specifications of the WR 10-011 and PLM 2.5-1 Boilers

Item	WR 10-011	PLM 2.5-1
Year of manufacture	1972	1955
Year of the last overhaul		1991
Nameplate parameters:		
Rating	10 Gcal/h (11.63 MW)	2.5 Gcal/h (2.9 MW)
Steam rating		4.2 t/h
Supply water temperature	70°C	80°C
Heated water temperature	150°C	-
Heating surface	740 m²	-
Calculated efficiency at nominal rated capacity	78%	75%
Fuel:	coal duf	coal duf
Heating value	18,436 kJ/kg	18,436 kJ/kg
Auxiliary equipment:		
Forced-draft fan	WPPS-60/1.4A	WPPO-40 A+k (2)
Overfire air fan	CM-25	-
Indiced-draft fan	WPWDS-70	WWO ax-63
Particulate control device	battery of 6 cyclones	battery of 6 cyclones

2.5.2 Normal Stoker-Fired Boiler Operating Procedure

Coal duf from the Ziemowit coal mine was used in the normal operating procedure. Under this procedure, the operators have only a very limited scope for regulating the boiler. The heat load on the boiler is regulated by the thickness of the fuel bed maintained by the coal gate. The speed of the mechanical grate is constant, adjusted to the kind of fuel fired. The overfire air fans at the Balicka boiler house normally are not used, and the chimney draught normally is not regulated; these boilers are operated with extremely high levels of excess air. This is particularly true at low loads as air dampers often are set for high loads and then not adjusted as load is decreased. All firing controls are manual, and generally, flue gas analyzers (for determining excess air) are not available at the sites.

2.5.3 Testing Objectives, Fuels Used, Study Program

The objectives of the testing program were to establish the baseline peformance of these boilers and to determine how their efficiency and the emission of particulates and gases change depending on the type of fuel fired, the heat load on the boiler, and excess air.

WR 10-011 BOILER TESTING PROGRAM AT THE BALICKA BOILER HOUSE

The WR 10-011 boiler selected for testing is installed in the Balicka boiler house at 4 Lindego Street, Kraków. This boiler house was built in 1968-72, and has three WR 10 boilers and two WLM 2.5 boilers supplying heat to the residential buildings of the Widok housing development, and two PLM 2.5 steam boilers supplying process steam to nearby industries. The total rated capacity of the boilers is 46.5 MW (40 Gcal/h). The condition of the boilers was moderately good.

Testing included the following fuels:

- coal duf (fine coal 0 to 20 mm) from the Ziemowit coal mine, this is the fuel which has been normally used at all MPEC, stoker-fired boiler houses,
- coal duf from the Staszic coal mine (hereafter referred to as Staszic I),
- washed coal duf from the Staszic coal mine (referred to as Staszic II)

Table 2-18 gives the grain-size distribution of these fuels for both the WR boiler at the Balicka boiler house and the PLM boiler at the Krzesławice boiler house, while the quality data are given in Table 2-19.

PLM 2.5-1 BOILER TESTING PROGRAM AT THE KRZESŁAWICE BOILER HOUSE

The PLM 2.5-1 tested is installed in the Krzesławice boiler house at 20 Makuszyńskiego Street, Kraków. The boiler house was built in 1957. It has 4 PLM 2.5-1 boilers with a total rated capacity of 11.6 MW (10 Gcal/h). In 1992, an additional ERM-8 type boiler was installed, with a 5.5 MW rated capacity. The boiler house supplies process steam for nearby industries. The technical state of the boiler tested was estimated as poor.

Testing included the following fuels:

- coal duf (0 to 20 mm size) from the Ziemowit coal mine (the fuel normally used)
- coal duf from the Staszic coal mine (hereafter referred to as Staszic I),
- washed and graded coal duf from the Staszic coal mine (hereafter referred to as Staszic III)
- semi-coke supplied by PROCHEM-ZACH Ltd., Chorzów (hereafter referred to as Semi-coke I)
- coal duf from the Powstańców Śląskich coal mine, washed and graded to obtain special granulation (henceforth referred to as Pea-size)
- semi-coke supplied by PROCHEM-ZACH with modified granulation composition (hereafter referred to as semi-coke II)

The grain-size distribution of the fuels tested is given in Table 2-18, while the quality data are given in Table 2-19.

For the first four fuels (Ziemowit, Staszic I, Staszic II, Semi-coke I) an attempt was made to optimize the procedure by the best selection of the heat load on the boiler and excess air.

Grate speed was not changed during the test but held at the speed considered to be optimal; the heat load was controlled only by changing the thickness of the fuel bed on the grate. Preliminary studies were performed to determine, for a given load, the range of variability of excess air practically achievable, to draw regulation curves, and to find rough settings for the control devices to obtain three different values of the λ (excess air) coefficient: minimum, moderate, and maximum.

For each fuel, tests were performed for three loads: 100%, 75% and 50% of attainable load, and for each of these loads, three values of excess air were tested: minimum, moderate, and maximum. Thus, nine tests were done for each fuel, totalling 36 tests, for the four fuels.

Additional tests were made on pea-size coal. From the experience gathered during previous tests, an optimum value of the excess air was determined and only three tests were performed: for 100%, 75%, and 50% loads. For semi-coke II, only one test was completed. The results were very poor and further testing was discontinued, the most obvious problem was the very poor efficiency of carbon utilization.

Table 2-18. Size Distribution of the Coals Tested

Grain size [mm]	Ziemowit [%]	Staszic I [%]	Staszic II [%]	Staszic III [%]	Semi-coke I [%]	Pea-size [%]	Semi-coke II [%]
>25	0.00	0.00	0.00	0.60	0.00	10.50	0.50
25-15	15.65	10.46	4.34	5.38	0.50	57.30	3.90
15-12	11.18	7.19	4.13	6.10	2.40	22.10	7.90
12-7.5	16.06	13.72	9.50	14.44	3.50	6.50	11.60
7.5-5	11.99	14.38	14.05	17.40	9.60	3.00	13.00
5-3	7.11	8.50	11.98	11.01	12.40	0.60	14.80
3-2	7.52	9.59	11.98	12.62	12.70	-	14.20
2-1	12.80	13.94	20.04	16.20	15.20	-	19.40
1-0.75	5.89	6.53	7.02	5.53	21.30	-	5.70
0.75-0.385	5.08	7.41	6.40	4.96	15.00	-	5.00
<0.385	6.71	8.28	10.56	5.76	7.40	-	4.00

Table 2-19. Analysis of the Fuels Used

Fuel property	Symbol[1] (G-04510)	Units	Ziemowit	Staszic I	Staszic II	Staszic III	Semi-coke	Pea-size	Semi-coke II
I. General properties									
Total moisture	w_t^r	%	17.39	17.44	13.76	7.58	12.39	10.90	17.60
Free moisture	w_{ex}^r	%	12.56	14.45	10.38	3.97	10.89	6.60	10.10
Moisture content in analytic sample	w^a	%	4.83	2.99	3.38	3.61	1.50	4.30	7.50
Ash content	A^r	%	22.91	23.10	9.32	6.05	7.75	4.60	12.60
Volatile components	V^r	%	27.21	26.91	31.92	30.89	0.80	33.70	5.70
Combustion heat	Q_s^r	J/g	20,104	22,957	27,424	27,830	27,450	29,982	25,703
Calorific value	Q_i^r	J/g	19,014	21.918	26,217	26,840	24,931	28,823	25,212
II. Chemical components									
Total carbon	C_t^a	%	53.12	61.33	72.03	72.70	85.92	75.10	76.40
Total hydrogen	H_t^a	%	3.46	3.66	4.57	4.60	0.27	4.80	1.40
Total nitrogen	N^a	%	0.44	0.93	0.95	0.94	0.89	1.27	0.89
Total oxygen	O^a	%	14.45	7.52	9.44	11.50	2.94	9.57	1.03
Total sulfur	S_t^r	%	1.50	0.73	0.59	0.72	0.73	0.52	0.58
Combustible sulfur	S_c^r	%	0.79	0.47	0.31	0.30	0.48	0.36	0.18

1 - These symbols refer to Polish standard nomenclature.

Ziemowit coal was tested only under the procedure normally applied by operators. The remaining two fuels, with better quality parameters, were treated as potential substitutes whose introduction could bring economic benefits and reduce the emissions of pollutants.
For these fuels, an attempt was made to optimize the procedure by the best selection of the following parameters:

- heat load on the boiler
- speed of the grate
- distribution of excess air
- overfire air

The following testing program was completed:

- preliminary studies

Ziemowit Coal / 2nd grate speed (11.2 meters/hour - the normal grate speed with this fuel)

Heat load	100%	75%	50%
Primary air	100%	100%	100%
Secondary air	0%	0%	0%

- principal studies

Staszic I Coal/ 2nd grate speed (11.2 meters/hour)

Heat load	100%		75%		50%	
Primary air	100%	50%	100%	50%	100%	50%
Secondary air	0%	-	0%	0%	0%	0%

Staszic I/1st grate speed (8.0 meters/hour)

Heat load	100%			75%			50%		
Primary air	100%	75%	50%	100%	75%	50%	100%	75%	50%
Secondary air	100%	-	-	100%	100%	100%	100%	100%	100%
	0%	-	-	0%	0%	0%	0%	0%	0%

Staszic II / 1st speed (8.0 meters/hour)

Heat load	100%			75%			50%		
Primary air	100%	75%	50%	100%	75%	50%	100%	75%	50%
Secondary air	100%	-	-	100%	100%	100%	100%	100%	100%
	0%	-	0%	0%	0%	0%	0%	0%	0%

METHODOLOGY OF TESTING

The methodology of the tests was similar to that for testing fixed-grate boilers, as described in detail in section 2.4.2. However, efficiency was measured using a heat loss method as opposed to a direct input-output method. Procedures were used that had been defined by the U.S. Amercian Society of Mechanical Engineers for determination of the efficiency of large steam boilers.

2.5.4 Test Results for Stoker-Fired Boilers

COMBUSTION CHARACTERISTICS IN STOKER-FIRED BOILERS

Unlike the hand-fired boilers, the stokers operate with steady conditions. The combustion process stabilizes within 3-4 hours from the time of a change in operating conditions.

The fuel, moving slowly with the grate, goes through subsequent stages of combustion:

- drying and warming of the fuel
- releasing volatile components ((CH_4, C_2H_4, CO i H_2)
- coke burning ($C+O_2+CO_2$)
- oxygen reduction ($CO_2+C=2CO$)
- burning out of the coal residues from the slag.

In the first phase, water evaporates by using heat absorbed from the furnace. In the second phase, the fuel is degassed. During the third phase, the parts of the fuel which are difficult to ignite burn, as well as degassed duf. In the next phase, there is reduction of oxygen with significant absorption of heat. Owing to availability of the secondary air, the gases produced during oxygen reduction (CO and H_2) burn again to produce CO_2 and H_2O, releasing heat in the space above the furnace. In the last phase, the slag burns out.

The distribution of combustion zones is different for each type of fuel and each phase requires a different quantity of air. The solution applied to solve this problem is called zonal air distribution, under which air is supplied by channels under the grate to each combustion zone in amounts most suitable for the particular stage.

The course of combustion could be controlled via:

- changes in quantities of primary air provided (if the design of the boiler allows zonal distribution)
- controlling draft
- changing the quantity of overfire air supplied (if it is provided at all)

The heat load could be regulated by feeding appropriate quantities of fuel by:

- changing the speed of grate
- changing the thickness of the fuel bed on the grate.

TESTING RESULTS FOR THE WR 10-011 BOILER AT THE BALICKA BOILER HOUSE

Table 2-20, 2-21, and 2-22 show the results of tests of the WR 10-011 boiler. Table 2-20 covers the results obtained for coal duf from the Ziemowit coal mine which was treated as the reference level for evaluating of all other fuels. Environmental performance was assessed on the basis of the amounts of particulate and gaseous pollutants, taking into account their harmfulness to the environment (related to the amount of energy in the fuel).

Table 2-21 presents the results obtained in firing run-of-mine coal duf Staszic I using the first grate speed (~7.4 meters/h). It can be seen that boiler efficiency increases with load. The same relationship occurs with respect to SO_2 emissions; its maximum value – 341 g/GJ – amounts to 34% of the maximum limit of 990 g/GJ, while the average for all Staszic I tests is 310 g/GJ, i.e., 31% of the limit. NO_x emissions are practically stable, although high. The average value of 144 g/GJ amounts to 90% of the limit value of 160 g/GJ. The maximum NO_x emission was 185 g/GJ, exceeding the limit by 16%. Particulate emissions decrease with increased thermal load on the boiler. The maximum particulate emissions of 129 g/GJ amount to 16% of the limit of 800 g/GJ, while the average for all tests (79 g/GJ) is 10% of the limiting value. CO emissions decrease with the thermal load. Neither regulating combustion air nor switching on the overfire air fan practically affected the boiler's operation. For Staszic I fuel, the best results were obtained with the maximum load, the first speed of the grate (~7.4 meters/h), and full opening of the combustion-air damper without switching on the secondary air fan.

Table 2-22 gives the results of testing Staszic II washed coal duf with the first grate speed. Here again, there was an increase of efficiency with increased heat load. SO_2 emissions are markedly lower than in the case of Staszic I fuel; the average value of 150 g/GJ amounts to 15% of the limit. NO_x is high; the average value of 182 g/GJ exceeds the limit value by 14%. Only under the maximum load are the NO_x emissions kept within the limit. Particulate emissions are higher than in the case of Staszic I fuel. The average value of 342 g/GJ amounts to 43% of the limit value. As in the case of Staszic I fuel, there was no effect on the boiler's operation of regulating the primary and secondary air. The best results were obtained with the maximum load and the first speed of the grate, with full opening of combustion air damper without switching on the overfire air fan.

Among the fuels tested, the best one is Staszic II - washed coal duf. Staszic I fuel is slightly worse, while Ziemowit coal duf is the most environmentally unsound fuel.

Table 2-20. Test Results for WR 10-011 Boiler - Ziemowit Fuel With 100% Primary Air and No Overfire Air

Test No.		39	40	41
Heat load		100%	75%	50%
η	%	74.0	63.0	51.1
E_p	g/GJ	131	328	775
E_{CO}	g/GJ	100	260	581
E_{NOx}	g/GJ	145	146	213
E_{SO_2}	g/GJ	463	586	620
E_{org}	g/GJ	0.68	1.96	0.54
KK	zł PLN/GJ	777	1080	1556
kk	zł PLN/GJMW	103	184	486

TESTING RESULTS OF PLM - 2.5-1 AT KRZESŁAWICE BOILER HOUSE

Tables 2-23 - 2-27 show the test results for the PLM 2.5-1 boiler. The procedures and conditions at this boiler house allowed operation with a wide range of excess air levels for three boiler loads. A comparison of the results allowed a choice of the best operation procedures for each particular fuel.

Table 2-23 presents the results obtained in firing Ziemowit coal duf. The highest efficiency was obtained under the maximum load (100%) and a medium level of excess air. Under loads of 75% and 50% and medium and minimum excess air, efficiencies were similar. The lowest emissions of particulate and gas pollutants were obtained with the lowest excess air, but with a high loss of efficiency from incomplete combustion (above 20%). The best operating procedure for 100% and 75% loads is combustion with a medium level of excess air, and for a 50% load, combustion with minimum excess air.

Table 2-24 shows the results for Staszic I run-of-mine coal duf. For 50% and 100% loads, the highest efficiencies were obtained with minimum levels of excess air during combustion,

Table 2-21. Test Results for WR 10-011 Boiler - Staszic I Fuel

Test No.	23	24	25	27	28	29	30	31	32	33	34	35	36	37	38
Load	100%			75%						50%					
Primary air	100 %	100 %	50%	100 %	100 %	75%	75%	50%	50%	100%	100 %	75 %	75%	50%	50%
Overfire air	0	100 %	0	0	100 %	0	100%	0	100 %	0	100 %	0	100%	0	100 %
η %	75.2	74.8	75.1	72.6	71.7	70.6	72.5	70.9	73.7	65.5	67.0	65.5	62.7	66.6	64.8
E_p g/GJ	107	121	199	123	158	267	216	227	460	190	200	362	1433	214	854
E_{CO} g/GJ	53	79	56	108	105	109	105	87	94	264	253	225	254	233	192
E_{NO_x} g/GJ	160	161	155	170	174	178	176	170	176	206	203	202	199	198	209
E_{SO_2} g/GJ	180	180	180	152	180	148	92	106	144	147	141	137	175	160	126
E_{org} g/GJ	1.34	2.29	0.95	2.62	2.48	1.40	0.90	1.38	1.07	2.60	0.21	4.65	1.49	1.45	3.12
KK zł PLN/GJ	454	471	505	406	516	552	456	466	658	582	574	658	13.47	592	938
kk zł PLN/GJMW	51	51	57	64	73	78	64	65	90	114	117	134	269	117	185

Table 2-22. Test Results for WR 10-011 Boiler - Staszic II Fuel

Test No.	8	14	10	17	18	13	12	19	11	20	21	22
Load	100%			75%						50%		
Primary air	100%	100%	50%	100%	100%	75%	75%	50%	50%	100%	100%	50%
Overfire air	0	100%	0	0	100%	0	100%	0	100%	0	100%	0
η %	73.7	73.1	72.8	72.7	72.7	70.7	72.4	69.6	73.5	62.4	59.4	61.6
E_p g/GJ	12	84	80	111	129	44	68	17	86	124	128	69
E_{CO} g/GJ	52	55	42	116	89	69	45	85	35	162	285	228
E_{NO_x} g/GJ	173	128	175	145	115	119	185	103	184	138	134	130
E_{SO_2} g/GJ	337	340	335	340	340	340	340	340	340	214	194	245
E_{org} g/GJ	0.79	0.35	1.81	1.09	1.27	1.01	0.60	1.62	1.53	4.31	0.29	0.74
KK PLN zł/GJ	584	582	622	635	605	552	632	523	638	510	523	522
kk PLN zł/GJMW	64	68	69	108	100	90	106	85	107	139	142	143

while under 75% load, a higher efficiency was obtained with the medium level of excess air because of losses from unburned coal in the slag. With the maximum amount of excess air used in normal operation, efficiency even may drop by 11%. The emissions of particulate and gas pollutants usually were lowest at minimum excess air. Operating with minimum levels of excess air was the best procedure under loads of 100% and 50%, and with a medium level of excess air under a 75% load.

Table 2-25 gives the results obtained in firing Staszic III washed and graded coal duf. For the three loads studied, the highest efficiency was obtained with minimum excess air. Efficiency increased with an increase in load and dropped with an increase in excess air Throughout the range of loads, the efficiency obtained with Staszic III fuel was higher than the other fuels.

Operating the boiler under 50% load and minimum excess air was found to be the best operating procedure. Under 100% load a medium level of excess air was considered to be the best [illegible]

. Results of PLM 2.5-1 boiler testing - "STASZIC I" fuel

Unit	Test data								
	10	11	12	13	14	15	16	17	18
[m/h]	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
[cm]	9	9	9	8	8	8	6.5	6.5	6.5
	min.	av.	max.	min.	av.	max.	min.	av.	max.
m/mm]	27/25	27/25	27/25	25/22	25/22	28/27	20/20	22/22	24/22
[cm]	60	60	60	45	60	60	30	60	45
	2.55	3.55	3.73	3.86	4.46	5.00	4.10	5.12	5.24
[%]	70.0	66.7	63.3	60.7	61.3	53.9	62.0	53.0	51.0
MW]	2.2	2.0	2.0	1.2	1.3	1.2	0.9	0.9	1.0
MW]	3.1	3.1	3.1	2.2	2.2	2.2	1.8	1.8	1.8
[t/h]	0.43	0.43	0.43	0.30	0.30	0.30	0.25	0.25	0.25
g/GJ]	138	245	676	407	444	488	187	239	369
g/GJ]	1.5	7.0	3.2	4.6	0.6	5.7	1.9	5.7	4.1
g/GJ]	10.5	27.2	7.3	22.4	25.0	12.9	11.1	14.1	13.6
g/GJ]	60	76	135	137	126	70	83	97	114
g/GJ]	1.6	5.3	3.9	1.5	4.0	4.3	5.5	4.9	5.0
g/GJ]	7.7	11.2	9.1	16.8	83.6	11.6	7.8	18.3	10.7
[%]	56.7	69.2	80.0	66.2	71.5	85.7	55.7	59.6	69.2
g/GJ]	183	194	207	439	373	339	427	384	373
g/GJ]	300	305	320	276	275	261	210	220	230
g/GJ]	90	127	115	131	138	179	133	117	118

Table 2-25. Results of PLM 2.5-1 boiler testing - "STASZIC III" fuel

Item	Unit	Test data								
Measurement number		28	29	30	31	32	33	34	35	36
Grate speed	[m/h]	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Fuel bed on grate	[cm]	9	9	9	8	8	8	6.5	6.5	6.5
Setting of forced draft fan		min.	av.	max.	min.	av.	max.	min.	av.	max.
Setting of blowing fans R/L	[mm/mm]	21/20	25/25	30/20	21/15	26/20	35/30	16/16	23/23	30/30
Damper position in the flue conduit	[cm]	37.5	45	60	30	45	60	30	45	60
ENERGY PARAMETERS										
Excess air coefficient		2.02	2.37	2.71	2.08	2.96	3.74	3.81	5.00	5.13
Boiler efficiency	[%]	73.9	66.2	60.9	73.3	63.9	61.6	68.4	58.1	57.5
Boiler capacity	[MW]	2.4	2.4	2.1	1.9	1.8	1.8	1.4	1.2	1.2
Heat input in fuel	[MW]	3.5	3.5	3.5	2.7	2.7	2.7	2.1	2.1	2.1
Fuel mass consumption	[t/h]	0.47	0.47	0.47	0.36	0.36	0.36	0.28	0.28	0.28
PARTICULATE EMISSIONS										
Flue conduit of the boiler										
Particulates	[g/GJ]	706	495	418	144	333	575	198	550	486
Organic parts	[g/GJ]	11.2	1.7	10.7	7.7	6.2	7.0	14.1	17.0	6.7
Inorganic parts emission	[g/GJ]	13.1	12.7	15.4	10.1	20.9	17.2	8.3	13.2	39.0
Flue ducts after particulate control devices										
Particulates	[g/GJ]	215	50	144	57	80	148	52	135	201
Organic parts	[g/GJ]	7.0	1.9	9.7	1.1	5.2	4.1	6.2	7.5	7.5
Inorganic parts	[g/GJ]	4.6	4.9	8.3	13.3	15.8	12.8	21.0	15.2	13.9
Cyclone efficiency	[%]	69.5	90.0	65.6	60.6	75.8	74.2	73.7	75.5	58.6
GASEOUS EMISSIONS										
CO	[g/GJ]	913	673	591	642	1,339	428	280	385	393
SO_2	[g/GJ]	171	176	191	160	176	179	170	185	181
NO_x	[g/GJ]	141	155	156	125	166	169	161	183	192

Table 2-26. Results of PLM 2.5-1 boiler testing - "Semi-coke I" fuel

Item	Unit	Test data								
Measurement number		19	20	21	22	23	24	25	26	27
Grate speed	[m/h]	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Fuel bed on grate	[cm]	12	12	12	10.5	10.5	10.5	9.5	9.5	9.5
Setting of forced draught fan		min.	av.	max.	min.	av.	max.	min.	av.	max.
Setting of forced draft fan ilet dampers R/L	[mm/mm]	60/42	52/42	52/42	55/39	55/39	65/44	52/38	55/35	52/36
Damper position in the flue conduit	[cm]	60	45	60	60	45	30	30	45	45
ENERGY PARAMETERS										
Excess air coefficient		4.24	4.01	4.15	3.92	5.18	3.85	5.18	5.93	6.27
Boiler efficiency	[%]	40.3	41.0	42.6	47.2	36.2	48.4	39.5	34.3	30.9
Boiler capacity	[MW]	1.2	1.3	0.8	0.8	0.7	0.7	0.5	0.4	0.4
Heat input in fuel	[MW]	3.2	3.2	3.2	1.7	1.7	1.7	1.2	1.2	1.2
Fuel mass consumption	[t/h]	0.46	0.46	0.46	0.25	0.25	0.25	0.18	0.18	0.18
PARTICULATE EMISSIONS										
Flue conduit of the boiler										
Particulates	[g/GJ]	6,164	3,502	6,564	2,552	5,853	4,986	4,593	3,942	5,889
Organic parts	[g/GJ]	5.8	4.2	17.6	4.4	6.2	6.2	3.5	6.0	3.7
Inorganic parts	[g/GJ]	58.0	37.5	66.9	55.5	51.8	50.5	42.0	73.9	42.6
Flue ducts after particulate control devices										
Particulates	[g/GJ]	573	395	401	274	474	342	346	364	489
Organic parts	[g/GJ]	3.8	3.6	11.8	1.4	4.1	4.9	3.1	1.7	1.1
Inorganic parts	[g/GJ]	140.4	39.3	40.7	32.1	40.7	37.6	46.9	35.2	46.8
Cyclone efficiency	[%]	90.7	88.7	93.9	89.3	91.9	93.2	92.5	90.8	91.7
GASEOUS EMISSIONS										
CO	[g/GJ]	1,510	1,074	1,730	1,583	1,685	1,427	1,821	1,592	1,954
SO_2	[g/GJ]	240	226	177	236	180	128	181	167	126
NO_x	[g/GJ]	127	122	110	110	101	126	101	123	120

Table 2-27. Results of PLM 2.5-1 boiler testing - Pea-size and Semi-coke fuels.

Item	Unit	Test data			
Measurement number		1	2	3	4
Grate speed	[m/h]	5.1	5.25	5.2	3.56
Fuel bed on grate	[cm]	8.1	7.2	5.5	7.7
Setting of forced draft fan		av.	min.	min	max.
Setting of forced draft fan inlet dampers R/L	[mm/mm]	30/27	22/25	18/18	max.
Damper position in the flue conduit	[cm]	33.5	35	35	56
ENERGY PARAMETERS					
Excess air coefficient		2.04	2.32	3.37	7.11
Boiler efficiency	[%]	65.8	62.1	58.3	26.1
Load (output)	[MW]	2.4	1.7	1.0	0.3
Heat input in fuel	[MW]	3.7	2.8	1.7	1.2
Fuel mass consumption	[t/h]	0.50	0.37	0.25	0.19
PARTICULATE EMISSIONS					
Flue conduit of the boiler					
Particulates	[g/GJ]	304	100	106	4,140
Organic parts	[g/GJ]	3.9	3.5	3.9	7.7
Inorganic parts	[g/GJ]	5.8	6.3	6.0	29.2
Flue ducts after particulate control devices					
Particulates	[g/GJ]	95.3	42.8	84.5	1,717.6
Organic parts	[g/GJ]	3.7	3.9	4.3	38.9
Inorganic parts	[g/GJ]	4	4	5	141
Cyclone efficiency	[%]	71	62	36	79
GASEOUS EMISSIONS					
CO	[g/GJ]	701	234	359	1,010
SO_2	[g/GJ]	211	213	228	125
NO_x	[g/GJ]	113	114	116	85

2.6 DISCUSSION OF THE BOILER TESTING RESULTS

2.6.1 COMPARISON OF THE RESULTS FOR THE TESTED BOILERS

Table 2-28 provides a comparison of the performance of all boilers tested during this program and all fuels tested in each boiler at one representative load - 75% of maximum. In addition to efficiency and emissions of individual pollutants combined measures of pollutants defined earlier (see Section 2.2) - Equivalent Emissions and Cost Criterion - have also been included. Generally, measured efficiencies are low, and vary considerably with fuel type. The lowest levels of emissions, based on the combined measure used here, are lowest for the larger, stoker-fired boiler particularly where improved fuels are used.

2.6.2 PARTICULATE CONTROLS USED IN THE TESTED BOILERS

The stoker-fired boilers, WR-10 and PLM 2.5 boilers are equipped with standard flue gas cleaning installations such as batteries of cyclones. The hand-fired boilers tested, Eca-IV and the steel boilers from Ułanów street are only equipped with low-efficiency settling chambers. This is also the most common manufacturer's standard for this type of boiler. None of the boilers tested have monitors for flue gas compositon or pollutant emission rates.

For all of the boilers tested the current particulate emissions are far below both the current standards and the standards which will become effective in 1998. At the Krzesławice boiler house, where particulate measurements were made both before and after the cyclones, the emission standards were met even before the dust collectors.

The test results at Krzesławice allow evaluation of effects of operating conditions on particulate emissions. It is generally known that such dust collectors differ in efficiency, depending on the following factors:

- amount of particulate emissions from the burner (entrainment)
- size distribution and density of the particulates (cyclones have a low efficiency for dusts with small sizes and low density)
- velocity of the flue gases flow

For the PLM-2.5 boiler dust collectors the efficiency varies from 57 to 97%. The highest efficiencies were reached for cases of high entrainment of fly ash from the furnace. With lower inlet particulate loading and lower gas velocities the efficiency of the cyclones decreased, but the total particulate emissions after the cyclones was also lower.

The high sensitivity to operating parameters is a disadvantage for cyclones generally. They should operate with a broad range of gas flows depending on the load. The authors expected better results for cyclone efficiency, exceeding 70% under all conditions.

Table 2-28. Summary Comparison of Performance of all Boilers Tested at 75% of Full Load

Boiler house	Type of boiler	Fuel	Boiler efficiency	Particulate emissions	CO emissions	NO_x emissions	SO_x emissions	CH_4 emissions	Equivalent emissions	Emissions fees Cost criterion	Relative energy production cost compared to PLM-2.5 on ZIEMOWIT coal
Unit			[%]	[g/GJ]	[g/GJ]	[g/GJ]	[g/GJ]	[g/GJ]	[g/GJ]	[zl/GJ]	%
Balicka	WR-10	Ziemowit standard procedure	63.0	328	260	146	586	0	2090.6	2324	87
	WR-10	Staszic I	72.7	129	89	115	340	0	1092.1	1130	79
	WR-10	Staszic II	72.6	107	53	160	180	0	980.8	850	85
Baseline	PLM-2.5	Ziemowit standard procedure	53.3	111	1065	186	667	0	2060.8	3366	100
Krzeslawice	PLM-2.5	Ziemowit improved procedure	55.4	131	385	128	608	0	1551.6	2460	97
	PLM-2.5	Staszic I	61.3	126	373	138	275	0	1227.1	1418	90
	PLM-2.5	Staszic III	73.3	57	642	125	160	0	1008.8	996	85
	PLM-2.5	Pea size	62.1	43	234	114	212	0	784.3	994	97
ul. Rydla	Eca-IV	coke, standard procedure	72.0	55	2546	52	437	20	2030.3	2505	125
	Eca-IV	coke, improved procedure	73.0	75	1684	50	448	20	1662.5	2039	123
	Eca-IV	coal/coke 1:1	71.0	214	2950	47	413	248	2768.9	3015	119
	Eca-IV	briquettes	69.0	636	1573	39	288	34	3049.0	2380	152
ul. Ulanów	Es-Żet	coal	60.0	650	1804	76	195	141	3272.9	2841	110
	Es-Żet	coke/coal 7:3 standard	65.0	242	2097	61	197	31	2139.7	2203	131
	Es-Żet	briquettes	71.0	69	1553	37	95	71	1214.4	1272	158

The WR-10 boiler dust collectors operate with a very strong induced draft fan which could not be controlled during the test program because the fan inlet dampers were inoperable. The primary result of this during the test program was high overall excess air even with a strong throttling of the dampers controlling air under the boiler grate. This resulted in relatively high gas flow through the cyclones over the whole load range - a condition which would be expected to be favorable for particulate collection . This situation, however, leads to very high excess air levels and excessive particulate carry over from the furnace at low loads. A possibility of controlling the draught fan output must be introduced, to allow reduction of the excess air coefficient according to the boiler load. This throttling should be controlled manually or automatically depending on:

- load
- operation of the forced draft fans
- general appearance of the burning fuel bed grate (apparent carbon conversion)
- analysis of the flue-gases

Attention should also be focused on the way the particulates are collected from the cyclone hoppers. In PLM-2.5 boilers it often happens that careless maintenance causes spilling of dust beneath hoppers creating an additional and rather burdensome source of local emissions.

2.6.3 IMPROVEMENT OF THE OPERATING PROCEDURES

The WR 10-011 boiler

For the normally used fuel - Ziemowit coal duf - and for standard operating procedure used, the following efficiencies were measure during the test program:

- 51.1% at minimum load
- 63.0% at average load
- 74.0% at maximum load

For this fuel the influence of the load is the most obvious factor and the difference between maximum and minimum efficiencies is almost 23 points. The primary reason for the dramatic decrease in efficiency with decreasing load is the lack of air control, leading to extreme excess air levels at the reduced loads. Under normal procedures at this site at the time of the test program no attempts were made to reduce air flow with load.

For the Staszic I coal attempts were made to optimize the grate speed. For both Staszic I and Staszic II fuels attempts were also made to control combustion air flow during the test program. Under normal operation of the boiler, using Ziemowit fuel, the second grate speed (11 m/hr) is used. For Staszic I and Staszic II fuels, having a higher calorific value, the first grate speed (7.4 m/hr) was found to produce a better combustion pattern along the grate. This was based on visual observation of the condition of ash falling from the end of the grate into the bottom ash hopper and the results of preliminary performance tests. The lowest load is an exception.

The second speed was found to produce a more even distribution of temperature along the grate under this load with the Staszic mine coal. Optimizing the grate speed for a particular fuel and load was found to give an increase in efficiency by 7%, even without air flow control.

Attempts to control primary and overfire air flows did not lead to the expected results during the Balicka test program. The value of the excess air was high in all cases and varied depending on the heat load of the boiler from 130% excess air on average for maximum loads to 360% on average for minimum loads. According to published data the value of excess air should be 40 to 60%. The high excess air, of course, results in high energy losses in the stack gas and low boiler efficiency. The inability to reduce excess air to acceptable levels was probably caused by an excessive draft in relation to the capacity of the forced draft fan. Certainly the draft must be controlled to enable excess air to be reduced to acceptable levels. This could be accomplished by returning the induced draft fan inlet dampers to operating condition and/or installing variable speed induced draft fan drives. Automatic controls would certainly be very useful in maintaining proper draft and excess air levels.

Taking under consideration the technical condition of the WR-10-011 boiler, the efficiencies attained with the Staszic coals at the Balicka boiler house are presented in Table 2-29. This table serves to provide some measure of the efficiency improvement which can be obtained by optimizing operations. With improved draft controls it is expected that still higher efficiencies would be achievable.

Table 2-29. Results of the WR 10-011 boiler testing
Attainable boiler efficiencies

Fuel	STASZIC I			STASZIC II		
Load	min.	aver.	max.	min.	aver.	max.
Minimum efficiency %	59.4	69.2	67.4	62.7	70.09	74.8
Maximum efficiency %	72.6**	73.5*	73.2	67	73.7***	75.2
Difference [points]	13.2	4.3	5.8	4.3	2.8	0.4

* excess of the permissible NO_x emissions

** lack of particulate measurements because of the probe damage - second grate speed (see measurement No. 6)

*** three and half times the standard particulate emissions

PLM 2.5-1 boiler

At this boiler house tests were not done on the effects of grate speed. The optimum velocity for the given fuel was selected during the preliminary analyses.

During the test program at Krzesławice great effort was put into adjusting excess air. Varying excess air required simultaneous adjustment of three parameters:

- position of the forced draft fan inlet damper blades,
- position of dampers in the flue gas duct at the boiler exit,
- position of the induced draft fan inlet damper.

The control process is time consuming and burdening and above all requires a flue gas analyzer. While gas anaysis equipment was available to the test group it is not normally available to operators. For this reason the highest efficiency levels achieved during this test program exceed those which would be normally realized. Table 2-30 shows the minimum and maximum efficiencies for tested fuels and loads. It can be assumed that because of the control difficulties in normal operation, the achieved values are closer to the indicated minima. The potential increase in efficiency thus amounts to several- up to a dozen percentage points.

Table 2-30. Results of the PLM 2.5-1 boiler testing
Attainable boiler efficiencies

Fuel	ZIEMOWIT			STASZIC I			StASZIC III		
Load %	min.	av.	max.	min.	av.	max.	min.	av.	max.
Minimum efficiency %	52.1	53.3	54.9	51	53.9	63.3	57.5	61.6	60.9
Maximum efficiency %	54.1	55.4	69.1	62	61.3	70.0	68.4	73.3	73.9
Difference [points]	2.0	2.1	14.2	11	7.4	6.7	10.5	11.7	13.0

Hand-Fired Boilers ECA IV and ES-ŻET
Because of the limited scope of control in this type of boilers the analyses have been restricted to the checking if the fuel layer charge and air quantity control would improve the energy and environmental indices.

For ECA IV, cast iron boilers it has been proven that the most efficient procedure is bulk feeding of the boiler with overfire air ports open, especially at the initial stage of the combustion process. This allows after-burn of CO and CH_4 emitted from the fuel bed, reduce the emissions of particulate and CO together with a few points increase in efficiency. Layer combustion (feeding coal in smaller batches) using the overfire air does not lead to good results both in terms of efficiency and emissions.

In ES-ŻET steel boilers, for all the fuels, the most efficient procedure is combustion without any interference.

In terms of particulate emissions, the normal operating procedures are the best. The situation is reverse with respect to CO and CH_4 emissions, which decrease with the introduction of secondary (overfire) air.

Summarizing this discussion of the influence of operating procedures the following conclusion can be made:

- the optimum operation procedure for a given fuel in terms of efficiency was also the best for environmental reasons
- the optimum operating condition varied for individual boilers. To determine them accurately, especially in boilers with mechanical grate is not possible without the use of a flue gas analyzer and visual inspection of the combustion chamber
- for boilers with a fixed grate, the operating procedure is less important, providing a required amount of air at the beginning of the combustion process allowed to lower CO and CH_4 emissions by approx. 35% increasing in the same time the particulate emissions
- the use of the installed capacity is low. The rule should be to operate the lowest possible number of boilers at a maximum load. Boilers should be refurbished to allow a continuous operation under maximum load. The heat demand analysis will be able to provide information about the number of boilers that are to be refurbished.

2.6.4 EFFECTS OF FUEL TYPE

To compare emissions from different fuel, Equivalent Emissions and Cost Criterion, defined in Section 2.2, have been used. Emissions at an average boiler load have been compared, assuming that the technical state of the boilers does not allow maximum loads during normal operation, and it was also determined that operation at minimum load is not cost-effective. Relevant data are presented in Table 2-28

For the WR 10-011 boiler the best fuel is "Staszic II". With this fuel only the NO_x emissions are higher than for other fuels. The Equivalent Emissions and the Cost Criterion are almost 50% lower than for the normally used Ziemowit fuel. For the PLM 2.5-1 boiler the best fuels in terms of the environmental factors is the pea-size graded coal. However, because of lower boiler efficiencies found during the test program with this fuel, it is recommended to use the Staszic III fuel which is only slightly worse. Increasing the scope of control of the boiler should allow to decrease the dominating CO emission, linked with the use of this fuel. The Equivalent Emission and the Cost Criterion are more than 60% lower for Staszic III fuel than for the baseline Ziemowit coal.

For the ECA IV (hand-fired, cast iron) boiler the best fuel is coke burned according to the improved operating procedure developed during the test program. The smokeless briquettes are promising fuel, under the condition that a proper operating procedure is applied to limit the particulate emissions.

For the ES-ŻET (hand-fired, steel) boiler, smokeless briquettes are the best fuel under all the conditions.

2.6.5 Economic effectiveness of the proposed solutions for reducing the emission and improve the combustion efficiency

Some simple economic comparisons can be useful for making preliminary assessments about the cost impacts that fuel switching for environmental purposes might have on boiler house owners and operators. At any boilerhouse, some of the annual costs, such as capital recovery, operator salaries, maintenance, and utilities, will be independent of the fuel. Others, such as fuel purchase cost, fuel transportation, ash disposal, and costs due to environmental fees, will be strongly dependent on fuel type. Only fuel dependent costs have been included in this comparison. Annual fuel consumption and annual fuel cost will, of course depend on annual boilerhouse output and installed capancity of all boilers. For the purpose of making simple economic comparisons these have been assumed here as 43,000 GJ for Balicka, 20,400 GJ for Krzesławice, 2,200 GJ for the ECA-IV, hand-fired boilers at Rydla Street, and 550 GJ for the hand-fired boilers at Ułanów Street.

Results of this simple comparison are given in Table 2-31 along with assumed efficiency, Equivalent Emissions, Cost Criteria (repeated from Table 2-28) and fuel price. The heat production cost for the PLM-2.5 boiler, using Ziemowit coal duf and a standard operating procedure has been used as a reference value. The cost of heat production is expressed relative to this reference value. It should be noted that the emission fees are only 1-3% of the heat production cost in any of the boiler houses and at this level these fees provide no incentives for reducing emissions through use of more expensive fuels.

An important conclusion from these results is that the efficiency improvements, which can be obtained using improved, more expensive fuels in connection with improved operations, can lead to lower operating costs. This provides the biggest incentive for owners and operators to use these better fuels and obtain the substanital emission reductions shown in this table. With a fixed grate this relationship is not so obvious. In the ECA boiler the improved coke combustion procedures do not cause a significant decrease in heat production costs. In the ES-ŻET boiler, the lowest emissions are observed when burning briquettes, but because of their high price, the heat production cost is then the highest.

Table 2-31. Results of a Simple Cost Comparison for Boiler Houses with Different Fuels

Boiler house	Type of boiler	Fuel	Boiler efficiency	Fuel Price	Equivalent emissions	Emissions fees Cost criterion	Relative energy production cost compared to PLM-2.5 on ZIEMOWIT coal
Unit			[%]	[$/metric ton]	[g/GJ]	[zl/GJ]	%
Balicka	WR-10	Ziemowit standard procedure	63.0	27.	2090.6	2324	87
	WR-10	Staszic I	72.7	32.	1092.1	1130	79
	WR-10	Staszic II	72.6	47	980.8	850	85
Baseline	PLM-2.5	Ziemowit standard procedure	53.3	27	2060.8	3366	100
Krzeslawice	PLM-2.5	Ziemowit improved procedure	55.4	27	1551.6	2460	97
	PLM-2.5	Staszic I	61.3	32.	1227.1	1418	90
	PLM-2.5	Staszic III	73.3	47.	1008.8	996	85
	PLM-2.5	Pea size	62.1	53.	784.3	994	97
ul. Rydla	Eca-IV	coke, standard procedure	72.0	95.	2030.3	2505	125
	Eca-IV	coke, improved procedure	73.0	95.	1662.5	2039	123
	Eca-IV	coal/coke 1:1	71.0	78.	2768.9	3015	119
	Eca-IV	briquettes	69.0	118.	3049.0	2380	152
ul. Ulanów	Es-Żet	coal	60.0	61.	3272.9	2841	110
	Es-Żet	coke/coal 7:3 standard	65.0	85.	2139.7	2203	131
	Es-Żet	briquettes	71.0	118.	1214.4	1272	158

3.0 ENGINEERING

3.1 EXTENSION OF THE HEATING SYSTEM

3.1.1 The Characteristics of Kraków's District Heating System

Central Heat Sources

Kraków's district heating system has been in operation since the late 1950s. The present municipal district heating network is supplied by three heat sources:

- Łęg Combined Heat and Power (CHP) plant (EC Łęg)
- Skawina CHP Plant (EC Skawina)
- CHP plant of the T. Sendzimira Steelworks (EC HTS)

A fourth source, the CHP plant of Kraków Soda Factory (EC KZS) was closed in 1994 and the Skawina CHP plant took over its part of the network.

Łęg CHP, currently called Elektrociepłowinia Kraków S.A. (ECKSA), was commissioned in 1968 and is the main producer of power and heat for Kraków. This capital project was completed in four stages:

- Stage I (1970) — commissioning EWP-70 Heat-Only Boiler (HOB), 80 MW output.
- Stage II (1971-1975) — commissioning three WP-120 HOBs, 500 MW output.
- Stage III (1977-1978) — commissioning two BC-90 cogeneration units, 870 MW output.
- Stage IV (1980-1985) — commissioning two WP-120 HOBs and two BC-100 cogeneration units, 1,520 MW output.

The Łęg CHP plant has a capacity of 1,460 MW to meet the needs of the municipal district heating network, and 60 MW in process steam. Its present electrical power capacity is about 450 MW.

The Skawina CHP plant was built in the 1960s as a condensing power plant, supplying the national grid, with 550 MW capacity. During the last few years, reconstruction was started aimed at transforming the plant from generating only power to combined heat and power production. At present, the EC Skawina provides 220 MW of heat output for the city of Kraków and the plant provides 80 MW.

The CHP plant of Sendzimir Steelworks is a source of power, heat, and process steam, mainly supplying the steelworks. The CHP plant supplies 36 MW to the municipal district heating network.

The CHP plant of Kraków Soda Factory was an industrial CHP plant supplying the municipal heating network with 23 MW. The nameplate output of the installed boilers was 122.5 MW.

The Extent of the Existing District Heating Network

The total length of the heating network in Kraków's district heating system is about 630 km. The heating networks vary from 2 x 32 mm Dn (nominal diameter of supply and return pipes) for connections to buildings, and 2 x 1,000 mm Dn and 2 x 800 mm Dn for them in pipelines. The structure of the network, by the pipe diameters is as follows:

- ≤Dn 100: 330 km of heating network,
- Dn 100 to Dn 350: 220 km of heating network,
- Dn 400 to Dn 1,000: 80 km of network.

The detailed operational age of the network is as follows:

- 0 - 5 years - 7% 44 km
- 5 - 10 years - 19% 120 km
- 10 - 15 years - 30% 189 km
- 15 - 20 years - 25% 157 km
- 20 - 30 years - 19% 120 km

The heating network in Kraków is divided into six subsystems, four connected to EC Łęg, one to EC Skawina, and one to EC HTS. The main pipelines connected to EC Łęg have been named according to the principal directions and they encompass the following Quarters of the city of Kraków:

- Eastern Pipeline - Nowa Huta Quarter.
- Western Pipeline - Dąbie, Grzegórzki, a part of Śródmieście, Półwsie Zwierzynieckie, Czarna Wieś and still for a certain period of time the regions of Zabłocie, Podgórze Stare, Mateczny and Wadowicka.
- Northern Pipeline - Wieczysta, Olsza, Prądnik Biały, Prądnik Czerwony, Bronowice, Azory, Wrocławska, Królewska .
- Southern Pipeline - Podgórze, Płaszów, Prokocim, Bieżanów, Wola Duchacka, Piaski Wielkie and Kurdwanów Quarters.

A main pipeline with nominal diameters of Dn 1,000 (9.1 km) and Dn 800 (5.6 km) connects Kraków to EC Skawina Until the 1992/1993 season, this pipeline supplied Ruczaj Zaborze, Kobierzyn, Zakrzówek and Dębniki Quarters. Beginning with the 1993/1994 season, the pipeline took over some customers in the western EC Łęg pipeline, and starting in 1994/1995 it will supply the former EC KZS region, i.e., Borek Fałęcki and Łagiewniki.

An outlay of the municipal district heating network is shown in Figure 3-1.

There are four network pumping stations on the main heating pipelines. Zabrówek with an output of 2,300 t/h and a water pressure of 0.55 MPa, and Wroelawska with an output of 1,050 t/H and a pressure of 0.25 MPa are located on the return system. Two other pumping stations are not needed yet and are not operated; the first, Dajwór, is located on the supply and return side of the system, the second, Misatrzejowice, is located on the supply side only.

The Construction of the Heating Network

Methods of pipe laying:

- traditional concrete channels (more than 90% of all the networks),
- traditional overland networks,
- foamed concrete,
- "fil" filler,
- pre-insulated pipes.

Foamed concrete and "fil" filler were used as insulating materials during construction of the heating network in the 1960s. The excavations with steel pipes welded in place were backfilled with "fil", or poured with foamed concrete. "Fil" is a filling mass of ground industrial asphalt, which was used alone or with some kind of other material (for example, fine-grained pumice-stone slag).

Types of Insulation.

Traditional mineral wool and glass wool are the basic insulation materials used in the city network. Until 1985, the standard required 40-100 mm of insulation thickness for the supply pipes, and 30-60 mm for the return pipes. In 1985, a new standard was introduced, increasing the thickness to 60-160 mm on supply pipes, and to 30-80 mm on return pipes. This standard is currently valid. In the fifties and at the beginning of the sixties, approximately 8 km of pipes were insulated with foamed concrete or "fil". Since then, only pre-insulated pipes have been used.

Compensators.

So-called natural compensation as well as U-shaped compensators and pipe-in-pipe compensators were the basic methods of extension levelling for the network. Starting in 1990, bellow

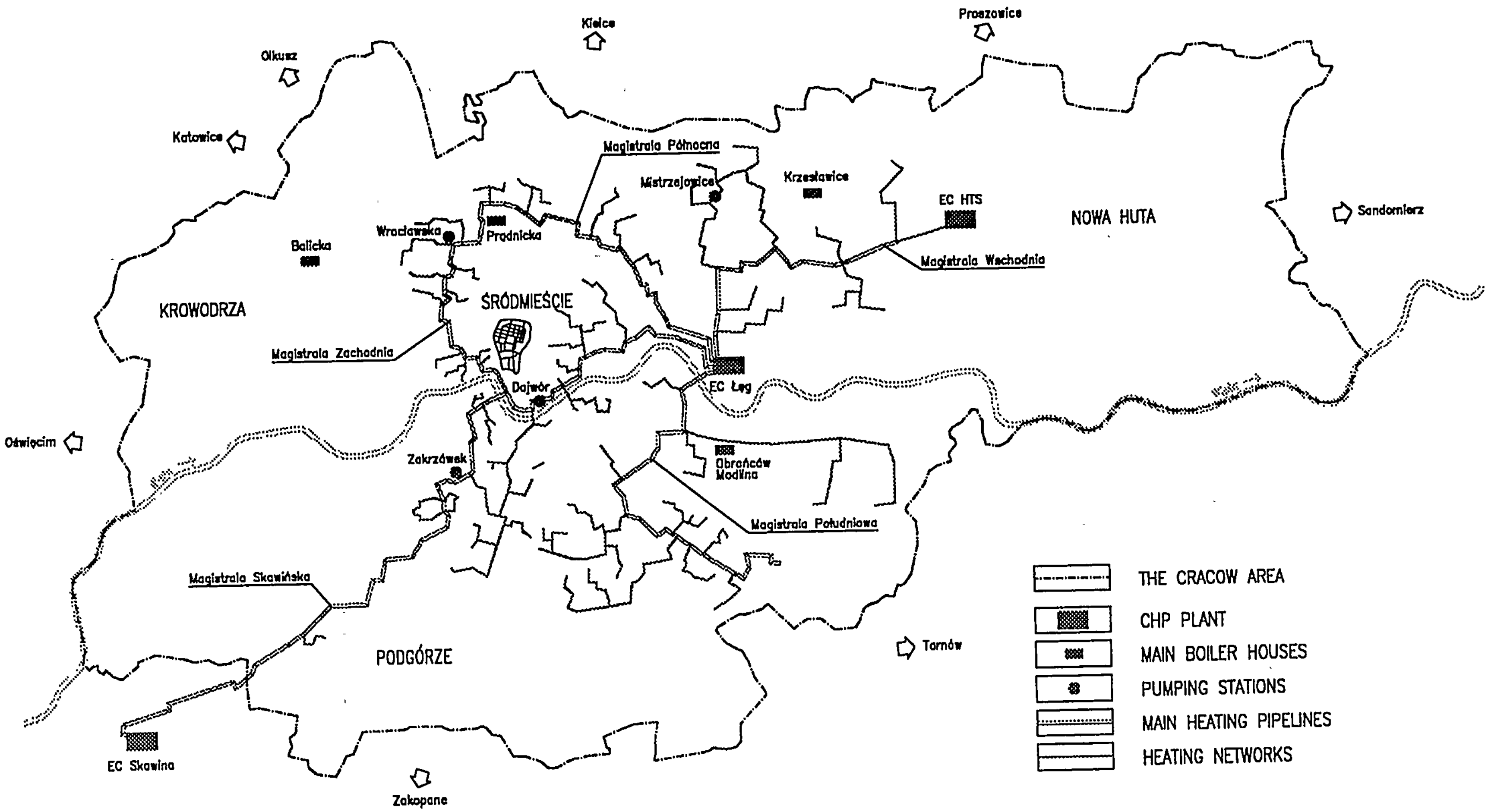


Figure 3-1. Kraków Municipal District Heating Network (Drawing prepared by Biuro Rozqoju Krakówa, 2/95)

compensators started to be used in municipal district networks. For operational reasons, a decision has been taken to start a program of exchanging all the pipe-in-pipe compensators with bellow compensators.

Connecting Nodes.

In Kraków's district heating network, the following types of connecting nodes currently are in operation: central (district) exchangers, local exchangers, mixing pumps, hydroelevators, direct connection and induced connection. During the past few years, as part of a plan to automate and control the system, the construction of new hydroelevators has been abandoned in favor of local exchangers. The existing hydroelevators will be replaced by exchangers. The distribution of nodes is shown in the Table 3-1; in all, there are 2,934.

Table 3-1. Distribution of Different Types of Nodes

Type of connecting node	Number
Local (district) exchangers > 1MW	76
Local exchangers	968
Mixing pumps	32
Hydroelevators	1,471
Direct	237
Induced	150
TOTAL:	2,934

Regulation of the Heat Supply

Nominal temperatures on the supply and return lines are 150°C/70°C. Control of these temperatures depends on weather conditions. The rate of water flow is constant and water's temperature is adjusted. The regulations on controlling water temperature are issued by a ministerial ordinance, that is the basis for the so-called regulation (control) tables for heat sources. Constant flow is achieved by installing throttling orifices or controlled iris orifices in the connection nodes of pipelines to the customers, based on hydraulic calculations. Constant differential-pressure valves complete the throttling orifices in certain connection nodes. Since 1990, newly commissioned connection nodes must have weather automation, differential pressure valves, and heat-metering equipment.

3.1.2 Description and Classification of Existing Solid Fuel-fired Boilers

According to a detailed inventory of low-emission sources, there are 1,134 solid fuel-fired boilers in Kraków providing 997 MW of nameplate power output. They use 375,000 Mg of solid fuel a year. There are 345 boiler houses, with a nameplate power output of 207.4 MW, in areas outside the range of the central heating system, including:

- Old Town - 49 boilers, 19.0 MW
- Kleparz - 111 boilers, 48.0 MW
- Kazimierz-Stradom - 30 boilers, 9.7 MW
- Peripheral Areas - 155 boilers, 130.7 MW

There are 789 boiler houses (769.49 MW) within the range of the municipal district heating network. Only some are heating boilers, the remainder being heating/process steam or purely process steam boiler houses.

Due to the seasonal operation of the network and the qualitative control of the heating water parameters, boiler houses serving industry cannot be eliminated by connecting them to the municipal heating network. A following general rule was applied to the heating/process steam boiler houses - if heating capacity is the dominant percentage of the output power, the boiler house may be connected to the municipal district heating network but must continue to operate the industry-serving unit. Table 3-2 is a summary of the boilers' qualification for connection to the municipal heating network.

Out of 789 boiler houses having a nominal output of 769,490 kW, 635 boiler houses (447.6 MW) could be eliminated by connecting them to the municipal-district heating network; these include:

- Eastern Pipeline - 16 boiler houses, 19.444 MW
- Western Pipeline - 328 boiler houses, 156.549 MW
- Northern Pipeline - 172 boiler houses, 157.295 MW
- EC Skawina Pipeline - 40 boiler houses, 20.94 MW
- EC KZS Pipeline (before closing) - 16 boiler houses, 23.792 MW

During the period of this analysis 20 boiler houses (30,817 kW) were connected to the network. Boilers which are not considered candidates for connection to the system include: 47 heating/process steam boiler houses (194,968 kW), 67 technological units in the heating/process steam boiler houses (53,410 kW) and 37 boiler houses (23,788 kW) qualified for gas fuel.

Table 3-2. Boiler Houses in the Main Sections of the District Heating System; Classification Relative to Connection to the District Heating System

Parameter		MAIN PIPELINE							
		Eastern	Western	North.	South.	EC Skawina	EC KZS	EC HTS	Total
Total number of boiler houses	houses kW	29 53,148	375 220,621	225 236,818	89 180,570	49 41,813	21 33,340	1 3,180	789 769,490
Peripheral boiler houses [1]	houses kW	2 274	5 1,190	23 13,358	14 2,567	4 1,191	2 327	- -	50 18,907
Connected boiler houses[2]	houses kW	- -	8 5,324	5 3,314	4 17,530	1 217	2 4,612	- -	20 30,817
Industry-serving boiler houses retained[3]	houses kW	11 32,490	8 16,600	14 41,794	9 85,996	4 17,983	1 105	- -	47 194,968
Industry-serving units retained[4]	houses kW	1 940	34 27,316	18 11,091	5 6,487	6 1,482	2 4,504	1 1,590	67 53,410
Proposed conversion to gas fuel	houses kW	- -	26 13,642	11 10,146	- -	- -	- -	- -	37 23,788
Not connected boiler houses (total)[5]	houses kW	13 33,704	39 58,748	48 76,389	23 95,050	8 20,656	3 4,936	1 1,590	134 291,037
Planned connection[6]	houses kW	16 19,444	328 156,549	172 157,295	62 67,990	40 20,940	16 23,792	- -	635 447,600

Notes:
1. Boiler houses located too far from the district heating system to be considered candidates for connection.
2. Boiler houses recently connected to the district heating system.
3. Boiler houses which provide process steam to industry and cannot be eliminated through connection to the district heating system.
4. Boilers providing process steam located within boiler houses which also provide heat to local district heating system.
5. Boiler houses which, for other reasons, aren ot considered candidates for connection to the district heating system.
6. Boiler houses currently considered candidates for connection to the district heating system.

3.1.3 Heat Demand Balance For The City Of Kraków

Components Of The Heat Balance

The prospective balance of heat demand includes current needs, future construction, existing buildings with individual stoves and the fuel requirements of solid-fuel heating boilers located in the range of the municipal district heating network.

Current needs were determined on the basis of present heat sales obtained after the 1991/1992 heating season (MPEC data). Broken down by the main pipelines, the balance has the structure shown in Table 3-3.

Solid fuel-fired boilers qualified for connection to the municipal district heating network are discussed in Chapter 3.1.2. The output of these boilers is 447,600 MW.

Balance of the Central Heat Sources

The present power output of the existing CHP plants supplying the municipal network is 1,716 MW.

- EC ŁĘG can presently provide 1,460 MW to the municipal heating network in Kraków. In a planned expansion "Stage V" of EC Łęg construction, a WP-120 HOB (140 MW) and a BC-100 co-gen units block (185 MW) would be installed. The target output of EC Łęg for the municipal network after implementing Stage V would reach 1,785 MW.

- EC Skawina can provide 220 MW of heat power to the municipal network, but there could be further transformation increasing output up to approximately 520 MW.

- EC KZS was not considered as the plant was closed and the customers taken over by EC Skawina.

- EC HTS supplies the municipal network with 36 MW. The possibility of increasing the output to about 48 MW was taken into consideration.

Table 3-3. Total Balance of Heat Demand for the Kraków District Heating System in 1992

PIPELINE REGION	HEAT DEMANDS [kW]					TOTAL
	1992 STATE	FUTURE PROJECTED DEMAND INCREASE (MPEC)	FUTURE CONSTRUCTION	ELIMINATION OF STOVES	ELIMINATION OF BOILER HOUSES	
EASTERN - EC ŁĘG	432,610	30,510	55,680	-	19,444	538,244
WESTERN - EC ŁĘG	275,950	19,215	33,280	14,433	156,549	499,427
NORTHERN - EC ŁĘG	345,180	22,320	69,510	6,294	157,295	600,599
SOUTHERN - EC ŁĘG	284,940	64,044	12,920	769	67,990	429,649
SKAWINA	56,940	18,060	18,800	1,978	20,940	116,748
EC-KZS (before closing)	22,910	150	11,530	139	23,792	58,521
EC HTS	36,030	900	9,350	-	1,590	47,870
TOTAL	1,454,600	154,185	211,070	23,613	447,600	2,291,028
PERCENTAGE OF THE BALANCE	63.5	6.7	9.3	1.0	19.5	100

3.1.4 Development Options for the Municipal District Heating Network

Given a situation where the estimated future balance of the city's heat demand is 2,291 MW, and the output of the existing CHP plants supplying the network only reaches 1,716 MW, the following issues should be analyzed:

- Can the existing heat sources be developed and how should such development be implemented?
- How will the development of central sources influence the modernization needs of the municipal district heating network?
- Have EC Łęg and EC Skawina the technical ability to increase their output?
- Can EC Łęg increase from 1,460 MW (present output) to 1,785 MW?
- Can EC Skawina increase the available output from 220 MW to 520 MW?

Meeting the estimated future heat demand of the city was studied on the basis of one of three options for the development of central heating sources.

Option 1 Extension of EC Skawina (+300 MW)
(increasing the heat output capacity of the Skawina plant by 300 MW)

heat supply from EC Skawina	520 MW
heat supply from EC Łęg	1,460 MW
heat supply from EC HTS	48 MW
TOTAL	2,028 MW

Option 2 Extension of EC Łęg (+325 MW)

heat supply from EC Skawina	220 MW
heat supply from EC Łęg	1,785 MW
heat supply from EC HTS	48 MW
TOTAL	2,053 MW

Option 3 Exchange of 1 turbine in EC Skawina and construction of a new HOB "Wroclawska"

(Under this option the heat output capacity of the Skawina plant would be increased by 150 MW, and the new plant Wroclawska have an output capacity of 163 MW)

heat supply from EC Skawina	370 MW
heat supply from EC Łęg	1,460 MW
heat supply from EC HTS	48 MW
heat supply from Wrocławska	163 MW
TOTAL	2,041 MW

After analyzing the network structure, the range of investment for the main heating pipelines was been evaluated for the particular options.

Option 1 - development of EC Skawina

This option consists in developing EC Skawina, increasing the output by 300 MW. The expected output supplied to Kraków would be 520 MW. An analysis of the network structure is given below.

Eastern pipeline — The pipeline load is 538.244 MW - 6,332 m^3/h; reconstruction of the K-XI pipeline (close to Rondo Kocmyrzowskie) to the K-13 chamber must be completed by laying a Dn 600 pipeline over 210 m.

Note: A "chamber" in the heating system network is a node at which the piping can be accessed or drained.

Western pipeline — The pipeline load is 228.422 MW - 2,619 m^3/h. It does not require any modification under this option.

Northern pipeline — The pipeline load is 600.599 MW - 6,888 m^3/h. Due to the high heat load, this pipeline will have to be upgraded. This can be achieved by laying new pipelines or by introducing network pumping stations that would increase the pressure available.

Network alternative — Laying a second pair of Dn 800 pipelines between EC and K-I, on a distance of 1,940 m.

Laying two Dn 800 pipelines between K-III and K-XIII, on a distance of 4,300 m.

Constructing a pumping station at Mlyńska Street

Completing construction of the pumping station on Racławicka Street.

Pumping stations alternative	Laying two Dn 800 pipelines between the CHP plant and K-I, on a distance of 1,940 m.
	Building a network pumping station at Lublańska Street.
	Constructing a network pumping station at Młyńska Street.
	Constructing a network pumping station at Racławicka Street.
Southern pipeline	The network load is 229.527 MW - 2,632 m³/h, and further investments are not needed.
EC Skawina pipeline	The pipeline load is 604.981 MW - 6,937 m³/h and requires:
	Laying two Dn 1000 pipelines between EC and K-I, over 2,229 m.
	Constructing a pumping station at Lubostroń Street.
	Completing construction of the "Zakrzówek" pumping station.
	Laying a pipeline stage in the direction of the Kurdwanów, Wola Duchacka, Prokocim and Bieżanów housing estates with Dn 800 over 5,530 m.
	Building a network pumping station at Zakopiańska Street near the K-X/7 chamber - adding a Dn 500 network segment of 3,425 m, and connecting K-XIII/10 and K-XIII/1

<u>Option 2 - Extending of the EC Łęg CHP Plant</u>

This option consists in extending EC Łęg, and increasing its output by 325 MW. The planned heating output would reach 1,785 MW.

Eastern pipeline	Load and investment range as above (see option 1).
Western pipeline	The load is 375.450 MW - 4,306 m³/h. No investment in the network is required.
Northern pipeline	Load and investment range as above (see option 1).
Southern pipeline	The load is 474.569 MW. There are two ways to increase the capacity of the network:

Network alternative	Laying two Dn 800 pipelines between K-IV and K-VII, over a 2,160 m.

Pumping stations alternative

Building a network pumping station: Gromadzka.

The EC Skawina main pipeline does not require further investments.

Option 3

This option includes:	Replacing one 150 MW heat turbine in EC Skawina, that will increase the available output to 370 MW.
	Installing a new gas or oil HOB in the closed Wrocławska boiler house, with 163.275 MW output.
	EC Łęg output will not be modified.
Eastern and EC HTS pipeline	As in option 1; further investment is not needed.
Western pipeline	As in option 2; does not require further investment.
Southern pipeline	Does not require further investment.
Northern pipeline	The load will reach 437,324 kW, requiring:
	Completing the construction of the Wrocławska pumping station.
	Laying Dn 800 network over 1,940 m between EC and K-I.
EC Skawina pipeline	Load is 389.457 MW. It requires the construction of 5,530 m of Dn 800 leg networks to the Kurdwanów, Wola Duchacka, Prokocim and Bieżanów housing estates that will be taken over from the southern pipeline.

Table 3-4 shows the extent of pipeline investments under various options.

Table 3-4. Summary of Options Evaluated for the Expanding of Kraków's District Heating System

Main Pipeline	OPTION I Extending of EC Skawina 300 MW Output Increase		OPTION II Extending of EC Łęg 325 MW Output Increase		OPTION III Exchanging turbine in EC Skawina. New gas- or oil- fuelled HOB Wroclawska with 163, 275 kW Output	
Eastern	DN 600mm Network (K-XI-K-13)	Length, 210 m	Dn 600mm Network (K-XI-K-13)	Length, 210 m	Dn 600mm Network (K-XI- K13)	Length, 210 m
Western						
Northern	Dn 800 network, 940 m (EC-K-I) Dn 800 network, 4300 m (K-III-K-XII) Młyńska pumping station G= 310 m^3/h; H= 2x0.18 MPa; N= 528 kW Wroclawska pumping station G= 2600 m^3/h; H= 0.30 MPa; N= 400 kW	Dn 800 network, 940 m (EC-K-I) Młyńska pumping station G= 310 m^3/h; H= 2x0.18 MPa; N= 528 kW Lublanska pumping station G= 5000 m^3/h; H= 2x0.41 MPa; N= 2520 kW Wroclawska pumping station G= 2600 m^3/h; H= 0.30 MPa N= 400 kW	Dn 800 network, 940 m (EC-K-I) Dn 800 network, 4300 m (K-III-K-XII) Młyńska pumping station G= 310 m^3/h H= 2x0.18 MPa N= 528 kW Wroclawska pumping station G= 2600 m^3/h H= 0.30 MPa N= 400 kW	Dn 800 network, 940 m (EC-K-I) Młyńska pumping station G= 6400 m^3/h; H= 2x0.37 MPa; N= 2000 kW Lublanska pumping station G= 5000 m^3/h; H= 2x0.41 MPa N= 2520 kW Wroclawska pumping station G= 2600 m^3/h; H= 0.30 MPa; N= 400 kW	Dn 800 network, 940 m (EC-K-I/PS) Wroclawska pumping station G = 2,600m^3/h; H = 0.30 MPa; N = 400 kW	
Southern			Dn 800 network 2160 m	Gromadzka pumping station G= 3400 m^3/h; H= 0.25 MPa; N= 500 kW		
Skawina	Dn 1000 network, 2229 m (EC-K-I) Dn 800 network, 5530 m (K-X- K -XIII/10) Dn 400 network, 3245 m (K-XIII/10-K-XIII/1) Lubostron pumping station G=6700 m^3/h; H= 2.042 MPa; N= 3000 kW Zakopianka pumping station G= 3000 m^3/h; H= 2x0.19 MPa N= 800 kW				Branch networks to the regions of: Star Podgorze, Borek Falecki, Wola Duchacka, Piaski Wielkie, Na Kozlowcę and Kurdwanow Dn 800 network, 5530 m (K-X -K- XIII/10) Dn 500 network 320 m (K-XI/8-2/1 - XI/8-1)	

3.1.5 Connecting Solid Fuel Boilers To The Municipal District Heating System

There are 789 solid fuel boiler houses in the range of the municipal-district heating network. Six hundred and thirty-five, with a total output of 447.6 MW, have been earmarked for elimination by connecting them to the municipal network. Two ways have been considered of connecting the eliminated boiler houses to the network; through heat exchangers (561 nodes), and through direct connection (21 nodes). The proposed number of connecting stations is less than the number of boiler houses that will be closed down - when there is more than one boiler at the same site, the addition of one heat exchanger is planned. Supplying the heating medium requires building about 94 km of network. Table 3-5 shows the diameter structure of the connecting network.

3.1.6 Costs of Eliminating the Low Level Emissions

The following elements are included in the investment costs of connecting eliminated boiler houses to the municipal district heating network:

- Costs of reconstructing the main pipeline networks according to the assumed option of developing central heat sources.
- Costs of connection networks.
- Costs of connection nodes.

Unit prices collected from heating systems contractors and MPEC were the basis for evaluating these costs. The costs of eliminating the boiler houses elimination do not include purchasing the land for constructing the network. Furthermore, the costs of extending the heat sources were not included.

Table 3-6 shows the investment costs for branching connections and heating nodes. Table 3-7 summarizes the total costs of eliminating low-level emissions in thousands USD, depending on the option taken for extending the sources of heat.

Investments for the main pipelines vary, depending on the selected option for extending the sources of heating, to which the main networks have to be adapted. When evaluating investment costs in the network and pumping station alternatives, the latter appear to be significantly lower:

- in option 1 53,504.4 thous. USD (network alternative)
  51,337.7 thous. USD (pumping st.alternative)
- in option 2 25,007.3 thous. USD (network alternative)
  19,914.9 thous. USD (pumping st. alternative)
- in option 3 18,618.7 thous. USD

Table 3-5. Distribution of Pipe Diameters in the Main Sections of Kraków's Heating System

Main Pipeline	Length of the pipelines [m]														
	40	50	65	80	100	125	150	200	250	300	350	400	450	500	600
Eastern	.	180	210	230	960	280	.	3655	1780	.	.	.	.	.	.
HTS	.	.	.	.	.	80	.	.	230	.	.	.	.	.	.
Western	440	1515	2400	6540	4200	2330	2280	1970	1570	300	.	.	.	.	.
Northern	230	1150	1720	3165	2040	900	4160	3950	4020	1590	.	1160	.	.	.
Southern	1770	1115	1635	2965	2230	1375	2240	1950	400	410	.	2920	.	.	.
Skawina	550	1075	1315	2185	2760	1980	1450	2900	870	250	.	800	.	.	1220
Former KZS region	140	270	120	490	470	120	380	240	460	650	.	.	.	.	.
	3130	5305	7300	15575	12060	7065	10410	14665	9330	3300	.	4880	.	.	1220

Total: 94,240 m

Table 3-6. Investment Costs Required for Branch Connections and Heating Nodes in Expanding of the District Heating System

Main pipeline region	Cost [thousands USD]				Index USD/kW
	Network	Heat exchangers	Direct stations	Total	
Eastern	2 597.5	208.4	34.0	2 839.9	146
HTS	150.7	25.8	-	176.5	111
Western	5 243.2	2 858.0	39.4	8 140.6	67
Northern	8 843.6	2 080.0	108.9	11 032.5	68
Southern	6 475.5	1 053.7	103.5	7 632.8	95
Skawina	7 103.5	1 157.9	53.3	8 314.6	138
KZS	1 261.6	138.5	36.0	1 436.1	60
Total	31 675.6	7 522.3	375.1	39 573.0	84

Table 3-7. Total Investment Costs Required for Expanding of the District Heating System.

Investments	REGION OF THE MAIN PIPELINE							TOTAL
	EAST.	HTS	WEST.	NORTH.	SOUTH.	SKAWINA	KZS	
OPTION 1								
M	450.0	-	-	19443.0 17276.3	-	33618.0	-	53504.4 51337.7
P	2597.5	150.7	5243.2	8843.6	6475.5	7103.5	1261.6	31675.6
W	242.4	25.8	2897.4	2188.9	1157.2	1211.1	174.4	7897.2
TOTAL	3289.9	176.5	8140.6	30475.5 28308.8	7632.7	41926.0	1436.0	93076.9 90910.5
OPTION 2								
M	450.0	-	-	19443.0 17065.5	5114.6 2188.9	-	-	25007.3 19914.9
P	2597.5	150.7	5243.2	8843.6	6475.5	7103.5	1261.6	31675.6
W	242.4	25.8	2897.4	2188.9	1157.2	1211.1	174.4	7897.2
TOTAL	3289.6	176.5	8140.6	30475.5 28308.8	12747.3 9821.6	8314.6	1436.0	59487.7
OPTION 3								
M	450.0	-	-	4593.7	-	13575.4	-	18618.7
P	2597.5	150.7	5243.2	8843.6	6475.5	7103.5	1261.6	31675.6
W	242.4	25.8	2897.4	2188.9	1157.2	1211.1	174.4	7897.2
TOTAL	3289.6	176.5	8140.6	15626.2	7632.7	21890.0	1436.0	58191.5

M - investments for main pipelines
P - investments for connection
W - investments for heating nodes

However the costs of operating a pumping station are high and, within a few years, they balance the increased costs of the network alternative. Comparing the costs of connecting a boiler house to the district heating network, the cost index of the used units was USD/1kW of the eliminated boiler house's output. For 73% of the branch connections, the index averaged 103 USD/kW, the average index for Kraków being 84 USD/kW. Boiler houses with the index not exceeding 172 USD/kW are the most satisfactory economically for connecting to the network - that figure encompasses 87% of all the connections. The following five specific regions were priorities for the next selection of local boiler houses to be eliminated:

- Wrocławska St. region
- Zwierzyniecka-Piłsudskiego St. region
- Piłsudskiego-Karmelicka St. region
- Halicka-Szeroka St. region
- Podgórze Stare region

Detailed designs of heating networks were developed for these areas as part of this project. There also is another problem, that was outside the present scope of subjects - the eventual necessity of extending the heating sources in Kraków (EC Łęg and EC Skawina).

There is a general opinion among energy professionals in the city that developing the central heat sources and further extending the pipeline system of the communal district heating networks may not be necessary and may not be required for a long time to come, despite connecting selected, existing boiler houses.

Such development can be avoided by introducting energy-conservation measures on both the end-user site and in the heating system itself.

3.2 CONVERSION OF SOLID FUEL-FIRED BOILERS TO NATURAL GAS

3.2.1 Introduction

To convert solid fuel-fired boiler houses to using natural gas has been one of the more popular ways of eliminating low emission sources. In the Old-Town part of Kraków, which is densely built-up, and inaccessible to district heating networks, it is practically the only way. Natural gas has been readily available for heating only in the last 4 to 5 years. Previously, the use of natural gas, mainly imported, was restricted. Applications to use it for heating required a permit from the State Inspectorate of Fuel and Energy Management. Under such a decision, the city of Kraków in 1968 obtained an allocation of natural gas for heating in the Old Town quarter; this enabled work to begin on converting coal-fired boiler houses to natural gas. The only projects implemented, initially, were those involving the restoration of historic buildings.

In 1984, after many years of efforts, a limited allocation of gas for heating was obtained by the Kazimierz-Stradom part of Kraków. Gas use was restricted to the central part only of this region. The allocation of gas was not fully utilized. The Gas Utility Enterprise estimated that at the beginning of the 1990s: utilization was about 30% With the introduction of market economy at the beginning of the 1990's, the prices of gas and other energy sources were increased to more realistic levels. Energy-intensive industrial activities declined, and new technology started to be introduced. This brought an end to limitations on the use of natural gas for individual heating systems in apartments, as well as in newly built houses and public buildings and sharp increases in gas prices. The Gas Utility Enterprise of Kraków is a distributing entity, a public enterprise subordinated to the Minister of Industry via the Carpathian Regional Gas Utility in Tarnów. The prices for natural gas are official ones fixed by the Minister of Finance.

Under the U.S.-Polish program of eliminating low emission sources, the three following technical studies were undertaken on converting solid fuel-fired boiler houses to natural gas:

1. The conversion of solid fuel-fired boiler houses to natural gas in the Old Town part of Kraków.

2. The conversion of boiler houses and home stove-based heating systems to natural gas within the "second ring" road.

3. The possible adaptation of the distribution network for natural gas in the city of Kraków to meet an increased demand for gas for heating purposes.

3.2.2 Municipal Gas Distribution System in Kraków

Natural gas is supplied to Kraków via four high-pressure pipelines (6.3 - 4.0 MPa) running east to west, flanking the peripheral parts of town. The pipelines transmit high-methane natural gas, both imported and from domestic beds. The pipelines supply gas to five main 1st-grade gauging and pressure-reducing stations at the following locations:

- Mogiła housing estate
- Zawiła Street
- Śledziejowice
- Zabierzów
- Mistrzejowice housing estate

and to three local stations providing supplementary supplies to Kraków at the following locations:

- Tyniec
- Wróblowice
- Kryspinów

The gauging and pressure reduction station at Mogiła also supplies a local, high-pressure network (1.2 MPa) with connections to six more gauging and pressure reduction stations. The five 1st-grade gauging stations supply local medium- and low-pressure networks. In all, this system supplies gas to about sixty 2nd-grade stations for community consumers, and to thirty-two gauging and pressure reduction stations belonging to industrial consumers. Sendzimir steelworks (the single, largest consumer of natural gas in town) has its own gauging and pressure reduction station supplied from the high-pressure gas pipeline. Gas supplies to municipal consumers are provided under medium- and low-pressures.

According to inventory information from the gas utility, at the end of 1993 there were 1287 km of operational medium- and low-pressure gas networks.

- About 258,000 consumers were registered, including about 235,00 households.

- 16,557 households used natural gas for heating.

- The total yearly consumption of natural gas (for 1993) was 429,249 thousand Nm^3.

The maximum daily consumption recorded occurred on November 20, 1993, and amounted to 72,948 Nm^3/h.

The existing district heating network is in good shape as the gas distribution company has a continuing program to replace old pipes as well as those of limited flow capacities. The gauging and pressure reduction stations also have been modernized and reconstructed.

In some sections of the pipelines there still are unsatisfactory conditions caused mainly by:

- unsealed cast-iron pipelines resulting from drying out of the pipe's bell seals after conversion from coke-oven gas to natural gas,

- damage to the pipelines close to tram and railway lines by stray currents, and

- the long time that the pipelines have been in use--50 to 80 years.

In 1993, there were still about 50 km of cast-iron pipelines which are being replaced by steel pipelines at the rate of about 15 km per year.

Apart from replacements, the following repairs are carried out in the network:

- external sealing,
- spraying leaking points from the inside,
- lining the network with polyethylene pipes,

- improvements to the sealings by installing bands of impregnated cloth, and
- building stations for cathodic protection against stray currents.

Figure 3-2 is a diagram of the basic gas distribution network.

3.2.3 Technical Options Employed in Converting Boilers to Natural Gas Regulations and Requirements

The replacement of solid-fuel boilers with gas-fired ones, especially in the historic parts of Kraków, is difficult sometimes. Because of conditions imposed by the State Services for the Protection of Antiquities, such projects cannot be implemented in many buildings. Hence, in past years it has been a principle that one boiler room was sited to heat several adjacent buildings. However, more recently, because of progressive privatization, individual houses are more often served by separate boiler rooms. In most of these buildings, the chimney ducts are in a poor state of repair and putting in new boilers requires, at the same time, either a major overhaul of the existing chimney or the construction of a new one. This work causes major inconvenience to the tenants. Thus, in most cases, new boilers are located in attics where constructing a chimney is trouble-free and less costly than elsewhere. This solution, however, limits the size of the natural gas-fired boilers, which principally must be small, low-output units, that can be manually carried to an attic and assembled there in suitable sets. In most cases, the boilers were of the KZG-4 type, with capacities ranking from 24 to 115 kW, manufactured by FAKORA Łódź.

When the space available allowed, the boilers used were mostly of the Hydrotherm or Juban Gaz types. In recent years, the availability of boilers of various makes has increased and the range of products of this type is extremely wide.

The following manufacturers market their boilers in Kraków: Vaillant, Viessmann, Schaffer, Rapido, Rendll, Geka, Strebel, and Junkers. Furthermore, the offerings of domestic manufacturers marketing their original designs or cooperating with foreign manufacturers has widened.

Under the existing laws, any activity in the field of converting boilers to natural gas requires compliance with the following regulations:

- The Building Code
- The Act on Protection of Culture and on Museums
- The ordinance on technical specification, which should be met by the particular buildings
- Construction regulations and standards
- Fire safety and occupational safety regulations

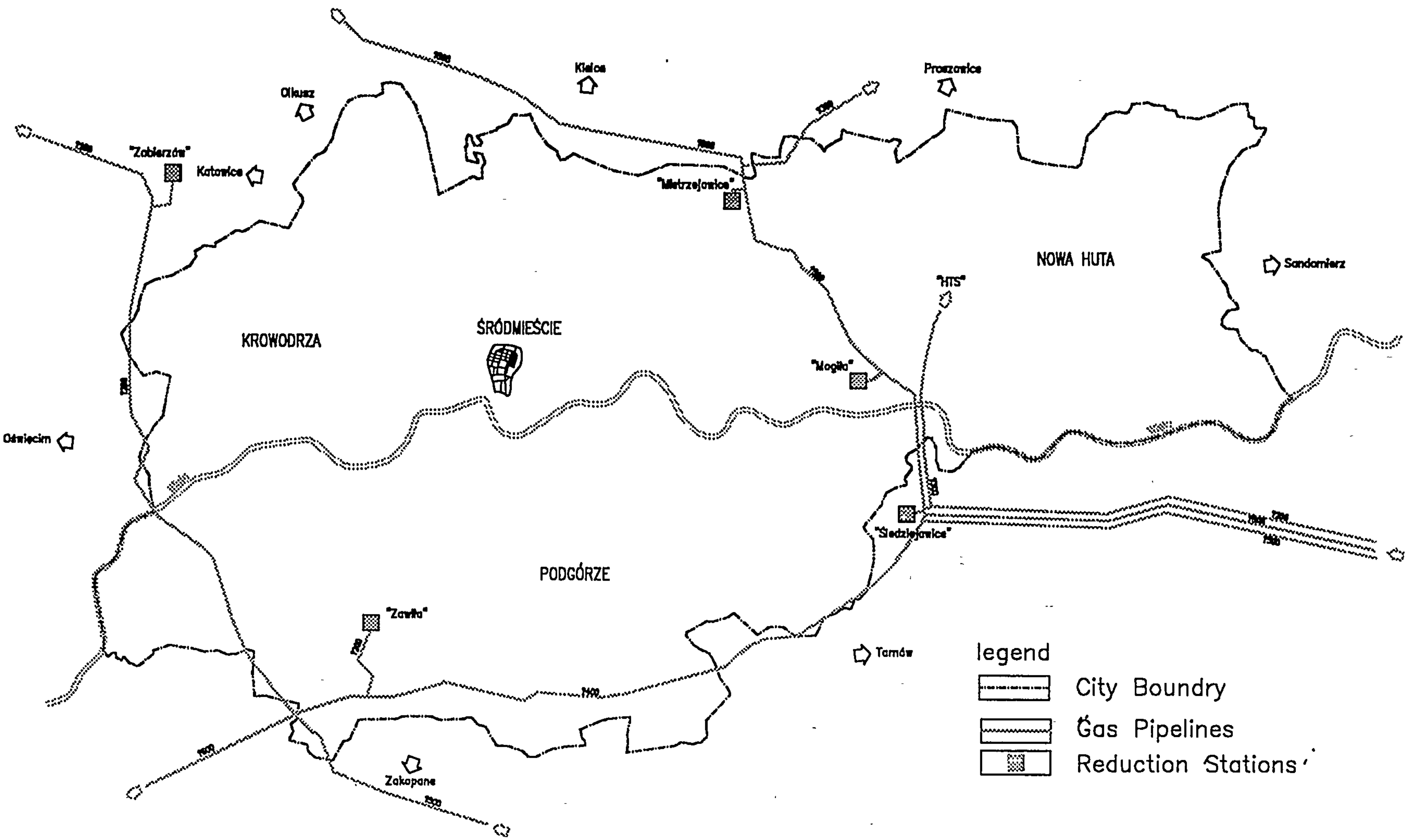


Figure 3–2. Krakow Gas Distribution Network

The following requirements are included in this last set of regulations:

- The entrance door to the boiler room should be either made of metal or metal sheet-covered wood, at least 80 cm wide, and opening to the outside,
- A fireproof floor, resistant to rapid changes in temperature, and impervious to penetration by ground water,
- Pressure-exhaust ventilation,
- Anti-explosion hole,
- Dedicated chimney.

If the building is supervised by the State Curator of Antiquities, the design and construction of the conversion also must meet the provisions of the Act on Protection of Culture and on Museums. The Act provides for a detailed analysis of the site-specific historical and cultural values of the building where construction of gas-fired boilers is planned. In many cases, this analysis leads to major increases in technical difficulties in meeting the requirements e.g., by the necessity to maintain original ceilings, or facades.

3.2.4 Converting Solid Fuel-Fired Boilers to Natural Gas in the Old Town

Engineering studies covered the Old Town area within the Planty green belt, except Wawel Hill. In studies done in 1990-1991, it was found that there were 48 solid-fuel boiler houses with a total output of 18.6 MW from 4,562 metric tons of fuel per year. During 1990-1991, five of them were eliminated. BRK (Kraków Development Office) has developed under this project detailed designs for the conversion into gas of each boiler house which has not yet been completed. As a result, the designs for 20 sites have been developed and were submitted to the boiler users. The costs were estimated as well within reach, both with respect to converting the boiler houses to gas and the necessary scope and cost of network extensions. The scope of work covers:

• converting the boiler houses to gas	36
• constructing Dn 400 gas pipeline - length	270 m
• constructing Dn 200 gas pipeline - length	205 m
• constructing Dn 150 gas pipeline - length	110 m
• constructing Dn 50 and 40 pipeline - length	132 m
• modernizing pressure reduction station	1

Construction costs:

- converting the boiler houses to natural gas for total of 16.252 MW capacity — 1.9 million USD
- constructing pipelines and the station — 0.1 million USD

The conversion will result in an increased demand for gas by 1.500 Nm^3/h.

Figure 3-3 shows the solid-fuel boiler houses in the Old Town that were included in the studies, and Figure 3-4 shows the gas distribution network in this part of town.

3.2.5 Analysis of the Possibility of Converting the Boiler Houses and Home Stoves to Natural Gas within the Second Ring Road

The aim of this study was to determine the possibility of converting to natural gas the existing solid-fuel boiler houses and some ceramic-tile stoves in the center of Kraków, between the 1st and 2nd ring roads. This is the area of Kraków just outside of Old Town.

This area has large concentration of boiler houses (339 of them with a total output of 137.5 MW) and also a predominance of heating stoves - 47 thousand.

In the part of town which is out of reach of the municipal district heating network, we assumed that 195 boiler houses with total output of 95 MW would be converted to natural gas. Also, we assumed that some of the home coal stoves would be converted.

The analysis showed that if heating in the area was based on natural gas there would be a huge increase in the maximum hourly demand for gas, from 7,000 Nm^3/h to 19,000 Nm^3/h (about a 170% increase).

Such an increase in gas consumption entails the need to extend the existing gas distribution network i.e. the system of medium- and low-pressure pipelines.

The following is required scope of this extension:

- constructing 2nd stage reduction stations — 5
- modernizing the existing stations — 2
- constructing medium-pressure pipelines Dn 150 to 500 [mm] — 3,050 m

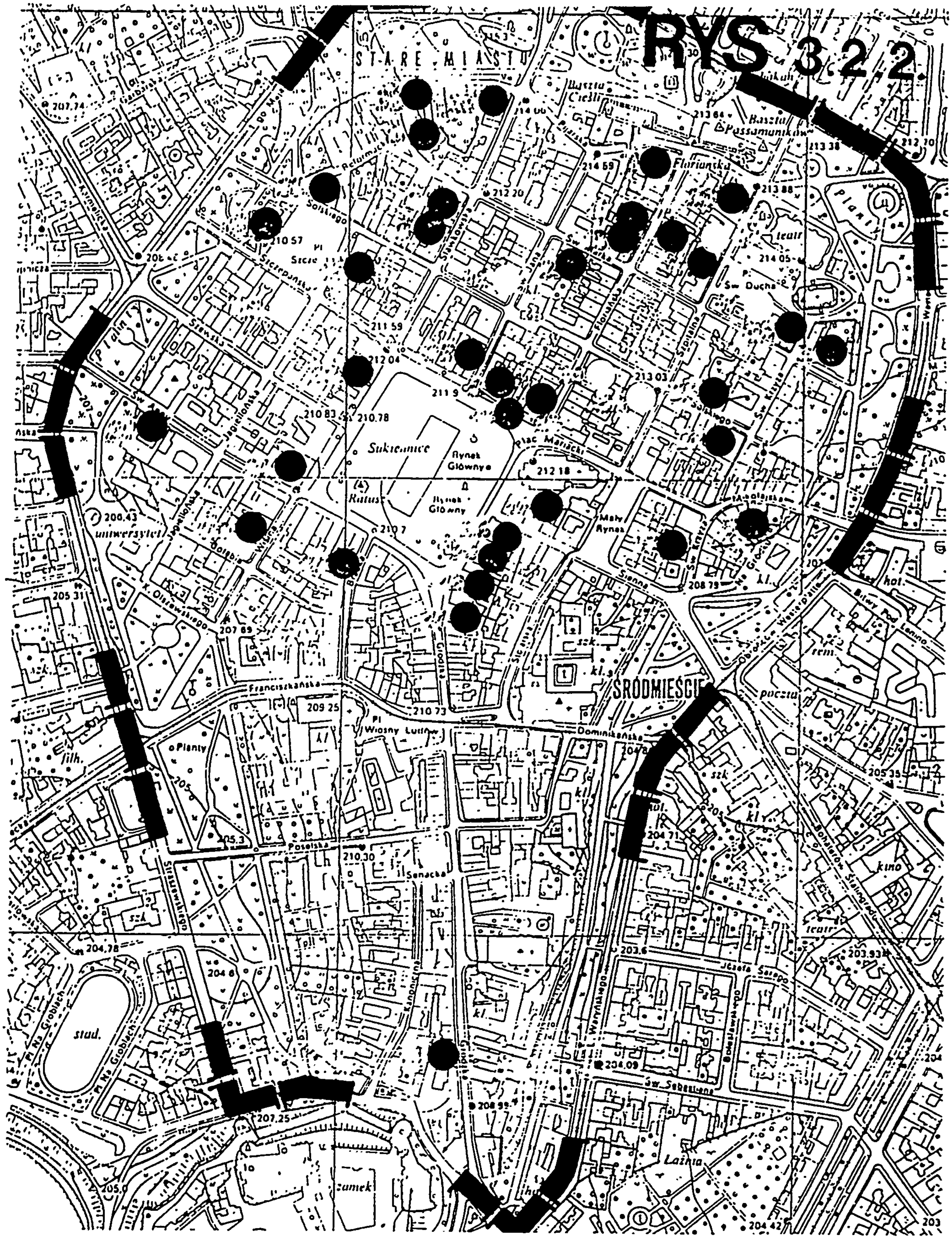
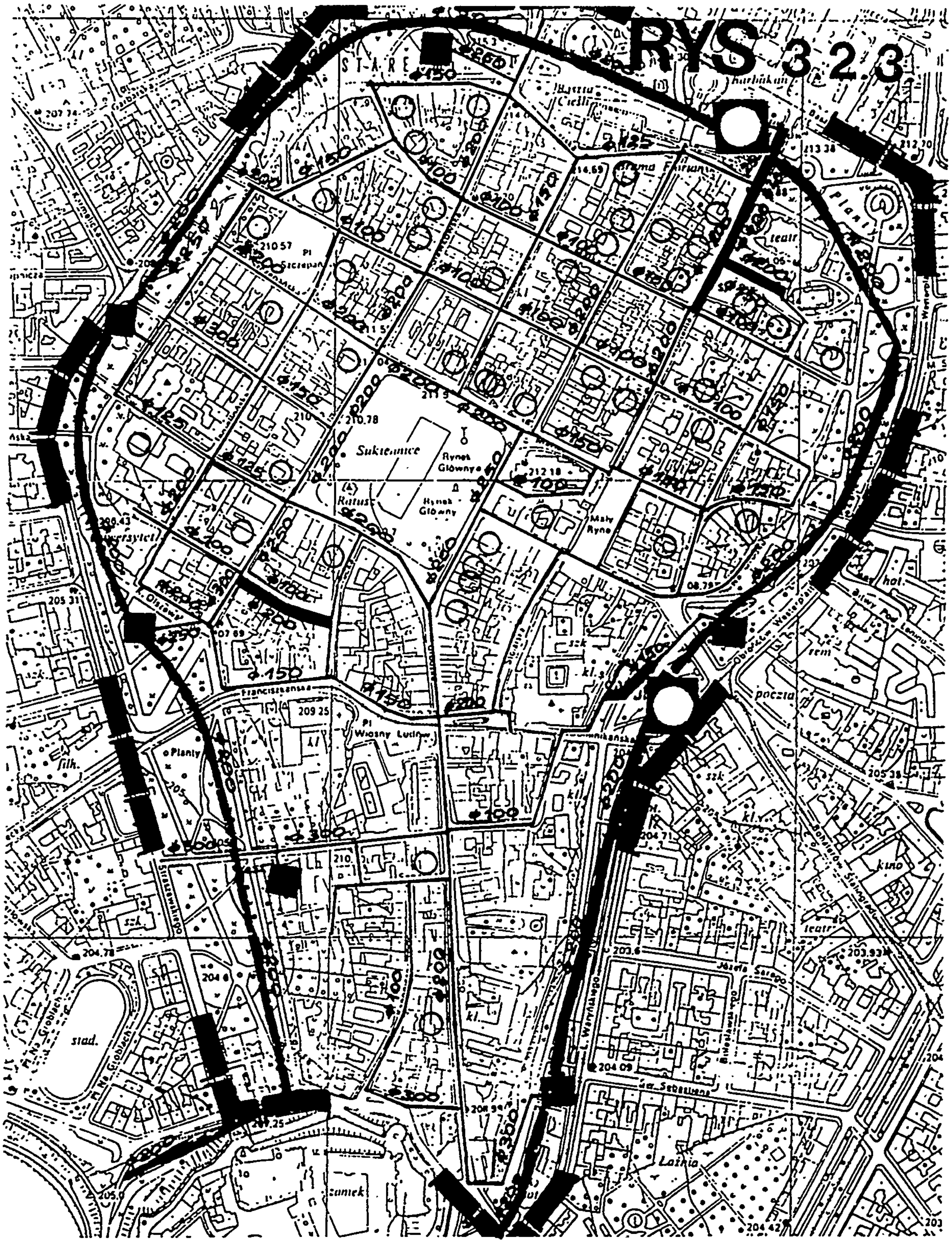


Figure 3-3. Boilers in Kraków's old town studied for gas conversion



Existing pressure reduction station

New pressure reduction station

Boilers included in this study

Figure 3-4. Details of the gas distribution network in the Old Town area

The capital cost of the above scope of work:

- construction costs of stations and pipelines 2.0 million USD
- conversion of boiler houses to natural gas total output 95 MW

		10.5 million USD
	Total:	12.5 million USD

The average index of capital cost for gas conversion of solid fuel boiler houses in this part of the city is 132 USD per kW. The scope of the above analysis does not include the costs of changes in the medium-pressure pipelines situated outside the area under analysis. Figure 3-5 shows the system of medium-pressure networks in the area studied.

3.2.6 Analysis of Possibilities of Adapting the Municipal Natural Gas Distribution Network in Kraków to Satisfy the Increased Demand for Gas for Heating

The aim of this part of the project was to determine the possibilities of securing gas supplies to satisfy the increased demand of the entire city of Kraków, and to assess the scope of necessary upgrades and extensions in the system's main medium-pressure pipelines. The analysis included the results of analyses described under sections 3.2.4 and 3.2.5, supplemented by the options of converting to gas some boiler houses that operate throughout the year, and provide domestic hot water and process steam (so-called "technological" boiler houses) outside the second ring road, and also some peripheral boiler houses; the study also took into account the supplies of natural gas needed for planned housing projects outside the reach of the municipal district heating system.

Option I: - Limited to 744,000 residents and selected technological boiler houses outside the second ring road.

Option II: - A maximum option for 928,000 residents, (according to the 1990 urban development plan for Kraków), and all technological and peripheral boiler houses.

In Option I, the overall demand for natural gas will be:

- total demand 209,000 Nm^3/h
  including gas for heating 109,000 Nm^3/h
  and "technological" boiler houses 3,700 Nm^3/h

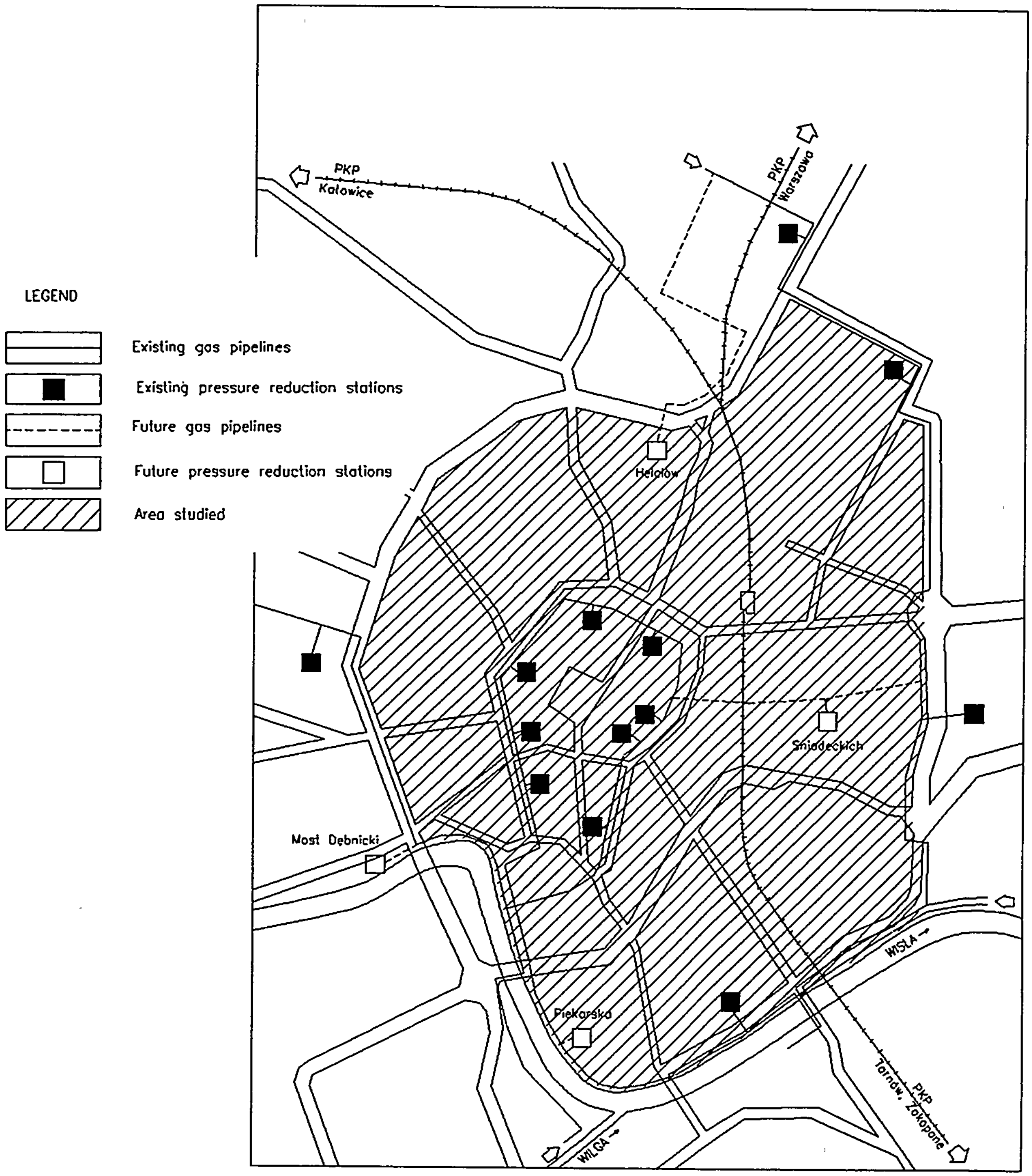


Figure 3-5. Details of gas distribution network in area between Old Town and the "second ring road"

In Option II:

•	total demand	236,000 Nm^3/h
	including gas for heating	109,000 Nm^3/h
	and "technological" boiler houses	11,000 Nm^3/h

Current consumption in the city is approx. 73,000 Nm^3, with about 50% being used for heating.

To meet this increased demand, two additional 1st-grade reduction stations at Górka Narodowa and Przewóz will be required.

New pipelines also will be needed:

Option I - Dn 125 to Dn 600 [mm] - 16 stages with a total length of 29.2 km.

Option II - Dn 125 to Dn 600 [mm] - 14 stages with a total length of 30.5 km.

The existing 1st-grade reduction stations at the following locations will have to be upgraded because of their inadequate capacities:

- Mogiła
- Zawiła Street
- Śledziejowice
- Mistrzejowice housing estate
- Niepołomska Street
- Wiślicka Street
- Krzesławice Hill
- Klasztorna Street
- Łęg
- Wróblowice
- Tyniec
- Kryspinów.

Capital cost estimates:

Option I:

•	network construction	3.48 million USD
•	construction of stations and upgrade	1.76 million USD
	Total	5.24 million USD

Option II:

- network construction — 3.89 million USD
- construction of stations and upgrade — 2.14 million USD

network construction		3.89 million USD
construction of stations and upgrade		2.14 million USD
	Total	6.03 million USD

3.3 CONVERSION OF COAL-FIRED HOME STOVES TO ELECTRIC HEATING

3.3.1 Technical Description of Conversion

Present State

The electricity supply for consumers in the city comes from Main Supply Stations (Polish abbreviation - GPZ) 110/30 kV. From these stations, electricity is supplied to municipal consumers, public buildings, small industries, and craftsmens' workshops.

There are 14 main stations of this type within the city limits with total installed capacity of 734 MW. On the secondary side (15 kV), the stations supply transformer stations 15/0.4 kV via an extensive medium-voltage distribution network. Industrial consumers with high demand are served by their own stations, 110/30 kV, designed to cover only their needs (e.g., Sendzimir Steelworks, Polish Railways).

According to the most recent data (end of 1993), there are 13,954 apartment units and 5,831 commercial units heated with electricity. The overall capacity used for heating is in the range of 90-100 MW.

Figure 3-6 shows the heating regions in Kraków, and Figure 3-7 gives the capacity used for electric heating in each region.

Analyses carried out by the Kraków Development Office (BRK) show that almost half of the total of 100,000 coal-fired home stoves used in Kraków are located in the central part of town, mainly regions 1-6, 12 and 17. Most of the electric-storage heating systems also are installed there. These areas will be targeted for future conversion of coal-fired stoves to electricity; their residents show the highest level of interest in electric heating.

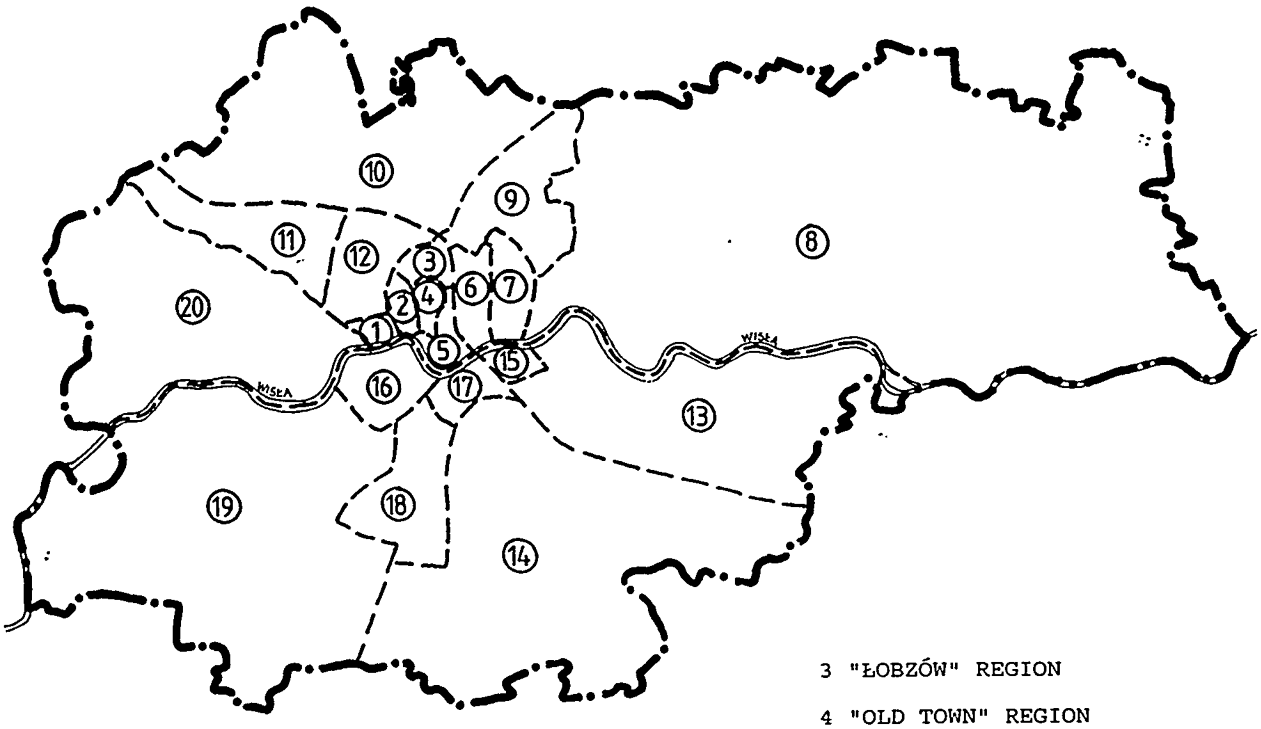


Figure 3-6. Kraków Heating Regions

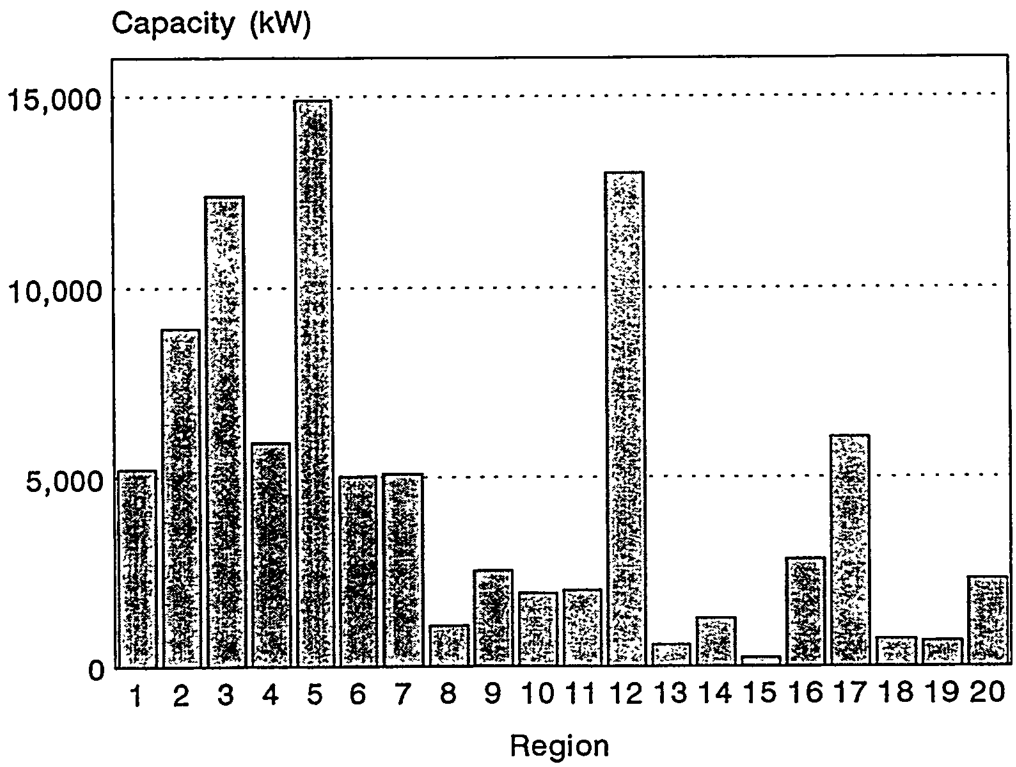


Figure 3-7. Installed Electric Heating Capacity in each of Kraków's Heating Regions

Designed State

1. Technical conditions.

The conversion of heating to electricity principally is effected in two ways:

- Removing the tile stoves and installing electric storage (accumulation heaters), and
- installing electric heating elements in existing stoves.

The Electricity Supply Company applies a special tariff for electric heating which is 50% of the regular rate for domestic use. Heating is limited to 8 hours during the night, and 2 hours during the day.

In some cases, the Electricity Supply Enterprise allocates additional capacity for heating (2.5-3 kW of installed capacity per stove). Installation of electricity in buildings requires adaptation of the internal cables to higher levels of power supply, as well as metering and control of the operation of the heating system.

Obtaining an additional allocation of capacity depends on the capacity of the supply network and the reserve capacity in transformer stations. When such reserves are not available, extra work has to be undertaken outside the building, such as installing new cables or a transformer station. Currently, there are no limits on the allocation of capacity nor are there any formal/legal conditions. The principal and only considerations are technical ones.

The cost of adapting the internal installations in the building to the requirements for electric heating are borne by the tenants via the building administrator (manager). The capital cost of network adaptations are borne mainly by the Electricity Supply Enterprise.

There are possibilities of obtaining soft loans for external infrastructure from the Fund for Environmental Protection, or from the Bank Ochrony Środowiska (Environmental Protection Bank).

3.3.2 Technical Conversion of Coal-Fired Stoves to Electricity for Heating in the Region of "Łobzów" Station

The American-Polish program included technical and economic analyses for replacing coal-fired stoves with electric heating systems around the 110/30 kV "Łobzów" station. This part of the town was earmarked for this conversion because of the great reserve of electric capacity (50 MW) in this station, and the large number of coal stoves, about 8500.

The area has 6884 apartments and commercial units. The following heating systems now are used:

- 325 units - natural gas-fired
- 104 units - central (district) heating
- 4712 units - coal-fired stoves
- 1743 units - electric heating

There are 43 operating 15/0.4 kV transformer stations with a total installed capacity of 23.67 MW. The balance of electricity supply/demand was determined by assuming that all the stoves would be replaced with electricity heating.

The scope of capital projects required to provide the necessary electrical supply for the increased demand was calculated and their cost estimated. A dedicated computer package was used to optimize technical options.

The analysis shows that converting 8500 stoves will require:

- Constructing 78 15/0.4 kV transformer stations.
- Constructing 19.4 kilometers of medium-voltage cable network.
- Constructing 19.0 kilometers of low-voltage cable network.

The overall cost of this scope of works is about USD 2.4 million; this estimate does not include converting the stoves to electricity with the necessary range of installation. The cost of adapting one stove was estimated to be around USD 200; hence, for all stoves in the area, the figure is around USD 1.7 million. Demand for electricity for heating purposes will be 18.1 MW. The average index of the capital cost of converting coal-fired stoves to electricity in the area of "Łobzów" station is USD 227/kW.

3.3.3 Technical Analysis of Conversion of Coal-Fired Stoves to Electricity for Heating in the Old Town Quarter

As the reserve capacity of 50 MW available for heating purposes in 110/30 kV "Łobzów" was not used in full for heating in this region, the Kraków Development Office (BRK) carried out an identical analysis for an adjacent area, the Old Town Quarter. This area still has around 3,100 coal-fired stoves.

The analysis shows the scope of construction required:

- 18 transformer stations
- 7.2 kilometers of medium-voltage network
- 4.0 kilometers of low-voltage network

The overall cost of this work is about USD 0.58 million. The capacity of installed electric heating systems will be 8.7 MW. The average index of capital cost of converting coal-fired stoves to electricity in Old Town Quarter is USD 138/kW.

3.3.4 Feasibility of Using Electricity to Heat Apartments in Kraków

In Kraków, there are still about 100,000 coal-fired stoves, most of which are located in the oldest part of the city center and its surroundings. The objective of this study was to show the feasibility of replacing all such stoves with electric heaters or inserting electric heating elements in them, and the effect this would have on the existing electrical system.

The analysis took into account that the town is divided into 20 regions with respect to heating systems, according to the principle applied in BRK for the district heating project.

At present, the consumption of energy for heating apartments and service facilities amounts to 90-100 MW. Figure 3-7 gives details of the existing electric systems. To replace all coal-fired stoves by electric heating would mean additional load of 190 MW on the electricity supply system. This amount is about 200% of the capacity now used for heating. Figure 3-8 shows the distribution of additional capacity among the 20 regions.

The prospects for using electricity for heating depend on reserves in the existing medium- and low-voltage networks, and on reserves in stations and transmission lines of the 110 kV system.

Estimates of the theoretical reserves in the medium- and low-voltage systems were based on daily load curves and the assumption that electricity would be used for heating during low-load periods. Hence, this reserve is about 50-70 MW in the daily low, and about 200 MW in the night low. This value reflects an overall balance of supply/demand balance for the whole town. The town's existing system was not designed and constructed with that level of heating need; to achieve such reserves, modernization and new investment projects are needed.

The situation is much better for the sources of power, i.e. the 110/30 kV station with industrial transmission power lines of 110 kV. The reserves there are able to cover fully the needs for electric heating.

During the engineering analyses, the scope and costs of capital projects required to convert stove heating to electricity was determined to include:

- 310 new 15/0.4 kV transformer stations, USD 6.8 million
- 84 kilometers of 15 kV cable lines, USD 1.8 million
- 77 kilometers of low-voltage cable lines, USD 1.1 million

Thus, the cost of the scope of work is around USD 9.7 million. The cost to adapt coal-fired stoves throughout the area will be about USD 19 million. Hence, the overall cost of converting coal stove-based heating to electricity will be USD 28.7 million.

An average index of capital cost of converting coal-fired stoves to electricity in Kraków is around USD 151/kW.

The combined installed capacity in these electric heating systems will be 190 MW.

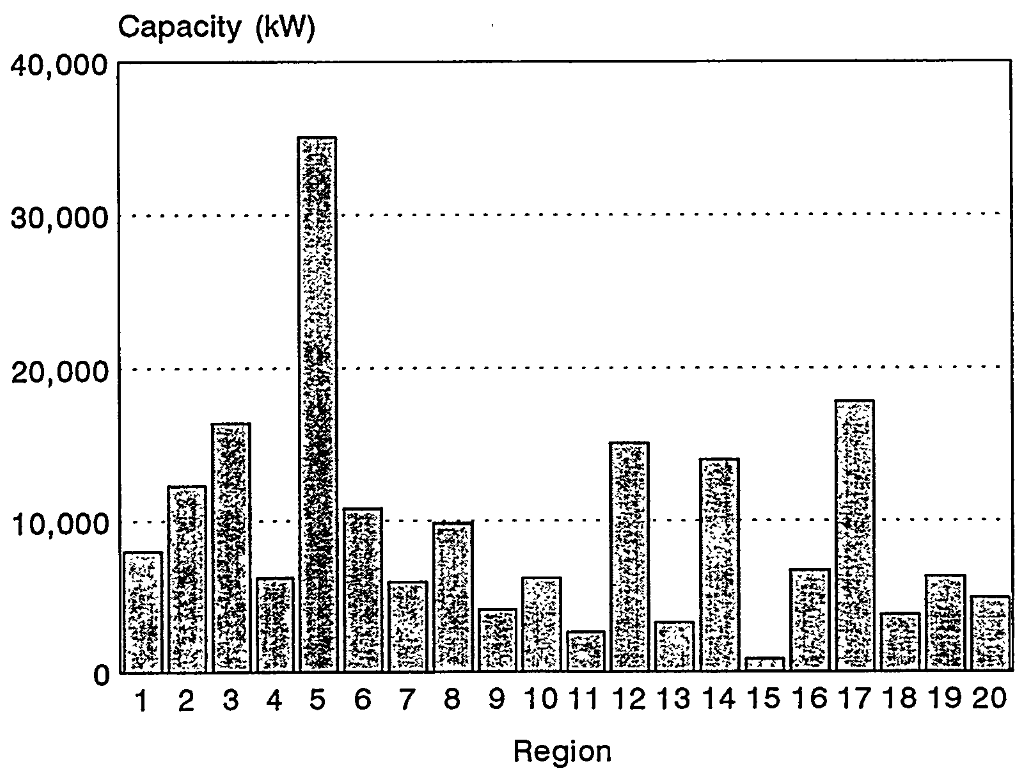


Figure 3-8. Electric Heating Capacity which would be required in each of Kraków's heating regions after converting all home stoves to electric heating

3.4. CONVERSION OF COAL-FIRED STOVE HEATING TO NATURAL GAS-FIRED SYSTEMS

3.4.1. Present State

Recently, the residents of Kraków have shown a great interest in using natural gas in individual heating systems for their apartments. According to a 1990 inventory, there are 15,682 apartments with a total usable floor area of 1,432,919 m^2, and 638 service businesses with a total usable floor area of 53,594 m^2 that are heated by individual gas-firing boilers.

Using natural gas instead of solid fuel for heating is justified by the high level of comfort enjoyed by the user, the high energy efficiency, and by environmental advantages. In Kraków, from 1990 to 1993, the number of apartments with individual gas-firing systems increased by 1,266.

Low-temperature gas-fired water boilers are built in a variety of types: as single-purpose (only for heating) or dual-purpose (for space heating and domestic hot water), with forced draft or natural draft burners, and also condensing boilers, suitable for heating systems with natural or forced circulation. Low-capacity boilers (830 kW) are manufactured as either free-standing or wall-hanging units. Modern natural gas-fired boilers are provided with regulating/safety systems and controls.

The major domestic manufacturers of such boilers include:

- Bielskie Przedsiębiorstwo Instalacji Sanitarnych (BPiS-type boilers)
- Fabryka Kotłów i Radiatorów "Fakora" (KZ4-G-type boilers)
- Predom-Termet Świebodzice
- Zakłady Produkcji Kotłów - Mikołów (JUBAM-GAZ-type boilers)
- Przedsiębiorstwo "EL-GAZ"
- Zakład Urządzeń Grzewczych Techniki Pomiarowej i Elektroniki" ATEST-GAZ"

The foreign manufacturers marketing their boilers include:

- Vaillant
- Viessmann Werke
- Schäfer-Heiztechnik
- Buderus Heiztechnik
- Hydrotherm
- Ocean

Boilers serving heating systems may be installed indoors provided they comply with requirements laid down by the Ordinance of the Minister of Construction and Building Material Industry, December 30, 1970 on the volume of the room, its height, and the exhaust of flue gases. When such units are installed in old buildings, problems arise with properly ventilating the room where the gas boiler is to be installed as well as adequately venting the combustion products (for example, no chimney ducts are available, or the need to remodel existing chimneys).

3.4.2. Analysis of Capital Cost of Reconstruction

An analysis of the cost of converting the heating system in an apartment by replacing the home stove by an individual gas-firing system was carried out for a typical 3-room apartment with kitchen, hallway and bathroom, having a floor area of 67 m^2, and situated on the second floor of a three-story building, with each story being 3.7 m high.

The scope of reconstructing the heating system included demolishing the existing ceramic stove and removing debris, installing a dual-purpose natural gas-firing boiler, installing heating pipes and fixtures, restoring the plaster on the walls, and repainting.

The analysis included three options:

- option 1 assumed using an existing free chimney duct to connect the boiler,
- option 2 assumed making a new brick chimney
- option 3 assumed that a chimney duct must be chiselled out in the living quarters of the second and third storeys, and a chimney added in the attic.

The costs involved under these three options were as follows:

	OPTION I	OPTION II	OPTION III
Installing central heating system			
(PLZ thousand)	57 016	57 016	57 016
($)	2 578	2 578	2 578
Demolishing stoves			
(PLZ thousand)	9 223	9 223	9 223
($)	417	417	417
Chimney construction			
(PLZ thousand)	136	4 568	3 298
($)	6	207	149
TOTAL			
(PLZ thousand)	66 376	70 808	69 538
($)	3 001	3 202	3 144

The overall cost of the conversion, including the cost of the boiler, will vary depending on the choice of the boiler. In the above table, the assumed cost of the boiler was approx. 23 million Polish zlotys (PLZ), equivalent to about 1,130 USD.

3.4.3. Conclusion

In recent years, converting coal-fired home stove heating to natural gas-fired systems often has been used as a way to modernize individual heating systems. As shown in this study, this is a very expensive option.

Apart from the economic aspect of using modern equipment, operational considerations are of importance, as well as environmental ones. The essential item in the overall costs is the installation of central heating system.

Because of regulations in force about installing natural gas-fired boilers in apartments, the most important technical problems were associated with ensuring the proper removal of flue gases, necessitating reconstruction of the existing chimneys or building new chimney ducts.

3.5 MODERNIZATION OF THE KRZESŁAWICE BOILER HOUSE

The detrimental impacts on air quality of existing, stoker-fired boiler houses can be largely eliminated by connecting them to the municipal district heating system or converting them from solid fuel-fired to natural-gas fired (possibly oil-fired). While these solutions have received considerable attention in Kraków, they may not be the most attractive economically, and in some cases, are not even possible. There is a group of several dozen boiler houses which provide steam to local industries for 12 months/year, and also boiler houses located on the peripheries which practically are too far from the district heating system and the gas distribution network.

This section describes the results of a study of options for a major modernization upgrade at one selected boiler houses. The upgrade would greatly improve its efficiency and reduce emissions while continuing to burn coal. In addition, one option involving conversion to oil-firing is included for comparison.

3.5.1 Selecting a Boiler House for Modernization

A boiler house was selected for a major modernization upgrade in 1990. It was decided that the selected site should be one of those owned by Municipal District Heating Enterprise in Kraków (MPEC). MPEC was asked to choose one of its boiler houses for this study; a boiler house at Krzesławice Supply Base was decided upon, which is operated all year.

The selection of the Krzesławice boiler house was based on the following:

- The existing boiler house is an old facility, operated for more than 30 years; the condition of the boilers and auxiliaries forces MPEC to plan either a major overhaul or replacement of the existing equipment.

- When the selection was made, the boiler house could not operate at its rated maximum output nor cover peak demand declared by the steam customers. Hence, there had been plans to extend the boiler house.

- In its present state, the boiler house could not comply with pollution emissions standards, not only future stringent standards, but also the more liberal present ones. The emissions from this boiler house have been and still are a major problem for the surrounding residential areas, aggravated by the fact that the boiler house is operated all year.

These conditions were essential in MPEC's selection of the Krzesławice boiler house from among several large "technological" ones that MPEC owns.

3.5.2 The Aims of Modernization of the Boiler House

The following were the aims of modernizing the boiler house:

- Installing modern equipment for combustion and pollution control, and hence, turning this facility into a nationwide pilot site.

- Significantly improving the efficiency of the heat-generating equipment so to significantly reduce the cost of fuel and other operational expenses.

- Bringing emissions from the boiler house into compliance with SO_2, NO_x and particulate emissions standards in force till December 31, 1997, and after 1997, when the standards will be tightened.

3.5.3 The Present State of the Boiler House

The Krzesławice boiler house provides high-pressure process steam for technological processes, and space heating for enterprises located within an industrial and warehouse quarter of Kraków. The following structures are located on the lot of about 0.5 hectare:

- Old boiler house building with 4 stoker steam boilers of water-tube type, PLM 2.5 type with a pump station, deaerator, and water-softening station - total output of the boiler house - 11.MW.

- New building with a back-up boiler type ERm - 8.0.

- A guardhouse used as an administration building.

- Fuel storage area with underground belt conveyor for feeding coal to the older boiler house.

- Additional fuel storage for the new, back-up boiler house.

The output of the old boiler house is about 18 to 20 tons/h of steam under 0.8 to 0.4 MPa pressure, while the back-up boiler house has an output of 8 tons of steam/hr with pressure up to 0.8 MPa. Both boiler houses use coal fines or small-sized coal. The fuel is delivered to the storage areas by truck. Coal is fed to the boiler house mechanically. The old boiler house has a belt conveyor in an underground tunnel. From there, coal is taken by a bucket conveyor to a belt conveyor over coal bins with daily supplies for PLM boilers. The new boiler house is supplied by two belt conveyors taking the fuel from a separate, small storage area. Bottom ash from PLM boilers is removed to larry cars and moved by elevator up to the ground level to an ash bin. Both boiler houses have cyclones with induced draft fans for controlling particulate emissions. The old boiler house has two steel chimneys 1,000 mm in diameter, about 16 m high, while the back-up boiler house has one new steel chimney.

A condensate-return system installation and a makeup-water preparation plant are situated in a basement of the old building. The system is replenished (at about 40% of the circulating volume) with water softened in cation exchanger-units.

The boiler house supplies steam to 8 nearby industrial plants including a laundry, food processing (meat, dairy, vegetable processing), and a bakery, construction material manufacturers, and a warehouse. Process steam is used for technological processes and for heating. The laundry requires process steam under 0.8 MPa; the remaining plants obtain steam under 0.4 MPa pressure.

The external piping network for steam and condensate is laid partially underground and partially elevated over the ground surface. The customer have meters for steam supplied. The overall length of overhead pipeline is 470 m:

- Steam pipes have diameters of 150 to 125 mm.
- Condensate pipes have diameters of 150 to 125 mm.

The overall length of underground pipelines is 780 m:

- Steam pipes have diameters of 150 to 65 mm.
- Condensate pipes have diameters of 100 to 50 mm.

The boiler house facility was commissioned in 1958. A continuing maintenance program allows the boilers to continue operation. During the 1992/93 heating season, the new back-up boiler house was commissioned, allowing outings for repairs and maintenance of the PLM-2.5 boilers and assuring that the peak customer demand will be met.

Balance of Heat Demand From Customers

Total process steam and heat demand balance for 1992 was as follows:

a. Present State:

- maximum 16.5 tons/h (39.3 GJ/h)
- daily average 197.5 tons/day (473 GJ/day)
- annual 57,350 tons/yr (137,400 GJ/r)

b. Projected Future State:

- maximum 17.4 tons/h (41.8 GJ/h)
- daily average 209.5 tons/day (502 GJ/day)
- annual 61,260 tons/yr (146,770 GJ/r)

Minimum demand levels - 1.5 tons/h (3.6 GJ/h) - occur in summer and during holidays. The following is the breakdown of daily average and annual demand for the projected future state:

- process steam 155.5 tons/day (49,930 tons/yr)
- for heating 53.9 tons/day (11,330 tons/yr)

According to the guidelines from MPEC Kraków, the modernization concept for the Krzesławice boiler house should encompass an unchanged thermal output, i.e. 11.6 MW. As some drop in the amounts of steam sold to the customers was observed recently, MPEC also would like to make provisions for modernizing the boiler house in stages.

Fuel Consumption

According to the data provided by the owner, in 1992, the Krzesławice boiler house generated 130,771 GJ, with 13,116 tons of fuel (coal fines) supplied. Monthly supplies of fuel range from 1,200 to 1,490 tons in winter months, and from 695 to 850 tons in summer. Fuel storage with bins has an area of 540 m^2 holding about 1,000 tons of coal fines. Additionally, near the new back-up boiler house, there is a roofed coal bunker with a usable area of about 100 m^2. At the present level of heat production, the boiler house can hold fuel reserve for one month.

Electricity

The old boiler house has two supply lines from the municipal transformer station; the back-up boiler house has a separate supply of electricity. In the old boiler house, all the equipment installed (including back-up systems) represents a total 260 kW. The maximum consumption of electricity of the equipment working at the same time is about 150 kW, while at average load it is 80 to 90 kW.

Pollution Control

Flue gases from PLM-2.5 boilers are sent through batteries of cyclones and then moved by induced draft fans to chimneys. Each boiler has an assembly of 3 cyclones with 630 mm diameters and a induced draft fan of WPWS-50 (2 pieces) or WWOax-63 (2 pieces). The flue gases then are released via two chimneys of 1,000 mm in diameter and about 16 m high.

Flue gases from the new of ERm-8.0 are cleaned in a battery of induced draft cyclones, and then removed by an induced-draft fan to a steel chimney of 700 mm in diameter, 37 m high.

Table 3-8 summarizes the present and future boiler emission regulations. The regulation of the Minister of Environmental Protection, 12 February 1990 requires that the existing installations meet the requirements for A group, till December 31, 1997 and, after that date the requirements for B group. However, new installations, i.e. commissioned after December 31, 1994, or installations whose construction was started after February 26, 1994, the date of the regulation coming into force, should meet requirements for group C.

The Krzeslawice boiler house should be modernized because of the environmental (air pollution) concern. In using boilers with different type of furnaces or changing the type of fuel, the boilers should meet standards envisaged for group C.

For hard coal (quantities of substances in g/GJ) referring to Table 3-8:

- coal fines-fired furnace with wet method of removing bottom ash

  SO_2= 200 NO_x= 170 particulates = 90

- coal fines-fired furnace with dry bottom-ash removal

  SO_2= 200 NO_x= 170 particulates = 130

For fuel oil (boilers of more than 50 MW_t):

- NO_2x= 35 [g/GJ]

  [NO_2x - sum of NO and NO_2 calculated as NO_2]

The options in this study were all developed to meet Group C regulations, at least.

Modernization Options Considered for the Boiler House

The engineering analysis was carried out by two teams, American and Polish.
Three American designs were prepared by Burns and Roe Services Corporation, Pittsburgh, under Morton Blinn, in cooperation with Peter Kemeny of Burns and Roe Company, Oradell,

N.J. Three Polish designs were prepared by the Kraków Industrial Construction Design Office (KBP-BBP), under Jerzy Sadowski. Each team adopted their own country's technology and equipment.

1. The American concept includes three options for modernizing the boiler house at Krzesławice Supply Base, using the following equipment:

- **a.** Two overfeed, vibrating grate-spreader stokers with fines recirculation and water-tube boilers and economizer. These are CP type, steam output 9 Mg/h, manufacturer: Tampella-Keller, Williamsport, Pennsylvania.

- **b.** Four atmospheric pressure circulating fluidized bed boilers (CFBC) steam output 4.5 Mg/h each, or, alternatively, two CFBC type boilers, steam output 9.0 Mg/h each, manufacturer: Donlee Technologies, York, Pennsylvania.

- **c.** A coal-fired boiler-feed water heater alternative based upon a near-commercial advanced coal-combustion technology supplied by Tecogen, Inc., Waltham, Massachussets.

2. The Polish concept of KBP-BBP includes three options for modernizing the boiler house with the following equipment:

- **d.** Three Polish-made circulating fluidized bed boilers, RPF type, steam output 7 Mg/h + 4 Mg/h.

- **e.** Two or four perforated-bottom fluidized pre-furnaces, KF type, with various steam boilers of steam capacities from 4 Mg/h to 8 Mg/h.

- **f.** Four Polish or imported oil-fired boilers, various types, steam capacities from 4 Mg/h to 5 Mg/h.

Description of Design Options

a. Options with CP boilers

The stoker-fired boiler option consists of two units, each producing 9.0 metric tons of steam per hour Tampella Power Corporation). Features include overfeed vibrating grates and fines recycle. Expected thermal efficiency is 87%. The units utilize a 20% slaked-lime water slurry fed to a spray dryer/absorber for controlling SO_2 and baghouses for controlling particulates. The slaked-lime suspension is introduced at the economizer's exit into a spray dryer/absorber vessel along with the flue gas. This vessel is sized for a 10-second gas residence time; 85-90% desulfurization is achievable. Emissions of SO_2 and particulates would meet, or be better than Polish standards. Without recirculation of flue gas NO_x emissions are projected to exceed Polish standards. However, these

Table 3-8. Maximum Permitted Emissions (g/GJ)

		A Existing Installations until Dec. 31, 1997			B Existing Installations After Jan. 1, 1998			C New Installations		
Fuel	Grate	SO_2	NO_2	Part.	SO_2	NO_2	Part.	SO_2	NO_2	Part.
Bituminous	Fixed Grate	990	35	1850	720	35	1370	650	35	1370
	Traveling Grate	990	160	800	640	95	600	200	95	600
	Pulverized Coal									
	Dry Bottom	1240	495	170	870	170	90	200	170	90
	Wet Bottom	1240	330	260	870	170	130	200	170	130
Brown Coal	Pulverized Coal									
	Dry Bottom	1540	225	140	1070	150	70	200	150	70
	Wet Bottom	1540	225	195	1070	150	95	200	150	95
Coke	Fixed Grate	410	45	720	410	45	235	410	45	235
	Traveling Grate	500	145	310	250	145	235	250	110	235
Heating Oil	Boilers < 50 MWe	1720	120	-	1250	120	-	1250	90	-
	Boilers > 50 MWe	1720	160	-	170	160	-	170	120	-
Natural Gas	Boilers < 50 MWe	60	-	-	35	-	-	35	-	-
	Boilers > 50 MWe	145	-	-	85	-	-	85	-	-
Wood	Grate	-	50	-	-	50	-	-	50	-

units were planned to include gas recirculation and NO_x is expected to be 1/3 of the uncontrolled level. These units incorporate oil guns for warm up. At the lowest demand levels of 1.5 to 2.0 tons of steam/hr, the load would be met using only the warm-up oil guns. This option requires a great deal of construction work, including new foundations for the new boilers replacing the existing PLM-2.5 units. Also an increase in electric supply capacity to the boiler house would be required.

b. Option with CFBC boilers

This option includes 4 U.S.-made circulating fluidized bed boilers (DONLEE Technologies, York, Pennsylvania) which may burn fuel of lower grade. Each unit consists of a combustor section, a cyclone for returning fines to the combustor via a sluice section, and an adjoining heat-exchange section that extracts heat from fluidized fines and ash coupled to a lift section that returns cooled solids to the combustor to control the temperature. Limestone is fed with the coal to control SO_2 levels and a baghouse is used for controlling particulates. Efficiency is expected to be as high as 87.7%, and Polish emission standards will be met. Each of the four units has a steam-production capacity of 4.5 metric tons per hour. Also considered was an option with two boilers, each with 9 metric tons per hour of output. Adopting the 4 units gives greater flexibility in meeting demand than in the option with two boilers. This option also requires major reconstruction of the boiler house and increased electric capacity.

c. Option with IRIS chamber

The combustor used in this option can generally be described as an Inertial Reactor with Internal Separation (IRIS) (Tecogen, Inc.) and it is currently at the demonstration stage of development. In this study, it was planned to use a small unit of this type only for pre-heating feedwater at Krzeslawice. The IRIS combustor concept employs centrifugal forces combined with a staged combustion process to achieve high carbon conversion efficiencies and low NO_x emissions. The combustion chamber is divided into multiple zones by partitions to retard the axial flow of unburned coal particles over a given size. This significantly increases the residence time for burning the coal to enable nearly complete carbon conversion for a wide range of particle sizes. Under this option only a small pilot unit would be installed for demonstration purposes with a coal feed of .166 metric tons per hour. The system includes a spray dryer/absorber for controlling SO_2 and a baghouse for controlling particulates.

d. Option with RPF boilers

A Kraków-based firm RENER reconstructs boilers, also of PLM type, as fluidized-bed boilers with a circulating bed. Each existing PLM-boiler can be refit with a new fluidized bed furnace with capacity of 7 tons of steam under medium pressure per hour. The structure of PLM boiler is partially used although new tube-heating surfaces are added. Traveling grates are replaced by fluidized beds with coils and circulating grates. Steam generation is carried by two units of 7 tons/h, and one unit of 4 tons/h output. Burning lower-quality fuel with sorbent allows compliance with air-quality standards. Particulates are collected in cyclones (adaptations of the existing ones) and bag filters. The boiler can be started up manually. The construction work required is limited to repairing the boiler's brickwork, adapting the roof to suspend a new furnace from it, and erecting new steel platforms for the dust collectors.

e. Option with KF boilers

This option includes using atmospheric fluid-bed pre-furnaces. The existing PLM-2.5 boilers are modernized by fitting a KF furnace with 4.5 tons/h steam output, plus additional superheaters. Coal of lower quality will be burned with sorbent. Cyclones and baghouses are used for controlling particulates. The boiler can be started up either manually or via oil-fired burners. Little construction work is required at the boiler house with this option, although an increase in electrical supply capacity is required. Another sub-option was also analyzed: applying KF pre-furnaces with cooled perforated bottom for a configuration of two new steel steam-boilers of ERm 8.0 type with 8 tons/h steam output, or with four ERm 4.5-type boilers with steam output of 4.5 ton/h, manufactured by SEFAKO - Sędziszów, or four, steel vertical boilers of VX type with steam output of 4 tons/h or 5 tons/h manufactured by Gdańsk Shipyard. Under this sub-option, the extent of construction work required will be greater because of necessary adaptations to the boiler's foundations.

f. Option with liquid fuel-fired boilers

In this option, the entire boiler house is converted to liquid fuel. Options involve four EOG-4.5 type boilers manufactured by SEFAKO, or VX vertical steel boilers with steam output of 5 tons, manufactured by Gdańsk Shipyard, or steel boilers of HK 5 000 type manufactured by HENSCHEL, Germany. The extent of construction work required includes adapting the foundations for new boilers. Fuel storage will require installing four fuel tanks of 50 m^3 capacity each. Flue gases would be removed by individual steel chimneys.

3.5.4 Summary of Options Analysis

In October 1993, comparative technical and economic analyses were made of all these concepts of modernization of the boiler house. Table 3-9 shows the results with the indices and characteristics. For the first three options, two cases were considered. In the first, all equipment would be purchased in the United States, and in the second, as much as possible of the equipment would be purchased in Poland.

The capital costs were highest in the options with full supplies of American equipment. In the options which envisage U.S.-Polish cooperation, the costs are much less; this is characterized by the index of capital cost related to the comparative output of the boiler house (item 11 in the

Table). This index has low values for stoker coal-fired boilers of CP type (supplier US/PL), and also for Polish fluidized-bed boilers RPF and KF. The lowest capital costs are incurred in options with oil-fired boilers, but the operational costs for these options are the highest.

The level of annual operating costs is more uniform among coal-fired boilers, with slightly higher values for CFB type fluidizied-bed boilers which, because of their high capital cost, involve higher sums paid for depreciation.

Evaluation Criteria

The following issues should be considered in selecting a modernization option:

- compliance with environmental regulations,
- factual heat demand from consumers and staging the modernization accordingly,
- owners's capability to allocate money to capital projects,
- the level of operational costs after modernization,
- technical quality of boiler units and auxiliary equipment.

All options presented will comply with air-quality standards. An issue in operating coal-fired boiler houses will be the considerable amount of waste generated in form of dust which will require dumping on landfills and paying dumping fees.

A very recent analysis of the heat demand of customers, which recently showed a declining tendency, will provide a basis for deciding on the extent of modernization and its staging. Presumably, a safe range of a capital project is to reconstruct 50% of the units under the first stage of modernization; this would spread capital expenditures over a longer period, and additionally will provide an opportunity to evaluate effectiveness of the modernization option.

Despite fluctuation of prices impairing the competitiveness of solid fuels in Poland, it is expected that operational costs will be relatively cheaper in many years to come because of their availability and the short distance for their transport to Kraków. Even with problems caused by solid waste, new combustion methods will burn the worst classes of coal, and thus bringing down the cost of generating heat. American CFB (Circulating Fluid Bed)-type options are interesting solutions and technically most effective, despite involving the highest capital costs, would be worthy of more widespread introduction than in only one facility. This would place modern known-how in much broader perspective, preparing ground in Poland for implementing environmental standards which will become effective after December 31, 1997.

Polish technologies of fluidized-bed combustion originated in Kraków also are worth considering as they show documented effectiveness and relatively low capital costs in implementation. Current stagnation in implementing capital projects is associated with the present economic situation in Poland, and is responsible for rather slow progress in this field in spite of undoubted advantages tested in concrete, completed projects, which are given as references by the firms involved in this study.

TABLE 3-9. Comparison of modernization options for the Krzeslawice boiler house. Indexes and characteristics [cost in $ from the mid of 1993 - November 1994 exchange rate = 23 300 zł/$, VAT tax included in investment cost]

No		Units	Modernization options									
			"a"		"b"		"c"		"d"	"e"	"f"
1	2	3	4	5	6	7	8	9	10	11	12
01	Option	-	CP	CP	CFB	CFB	IRIS	IRIS	RPF	KF/VX	E OG- 4.5-VX
02	Equipment supplies from	-	USA	USA/PL	USA	USA/PL	USA	USA/PL	PL	PL	PL
03	Furnace	-	stoker travelling grate		fluidized bed		fluidized bed		fluidized bed	fluidized bed	oil-fired
04	Number of boilers units	items	2	2	4	4	1	1	3	4	4
05	Boiler house steam output	Mg/h	18	18	18	18	-	-	18	18	18
06	Boiler house capacity (comparative)	MW	11	11	11	11	0.65	0.65	11	11	11
07	Boiler efficiency	%			up to 87.7		from 84 to 86		80	80	80
08	Fuel consumption (estimate)	Mt/year	9.00	9.00	8.70	8.70	about 0.50		9.40	9.70	4.80
09	Cost of boilers with auxiliary equipment	$ thousand mld zl	2 135.30 49.75	1 400.00 32.00	4 664.70 108.70	2 635.30 61.40	435.30 10.10	300.00 6.99	947.00 22.00	729.40 17.00	529.40 12.30
10	Total capital cost of the project	$ thousand mld zl	3 211.70 74.80	2 400.00 55.90	6 158.80 143.50	3 929.40 91.60	582.30 13.60	435.30 10.10	2 688.20 62.60	2 482.30 57.80	1 082.30 25.20
11	Index of capital costs	$ thousand/MW mld zl/MW	292.00 6.80	218.20 5.10	559.90 13.00	357.20 8.30	895.80 20.80	669.70 15.60	244.40 5.70	225.70 5.30	98.40 2.30
12	Operating costs	$ thousand/rok mld zl/rok	723.50 16.80	682.30 15.90	894.10 20.80	782.30 18.20	-	-	729.40 17.00	717.60 16.70	1 858.80 43.30
13	Index of operating costs	$ thousand/MW mld zl/MW	65.80 1.53	62.00 1.44	81.30 1.90	71.10 1.65	-	-	66.30 1.54	65.20 1.51	169.00 3.93

Rationale for Implementation

The main reason for modernization of Krzeslawice boiler house is to improve the efficiency of heating equipment and to reduce emissions of pollutants. The existing, several decades old stokers boilers, even if underwent overhauls, have average efficiency not much higher than 50%. New units with the expected efficiency over 80% will allow a significant reduction in costs of fuel (the main component of operational costs).

The other reason for modernization is to adjust the boiler house to more stringent environmental requirements which will come into effect after December 31, 1997. It should be expected that after that date the so-called environmental fees will have a decisive impact on calculation of costs. The present share of such fees in annual operational costs, below 3%, have not compelled any actions leading to emission reduction.

Option Selection

a) From the technical and economic analyses of the options for modernizing the boiler house, we do not recommend those options with complete supplies from the United States (high capital costs), nor conversion of the principal boiler house to use heating oil (an out-of-proportion increase in operational costs).

b) The option with CP-type stoker boilers (column 5) with U.S.-Polish supplies is characterized by beneficial indices for capital and operational costs, but has a disadvantage associated with the size of the boiler units. Using two units with steam output of 9 tons/h each will impede the flexibility of operating the boiler house, particularly under the present circumstances of declining demand from local customers.

c) Applying fluidized-bed boilers of smaller capacity will be more beneficial in terms of boiler-house operation; it also will allow adjusting the stages of modernization to the current energy demand. The choice should be made among three options: CFB boilers with combined US/PL supplies, Polish RPF, or Polish KF boilers.

d) The option with U.S.-supplied CFB boilers (column 7, Table 3-9) that has the best operational characteristics requires the highest capital expenditures, about 50% more than Polish options.

e) The cost of implementing Polish options involving RPF boilers (column 10) and KF boilers (column 11) are similar and represent about two-thirds of cost of CFB boilers. Currently operated units of RFK boilers show good operational characteristics supported by certificates from research institutes. Prototype units of KF type are characterized by simple design and effectiveness, and with the use of low-quality solid fuel, they hold prospects of further significant decreases in the cost of this single, largest component of operational costs.

f) Each of the options with fludizied-bed boilers permits compliance with air quality standards. The operational costs for these boilers will be similar, and higher by 10 to 15% than the current costs of operating boiler house with PLM boilers.

g) If the principal boiler house is modernized and the coal-fired boilers retained, it would be beneficial to convert the back-up boiler house to heating oil so it can be used in periods of low demand for heat, or as back-up facility for outings and repairs of the main boiler. Also, this gives the ability to start-up the facility in short time, and to reduce the number of workers employed. Capital costs will be required only to adapt ERm to liquid fuel and to install fuel storage tanks. With this approach, the operational reliability of the entire facility would be enhanced.

Final Remark

As a result of a bidding procedure carried out by the U.S. Department of Energy under a Program Opportunity Notice, being the II Phase of U.S.-Polish Program for Elimination of Low Emission Sources, an American firm, Tecogen, Inc. in a joint venture with the Municipal District Heating Company (MPEC Kraków), has undertaken a modernization project at the Krzesławice boiler house based on its own proposals. At present, the course and scope of modernization are being discussed under preliminary arrangements. While this modernization study was based on the Krzesławice boiler house, this site was selected as a typical example. Results of this study are considered applicable in Poland generally.

3.6 SOLID FUEL SUPPLIES TO KRAKÓW

3.6.1 Present State

A 1991 survey of Kraków boiler houses and homes indicated that the following quantities of solid fuels were used:

A. In Boiler Houses [metric tons per year]:

A 1991 survey of Kraków boiler houses and homes indicated that the following quantities of solid fuels were used:

A. In Boiler Houses [metric tons per year]:

- fine coal in stoker-fired boilers 237,700
- lump coal in hand-fired boilers 52,400
- coke in hand-fied boilers 83,700

One very important emission source which is strongly affected by fuel quality is boilers with travelling grates that burn coal of 0 to 20 [mm] grain size. Up to now, these boiler houses have used run-of-mine coal fines i.e. fines that are neither washed nor graded, which generate large amounts of gaseous pollutants and, despite control devices, also emissions of particulates. Until 1993, MPEC, the owner of the greatest number of boilers with travelling grates, purchased its coal fines from the Ziemowit mine. After 1993, and also because of the results of the tests completed under the U.S.-Polish program, MPEC has bought coal fines from the Staszic coal mines. This fuel has lower emissions than that of coal fines from the Ziemowit mine. Most of the coke used in Kraków's boiler houses is produced by a coking plant at Knurów near Zabrze.

B. Individual Ceramic Coal Stoves and Small Boilers for Apartments

A survey conducted by BRK during this program showed that there were 99,986 stoves and 4,314 small boilers in apartments, using an estimated 100,000 tons of coal per year. As a rule, the coal is in big chunks with good physical and chemical characteristics (0.5% sulphur and about 6.5% ash). In the past, this coal was obtained mainly from the Wujek coal mine. At present, the Wujek coal is being pushed out of the market by inferior but cheaper kinds of coal from other mines. The very fact of burning coal and the methods of its use is a reason for the existence of low emissions in Kraków. The issues associated with emissions produced by coal combustion in boiler houses and home stoves were included in the scope of the U.S.-Polish program to eliminate low-emission sources in Kraków. One possible remedial measure that was offered was to obtain better fuels which cause significantly lower emissions. Until quite lately, all coal mines have offered only run-of-mine coal, i.e. without washing and adequate grading to separate out the least desirable, finest fractions 0 to 5 [mm]. In the last 2-3 years, significant changes have occurred. Many coal mines have started to operate washing plants and are offering fuel of a significantly higher quality.

3.6.2 The Possibilities of Obtaining "Improved" Fuels

As part of this program on low emission sources, a study was conducted to evaluate the costs associated with providing better quality fuels for Kraków users.
The following fuels are considered "improved" ones:

a. coal fines washed and graded - for boilers with travelling grates
b. smokeless briquettes - for steel boilers with fixed grates, and also for home stoves

The most available and suitable coal for producing "improved" fuels, i.e. washed and graded coal, and for making briquettes is coal of the types 32.1 to 43.0, i.e., flame-gas coal. Polish mines, which have coals of 33.0 type and higher, already have their own facilities allowing them to grade coal. More and more mines are upgrading their processing facilities, and not only do they grade the coal fines, but also wash them.

The following mines have coal of 33.0 type and installations to improve it:

- Rydultowy, Anna, Marcel, Rymer, Chwałowice, Jankowice, 1-Maja mines of Rybnik Coal Company

- Borynia, Jastrzębie, Krupiński, Morcinek, Moszczenica, Pniówek i Zofiówka mines of Jastrzebie Coal Company

- Gliwice, Sośnica, Knurów, Makoszowy, Szczygłowice, Dębińsko i Bolesław Śmiały mines of Gliwice Coal Company

- Barbara, Halemba, Nowy Wirek, Pokój, Polska, Siemanowice, Wawel i Zabrze mines of Ruda Coal Company

Coal of lower types - 31.1-32.2 - is extracted at mines closer to Kraków, i.e. in the Bytom Coal Company mine and the Nadwiślańska Coal Company mine. These mines also have taken steps to set up and operate coal improvement facilities. Their target is to produce improved fuel with grain sizes within the 0-20 mm range. The American-Polish company, ECOCOAL, set up under the U.S.-Polish program is currently negotiating with these coal companies for deliveries of run-of-mine coal for its own coal improvement facility. This facility is intended in future to supply good quality coal to Kraków - including coal of a 5-10 mm grain size that is suitable for boilers with travelling grates.

Smokeless ("ecological") briquettes for ceramic coal stoves and for steel boilers are not yet manufactured on an industrial scale. In the past few years, attempts have been made, and still continue, to develop the appropriate technology and to find the right site for a plant which would produce ecological fuel in form of smokeless briquettes based on coal fines. At the Institute for Chemical Process of Coal in Zabrze, such a technology was developed, and then a pilot-scale installation was operated to produce two types of briquettes:

- based on chars obtained from various types of coal. Pressed in a cold process with binders and some additives to bind noxious combustion products. A several fold reduction in emissions of particulates, SO_2 and tar products was achieved.

- smokeless, based on highly degasified coals, formed in a hot process with additives binding noxious combustion products. The technology involved inmanufacturing these briquettes is more involved and expensive. Burning these briquettes significantly reduces harmful emissions, particularly those of particulates, tar substances, and aromatic hydrocarbons; this is why the briquettes are the most suitable for ceramic home stoves and their use is highly advisable. This fuel is environmentally "clean" and smokeless, and also offers energy savings because of its very good characteristics of maintaining combustion.

Recently, there has been increased interest in manufacturing briquettes from various raw materials, and offering various degrees of "environmental soundness":

- based on coal from a coal mine at Bogdanka near Lublin, Brikpol Ltd. manufactures so-called "coal cubes" which consists almost 100% of coal fines powdered under high pressure, with a fraction of a percent of the newestgeneration ecological binder added. In the 1994-1995 heating season, the cubes had a promotional price of 795,000 PLZ (i.e. $ 35 USD) - loco Bogdanka + 7% VAT. The characteristics of the emissions are unknown.

- several firms entered a tentative agreement to consider the staged construction of a large coal-processing installation in Silesia, near Blachownia to produce sorted, graded, and washed coal fines, and smokeless briquettes.

At the same time, there have been some attempts to manufacture and sell briquettes made of sawdust:

- bark-sawdust briquettes (so-called "ecobriquettes") for burning in ceramic stoves, small central-heating boilers of single-family houses, and small boiler houses serving multi-family housing. The calorific value equals that of high quality hard coal; (5,690 Kcal/kg), sulfur-free fuel with 5% ash content. They are manufactured by Nabru Ltd. at Świecie.

- sawdust briquettes - manufactured by ZEUKO - TES TARTAK of Franciszek Niedźwiedź 190, near Mszana Dolna.

3.6.3 Cost of Improved Fuels

For the purpose of developing costs estimates for improved coal for stokers, five mines in Silesia were selected for study. Based upon run-of-mine coal quality, capacity, current output, and facilities, these were considered most suitable for the production of washed and graded coals for stokers. At each site, studies were done under this program (Main Coal Processing Study and Design Office - SEPARATOR - Katowice) of the facilities upgrade requirements and the projected sales price for the improved fuels. These studies were done in cooperation with the engineering staff at the mines. Table 3-10 provides a summary of the results.

Briquettes produced by the Institute for Chemical Processing of Coal in Zabrze on May 1, 1994 were priced at:

1,800,000 PLZ/ton - 80.5 USD/ton

This price can be considered only a rough estimate because this fuel is not now on the market.

Sawdust briquettes ZEUKO-TES, priced at local manufacturer:

856,000 PLZ/ton - 38.2 USD/ton

In addition to these estimated prices, it is useful to review prices currently paid by MPEC for stoker fuels. Until 1992, MPEC purchased fine, unwashed and ungraded (0 to 20 mm) coal from the Źiemowit coal mine. The price for this coal in 1992 was 165,900 Źl/ton - $12.20/ton. Presently, MPEC purchased coal from the Staszic mine. Table 3-11 summarizes the cost and quality of these fuels.

Table 3-10. Estimated Prices for Improved Fuels for Stoker-Fired Boiler Houses. Based on Study Completed by the Main Coal Processing Study and Design Office - SEPARATOR - Katowice.

Mine	Staszic	Katowice	Wieczorek	Rozbark	Powstańców Śląskich
Raw Coal 0 to 20 mm					
Sale Price PLZ/metric ton at mine	327,000	580,000	572,000	380,000	360,000
$/metric ton (1992)	$24.00	$42.60	$42.00	$28.00	$26.50
Improved Coal					
Coal Size [mm]	5 to 10	8 to 16	5 to 16	6 to 14	8 to 16
Ash Content [%]	<5	3-5	4-5.5	5.5	5
Sulfur Content [%]	0.6	0.4-0.6	0.6	0.6	0.55
Design Output [metric tons per year]	280	280	200	280	280
Investment Cost [million ZL]	1500	7500	1000	0	0
Sale Price PLZ/metric ton at mine	1,000,000	700,000	700,000	720,000	800,000
$/metric ton (1992)	$73.50	$51.50	$51.50	$52.90	$58.80

note: all prices in this table include VAT - Value Added Tax.

Table 3-11 Fuels Currently Purchased by MPEC. Cost and Quality

Coal Mine	Staszic	Staszic
Type	run-of mine	washed
Size	0 to 20 mm	0 to 20 mm
Ash [%]	20	10
Sulfur [%]	0.8	0.8
Price at the mine [Zl/ton]	780,000	909,900
Price at the mine [$/ton]	36.00	42.00

4.0 EFFECTS ON AIR QUALITY

4.1 BACKGROUND

Many centuries of development, with a rapid acceleration in housing construction after WW II (a threefold increase in the city's resident population), has brought many different heating systems into Kraków; they range from primitive coal-fired home stoves, in-building coke- and coal-fired boilers, local boiler houses serving multi-family housing and whole housing estates, up to district heating systems supplied from central combined heat and power (CHP) plants.

Because of its natural resources, more than 90% of heating in Poland is based on burning solid fuels. Air quality monitoring studies in Kraków during the 1980s indicated that around 40% of the high concentrations of air pollutants adversely affecting residents and the natural environment were contributed by solid fuel-fired home stoves and local boiler houses. The most convincing proof was provided by the similar increase in pollution in winter.

A 1991 inventory showed the following sources operating in Kraków:

- 1134 solid fuel-fired boiler houses with a designed capacity of 997 MW,
- about 100,000 coal-fired home stoves, and
- some 15.6 thousand rooms and spaces heated by small boilers using solid fuel.

The boiler houses consume about 375,000 Mg of solid fuel per year, the home stoves a further 100,000 Mg, giving combined consumption of coke and coal by low-emission sources of around 500,000 Mg per year.

Correspondingly, the annual average values for the concentrations of SO_2 and particulate pollutants in the Kraków area are given below, together with their permissible levels:

	Particulates	SO_2 ($\mu g/m^3$)
1988	70	78
1989	61	66
1990	54	63
1991	48	69
1992	45	60
1993	39	50
Permissible Levels	50	32

The permissible levels for annual average concentrations of NO_x and CO are 50 $\mu g/m^3$, and 120 $\mu g/m^3$, respectively.

The U.S.-Polish Program centered in Kraków has assumed that all available technical means of reducing low-emissions sources will be used to abate air pollution, especially those solutions using the existing reserves in city's district heating, gas, and power supply systems.

As an alternative, transitional solution, the existing heating systems were tested with clean fuels, such as smokeless briquettes for home stoves, and graded and washed coal for boilers. All the engineering analyses were evaluated for potential reductions in air pollution, by determining the expected reductions in pollution loads and in the major concentrations of pollutants.

4.1.1 Legal Regulation and Standards

At present, environmental fees and fines in the field of air pollution are regulated by the following legislation:

- Act on Environmental Protection and Management of January 31, 1980 (Dz. U. Official Journal, No. 3, item 3 amended in 1989, 1990, and 1993).
- Ordinance of the Council of Ministers of December 21, 1991 on fees for using the environment for economic purposes (Dz. U. No. 125, item 558 amended in 1992 and 1993).
- Ordinance of the Council of Ministers of December 23, 1987 on levels, rules for imposing and procedures for enforcement of monetary fines for non-compliance with environmental protection requirements (Dz. U. No. 84, item 404).

The enforcement of environmental provisions is implemented by the following system of administrative rulings:

- ruling on permissible emissions (emission permit);
- ruling on assessment of fees for using the environment for economic purposes;
- ruling on imposing fines for non-compliance with environmental protection requirements

An emission permit sets the following requirements:

- types and amounts of pollutants allowed to discharge into the environment from particular sources, and
- technical specifications of permissible discharges.

Pursuant to the provisions of Article 30 of the Act on Environmental Protection and Management, this kind of permit should be obtained by any administrative unit (firm, enterprise), or any individual pursuing business. The provisions are not binding on persons who do not run businesses, but only use fuel for heating their apartments. The administrative rulings are issued by the voivode (governor).

The fees for using the environment for economic purposes also are assessed by the voivode, under administrative ruling procedures. The obligation to pay these fees rests with entities and administrative units who own the businesses. Individuals not involved in businesses are exempt from this environmental fee. The levels of fees are assessed according to the "Schedule of emissions fees" which gives rates for mass units of various pollutants. If a polluter discharges several pollutants, the fee is calculated as a sum of partial fees. The fee is assessed for actual emissions of pollutants, derived from data on fuel consumption, and not against the permissible amount set in a "decision of permissible amount of pollution."

A system of fines is established in Art. 110, 110a, 110b, and 110c of the Act on Environmental Protection and Management. A unit rate of fine is 10 times the amount of fee; these penalties are imposed whenever the permissible emissions are exceeded. Proof of excessive emissions is obtained by on-site measurements of actual emissions. The authority imposing the fines is the Voivodship Inspectorate for Environmental Protection.

The fines are imposed as hourly rates, i.e., the amount exceeding permissible emissions x 10 times basic fee, or as 24-hourly rates, i.e., the hourly rate x number of hours of daily operation of an installation. The fines are calculated from starting the measurement until the emissions are brought down to the permissible level.

A new Act to protect the air against pollution is expected to be passed within a year. This Act should ensure the timely payment of fines, as the present legislation contains some loopholes allowing polluters to evade these payments.

The air pollution standards contained in the ordinance of Ministry of Environmental Protection of July 7, 1990 are binding till December 31, 1997, and new standards for after that date are given there. Hence, no updating is expected.

The rates of fees for using the environment, and the non-compliance fines will be updated annually.

4.2 METHODS OF CALCULATION

The environmental effects of engineering options included in the program for eliminating low-emissions sources were calculated in the following forms:

a. Values of pollutant concentrations occurring as a result of discharging certain loads of pollution into the air, and
b. absolute quantities of pollutant-emissions loads, defined as the difference between the present level of pollutant load, i.e. before the program, and the load after its implementation.

Air quality was modelled with Pasquille's model. This mathematical model is popular and widely applied world-wide. It is relatively simple but, at the same time, gives a high level of correspondence between the calculations and the actual situation.

The evaluation covered four basic pollutants from the energy sector: particulates, sulfur dioxide, nitrogen oxides, and carbon monoxide. Balances of emissions were completed for these four pollutants. Calculations of concentrations were done for two components, suspended particulates and sulfur dioxide; assessments of their emissions were supplemented with "equivalent emissions" calculations.

Equivalent emissions is the sum of products obtained by multiplying emissions by their "toxicity coefficients," defined by the Ministry of Environmental Protection. The toxicity coefficients relate the degree of environmental effects of a particular pollutant to those of sulfur dioxide:

- toxicity coefficient of sulfur dioxide 1.0
- toxicity coefficient of particulates and nitrogen dioxide 2.9
- toxicity coefficient of carbon monoxide 0.5

$$Er = 2.9 (E_p + E_{NOx}) \times 0.5 E_{co} + E_{SO2}$$

Calculating the equivalent emission is a common denominator for various pollutants. This value is of particular importance in cases where some heating systems are replaced by other systems with notably different emissions characteristics. Other definitions of equivalent emissions include hydrocarbons (see Chapter 2, for example), but the difference in results is small and not relevant to this analysis.

4.3 SUMMARY OF RESULTS: CONVERSION OF OLD TOWN BOILER HOUSES TO NATURAL GAS FIRING

The main aim of this part was to evaluate the environmental effects for engineering options under Subproject 2, i.e. conversion of solid fuel-fired boiler houses within the Old Town district of Kraków to natural gas-fired ones.

The 1991 survey showed that 48 solid-fuel boiler houses of 18,653 kW designed capacity still operated in the area. Forty-three of these are earmarked for conversion to natural gas; 5 will be eliminated without replacement. During heating season, these boiler houses emit about 40 Mg of sulfur dioxide, representing about 30% of the overall load of SO_2 in this part of town from low sources (with the remaining 70% of emissions coming from coal-fired home stoves).

After converting these boiler houses to natural gas, the following effects will be obtained:

- practically complete elimination of SO_2, particulates and CO from these sources,
- an increase in nitrogen dioxide emissions by about 70% of present load.

Table 4-1. Effect on Emissions of Replacing Coal Boiler Houses by Gas

POLLUTANT	EMISSIONS	TOXICITY COEFFICIENT	EQUIVALENT EMISSIONS
-	[kgs/season]	-	[kgs SO_2/season]
PRESENT EMISSIONS STATUS			
TOTAL PARTICULATES	61 314	2.9	177 810
SULFUR DIOXIDE	39 970	1.0	39 970
NITROGEN DIOXIDE	6 815	2.9	19 763
CARBON MONOXIDE	204 435	0.5	102 217
OVERALL PRESENT EMISSIONS STATUS			339 760
DESIGNED EMISSIONS STATUS			
TOTAL PARTICULATES	1 304	2.9	4 147
SULFUR DIOXIDE	1 567	1.0	1 567
NITROGEN DIOXIDE	12 045	2.9	34 931
CARBON MONOXIDE	1 296	0.5	648
OVERALL DESIGNED EMISSIONS STATUS			41 293
IMPROVEMENT			298 467

Emission reductions are shown in Table 4.1, above.

In conventional units of equivalent emissions, the effect of this conversion will be 298 Mg SO_2.

In comparison with the present conditions, the SO_2 concentration in Old Town will drop by about 10 $\mu g/m^3$, with average concentrations noted in 1991 at about 110 $\mu g/m^3$.

4.4 SUMMARY OF RESULTS: MODERNIZATION OF THE KRZESŁAWICE BOILER HOUSE

The Krzesławice boiler house is a heat/process steam-producing facility built in 1957 which is owned and operated by MPEC Kraków. This facility supplies process steam to nearby industries and provides heat to some of them during the heating season.

Technical Specifications:

- equipment: 4 boilers of PLM-2.5, each of designed capacity of 2.9 MW
- overall designed steam output: 4.2 Mg/hr
- theoretical efficiency: 75%
- actual efficiency: 54%
- 1992 fuel consumption: 13,116 Mg/year

Air Pollution Control Equipment:

- blowing fans: 2 pcs
- flue gas exhaust fan: 1 pc
- battery of cyclones: 6 cyclones in a battery

The boilers use coal fines of M II class, previously from the Ziemowit coal mine, at present from the Staszic coal mine.

Calculations of the effects on ambient air quality from the present state of pollution were based on a test series carried out on Boiler No. 3 under the scope of work of Energoekspert company.

These assessments were completed for particulates and sulfur dioxide; the results are as follows:

- suspended particulates - momentary concentration:
  0.0568 $\mu g/m^3$ = 22.7% of permissible level

- particulates - annual average concentration:
  5.377 $\mu g/m^3$ = 10.8% of permissible level

- sulfur dioxide - momentary concentration:
  1.4077 $\mu g/m^3$ = 234.6% of permissible level

  sulfur dioxide - annual average concentration:
  113.04 $\mu g/m^3$ = 353% of permissible level

- particulate fallout:
  793.1 $Mg/km^2/year$ = 400% of permissible level

Thus, the facility presently has a considerable detrimental effect on the environment, and pollution control is unsatisfactory.

To calculate the designed pollution status, an option was considered of installing 4 fluidized-bed units of the CFBC type, manufactured by Donlee and supported by the IRIS system for preheating feed water (see Section 3.5). Because the specifications of Ziemowit coal do not achieve compliance with the emission standards for sulfur dioxide, it was assumed that after the achieve compliance with the emission standards for sulfur dioxide, it was assumed that after the modernization is completed, the coal supply will be obtained from Staszic mine.

With these changes, the status of air quality will be as follows:

- suspended particulates - momentary concentration:
  0.0112 $\mu g/m^3$ = 4.5% of permissible level

- particulates - annual average concentration
  0.681 $\mu g/m^3$ = 0.1% of permissible level

- sulfur dioxide - momentary concentration:
  0.3429 $\mu g/m^3$ = 57.2% of permissible level

  sulfur dioxide - annual average concentration:
  20.84 $\mu g/m^3$ = 65.1% of permissible level

- particulate fallout:
  65.2 Mg/km^2/year = 33% of permissible level.

It is evident that the suggested option of modernizing the boiler house will provide a complete solution in terms of abatement of air pollution, bringing emissions down to compliance levels.

Table 4-2 shows the detailed calculations of environmental effects for the present and designed system, together with the equivalent emissions.

Table 4-2. Effects on Emissions of Modernizing the Krzesławice Boiler House

POLLUTANT	ANNUAL EMISSIONS (Mg)			EQUIVALENT EMISSIONS (Mg)		
	PRESENT	DESIGNED	IMPROVEMENT	PRESENT	DESIGNED	IMPROVEMENT
TOTAL PARTICULATES	28.575	1.995	26.580	82. 868	5.787	77.081
SULFUR DIOXIDE	166.049	17.041	149.008	166.049	17.041	149.006
NITROGEN DIOXIDE	40.503	19.809	20.694	117.439	57.445	60.014
CARBON MONOXIDE	236.546	3.100	233.446	118.273	1.550	116.723
T O T A L				484.648	81.823	402.826

4.5 SUMMARY OF RESULTS: CONVERTING HOME COAL-FIRED STOVES TO ELECTRICITY

The aim of this part of the program was to evaluate the environmental effects for engineering analysis under Subproject 3, i.e. "conversion of coal-fired home stoves to electricity within the range of Łobzów Substation." This section of the town has 592 residential buildings, 552 of which use individual solid fuel-firing systems for heating.

The structure of solid fuel-fired heating systems, by type, is as follows:

- 3184 apartments are heated, with 7897 coal stoves,
- 84 apartments are heated by small boilers,
- 149 commercial premises are heated by 505 coal-fired boilers, and
- 22 commercial premises are heated by small boilers.

In the environmental analysis, it was assumed that the remaining heating systems in buildings and other premises, such as boiler houses, natural gas-fired stoves and existing electric heating, continue without any changes.

Also, it was assumed that the energy needed to generate an equivalent amount of electricity will be shifted entirely to the Łeg CHP Plant.

Characteristics of average quality coal were adopted for the calculations.

Table 4-3 shows the environmental effects, together with the equivalent emissions. The calculations indicate that converting home stoves from coal to electricity will eliminate:

- particulates 101.7 Mg/season
- SO_2 31.7 Mg/season
- CO 317.0 Mg/season
- equivalent emissions 474.2 Mg/season

At the same time there will be an increase in NO_x emissions by 2.7 Mg/season related to the much higher temperature of combustion process in ECKSA facility.

The resultant decrease in concentration of SO_2 in air will be about 10 $\mu g/m^3$ (currently averaging 110 $\mu g/m^3$).

This effect will be attainable at the cost of increasing emissions from heat and power plants by 88.9 conventional units of equivalent emissions.

In this case, emissions of suspended particulates, nitrogen oxide, and carbon monoxide are a marginal nuisance as these increased loads from central sources are several orders of magnitude

Table 4-3. Effect on Emissions of Converting Home Stoves to Electric Heating in Łobzów Region

POLLUTANT	EMISSIONS	TOXICITY COEFFICIENT	EQUIVALENT EMISSIONS
	kg/season		kg SO_2/season
PRESENT EMISSIONS STATUS			
TOTAL PARTICULATES	101 611	2.9	294 672
SULFUR DIOXIDE	79 242	1.0	79 241
NITROGEN DIOXIDE	10 585	2.9	30 696
CARBON MONOXIDE	317 536	0.5	158 768
OVERALL STATUS			563 167
DESIGNED EMISSIONS STATUS			
TOTAL PARTICULATES	925	2.9	2 682
SULFUR DIOXIDE	47 360	1.0	47 360
NITROGEN DIOXIDE	13 320	2.9	38 628
CARBON MONOXIDE	520	0.5	260
OVERALL DESIGNED EMISSIONS STATUS			88 930
IMPROVEMENT			474 237

lower, and the load of pollution shifted to Łeg CHP Plant will cease to be felt by the city due to high stacks and greater plume rise, as well as control equipment.

4.6 SUMMARY OF RESULTS: ELIMINATING HOME STOVES OR USING BRIQUETTES IN HOME STOVES

During the heating season, there are about 100,000 coal-fired home stoves and several thousand small, solid fuel-fired boilers (apartment heating) operating in Kraków.

A report was prepared showing the environmental effects of replacing these low emissions sources with "clean" heating media (electricity, natural gas) as SCENARIO I; SCENARIO II included using smokeless briquettes for firing in home stoves and boilers. For easier analysis, the entire area of the town was divided into 20 heating districts. The basic data for the calculations were provided by BRK's 1991 inventory of the emission sources.

The survey gave the structure of heating systems in the individual districts (Table 4-4). Almost half of the area is heated by stoves, and more than a quarter by gas. As in the previous analyses the environmental effects were estimated in units of pollution load reduction (Mg/year), and in units of ambient concentrations of sulfur dioxide and suspended dust within town.

Table 4-5 shows the calculations made for the existing status of four basic pollutants and for the equivalent emissions. The results of calculations for SCENARIO I, i.e. "clean" heating media are shown in Table 4-6. SCENARIO II, "smokeless briquettes" is illustrated in Table 4-7. Tables 4-8 and 4-9 give the combined results for the scenarios.

As shown in these Tables replacing coal-fired stoves by natural gas-fired and electric units, SCENARIO I, reduces pollution in the following way:

Total Particulates	3,468 Mg/year
SO_2	539 Mg/year
NO_x	529 Mg/year
CO	4,558 Mg/year
Equivalent Emissions	14,409 Mg/year

Similarly, for SCENARIO II i.e. using smokeless briquettes instead of coal in home stoves:

Total Particulates	3,133 Mg/year
SO_2	562 Mg/year
NO_x	551 Mg/year
CO	1,995 Mg/year
Equivalent Emissions	12,243 Mg/year

Thus, the overall effects of both scenarios are similar; however, the first one requires some capital expenditure by residents while the second can be implemented practically without any expenditure. An overall reduction in pollution (particulates, SO_2, NO_x) is almost identical in these two cases. The advantage of SCENARIO I lies only in the reduction of CO emissions which is almost double.

In STRADOM-KAZIMIERZ (No. 5) the district with the highest number of home stoves, the concentrations of pollutants are the most threatening, reaching 10-50 $\mu g/m^3$ of particulates, and 8 to 32 $\mu g/m^3$ for SO_2. As the result of many years of preferences for clean energy media within the OLD TOWN (district 4), the concentrations dropped in the Main Market Square district.

Under the "clean media" scenario, almost all of low emissions would be eliminated from the town. The pollution load is shifted to the central source (CHP at Łeg under the model's assumption) and is no longer felt by Kraków residents. The overall increase in concentrations brought about by additional emissions from CHP at Łeg are three orders of magnitude lower than those presently occurring. Indeed, a map showing concentrations for the designed stage would be empty.

Under the "briquettes" scenario, the concentrations would be four times lower than with the present emissions.

Table 4-4. Structure of Individual Heating Systems (in m³ of heated space)

DISTRICT	STOVES	BOILERS	GAS	ELECTRICITY	TOTAL
01	294 622	10 914	44 059	110 211	459 806
02	591 996	32 621	72 749	285 832	983 198
03	722 162	30 140	100 186	366 379	1 218 867
04	326 719	9 219	49 608	172 020	557 566
05	1 703 923	53 881	60 495	273 529	2 091 828
06	314 110	19 267	47 633	94 844	475 854
07	205 412	30 807	168 818	94 048	499 085
08	212 024	263 377	428 063	50 358	953 822
09	124 548	30 416	152 791	32 621	340 376
10	155 994	77 770	240 060	34 155	507 979
11	81 479	24 673	193 462	30 230	329 844
12	554 882	67 107	149 022	267 547	1 038 558
13	79 784	47 678	134 838	110 211	372 511
14	332 955	133 754	919 060	33 286	1 419 055
15	27 053	580	4 993	5 603	38 229
16	217 206	14 382	79 184	47 712	358 484
17	643 563	15 551	44 655	109 600	813 369
18	100 880	28 220	280 806	16 002	425 908
19	137 856	97 629	448 552	11 498	695 535
20	294 622	117 587	551 540	25 377	989 126
m³	7 121 790	1 105 573	4 170 574	2 171 063	14 569 000
%	48.9	7.6	28.6	14.9	100

Table 4-5. Annual Emissions (Mg/Year): Present State

DISTRICT	TOTAL PARTICULATES	SULFUR DIOXIDE	NITROGEN OXIDES	CARBON MONOXIDE	EQUIVALENT EMISSIONS
01	136	42	33	167	616
02	276	85	66	342	1 250
03	334	103	81	410	1 513
04	150	46	37	183	679
05	785	239	187	957	3 535
06	147	46	36	183	666
07	101	33	27	132	469
08	161	72	39	289	795
09	64	22	18	88	303
10	90	34	24	136	434
11	43	15	14	61	212
12	268	86	65	344	1 223
13	48	19	13	75	233
14	185	67	61	270	917
15	12	4	3	15	56
16	102	32	26	127	466
17	295	90	71	358	1 331
18	53	18	18	74	263
19	87	35	28	140	438
20	163	59	48	238	790
TOTAL	3 502	1 144	895	4 587	16 188

Table 4-6. Pollutant Emissions Scenario I - Clean Heating Media

DISTRICT	DESIGNED STRUCTURE OF HEATING SYSTEMS m^3		EXPECTED LOW EMISSIONS, Mg/YEAR*			
	GAS	ELECTRICITY	TOTAL PARTICULATES	NO_x	CO	EQUIVALENT EMISSIONS
01	139 116	320 690	0	3	0	9
02	225 474	757 724	1	5	1	18
03	285 397	933 470	1	7	1	24
04	131 958	425 608	0	3	0	9
05	422 973	1 668 855	1	10	1	32
06	171 913	303 941	0	4	0	12
07	331 545	167 540	1	8	1	27
08	881 147	72 675	2	21	2	68
09	285 842	54 534	1	7	1	24
10	454 394	53 585	1	11	1	35
11	288 603	41 241	1	7	1	24
12	414 631	623 927	1	10	1	32
13	226 417	146 094	1	5	1	18
14	1 374 132	44 923	4	33	4	109
15	18 321	19 908	0	0	0	0
16	229 104	129 380	1	6	1	21
17	246 510	566 859	1	6	1	21
18	404 467	21 441	1	10	1	32
19	680 592	14 943	2	17	2	56
20	950 789	38 337	2	23	2	74
TOTAL	8 163 325	6 405 675	22	196	22	645

* Under this scenario, there would be no emissions of SO_2.

Table 4-7. Pollutant Emissions Scenario II - Briquettes

DISTRICT	DESIGN STRUCTURE OF HEATING SYSTEMS m^3		EXPECTED LOW EMISSIONS, Mg/YEAR				
	Briquettes	Gas	Total Particulates	SO_2	NO_x	CO	Equivalent Emissions
01	305 536	44 059	15	21	10	106	147
02	624 617	72 749	30	43	20	216	296
03	0	130 326	0	0	3	0	9
04	335 938	49 608	16	23	11	116	159
05	1 757 804	60 495	84	121	54	607	825
06	333 377	47 633	16	23	11	115	159
07	236 219	168 818	12	16	11	82	124
08	475 401	428 063	24	33	25	165	258
09	154 964	152 791	8	11	8	54	84
10	233 764	240 060	12	16	13	81	129
11	106 152	193 462	6	7	8	37	66
12	621 989	149 022	30	43	22	215	301
13	127 462	134 838	6	9	7	44	69
14	466 709	919 060	25	32	36	164	291
15	27 633	4 993	1	2	1	10	13
16	231 588	79 184	11	16	9	80	114
17	659 114	44 655	32	45	21	228	313
18	129 100	280 806	7	9	11	45	84
19	235 485	448 552	12	16	18	82	144
20	412 209	551 540	21	28	26	144	236
TOTAL	7 475 061	4 200 714	368	514	325	2 591	3 821

Table 4-8. Effect on Emissions
Scenario I - Clean Media

	Total Particulates	SO_2	NO_x	CO	Equivalent Emissions
	Mg/YEAR				
Present State	3 502	1 144	895	4 587	16 188
Remaining Low Emissions	22	0	196	22	643
Increase in High Emissions	12	605	170	7	1 136
Net Improvement	**3 468**	**539**	**529**	**4 558**	**14 409**

Table 4-9. Effect on Emissions
Scenario II - Briquettes

	Total Particulates	SO_2	NO_x	CO	Equivalent Emissions
	Mg/Year				
Present State	3 502	1 144	895	4 587	16 188
Remaining Low Emissions	368	514	325	2 591	3 819
Increase in High Emissions	1	68	19	1	127
Net Improvement	**3 133**	**562**	**551**	**1 995**	**12 243**

Thus, the concentrations reach a maximum of 10 $\mu g/m^3$ of particulates, and 8 $\mu g/m^3$ of SO_2.

However, these data do not pertain to the overall pollution in the town. The analysis covered only one precisely defined group of low emissions sources. The expected effects concern only modernization of individual heating systems (the remaining elements of overall pollution e.g. influx of pollution, high emissions, do not change).

4.7 SUMMARY OF RESULTS: CONNECTING BOILER HOUSES TO THE MUNICIPAL DISTRICT HEATING NETWORK

This work was carried out under Subproject 1 of U.S.-Polish program for eliminating low emissions sources within the framework of agreement between the Kraków Development Office (BRK) and the Pacific Northwest Laboratories. This task, the single largest project in the program, aimed at estimating the environmental effects which could be brought about by connecting solid fuel-fired boiler houses to the municipal district heating network.

The basis for these calculations was BRK's engineering analysis (June 1993) which outlined the scope of technical projects that should be completed to connect to the municipal district heating network all the boiler houses within its reach. In all, 635 boiler houses of a combined 447.6 MW installed capacity were earmarked as suitable for connection.

In a single heating season, these boiler houses use:

- 49,900 Mg of coke
- 58,500 Mg of coal
- 56,600 Mg of coal fines

As in other subprojects, the environmental effects were estimated in terms of absolute reductions in loads of pollutant emissions, and in the concentrations resulting from these emissions being introduced into the air. Table 4-10 summarizes the effects on emissions.

Compared with solutions presented earlier (Old Town - natural gas, Łobzów - electricity) the emissions here are three times higher; this stems from the scope of this task, covering practically the whole town.

The calculations proved that emissions shifted to the central sources almost cease to be felt within town (the efficiency of ESPs in the central sources is about 99.5%, and the height of stacks is 225 m).

The SO_2 ambient concentrations associated with the operations of boiler houses earmarked for elimination fall within the 5-10 $\mu g/m^3$ range. The area affected by concentrations of this magnitude practically covers the whole town. The average effect, estimated at about 10 $\mu g/m^3$, confirms the notion that the influx of pollution exerts a significant effect on the overall pollution

Table 4-10. Effect on Emissions of Implementing Subproject 1

ITEM	POLLUTANTS	EMISSIONS LOADS IN HEATING SEASON [Mg/SEASON]		
		Present State	Designed State	Improvement
1.	Total Particulates	3 078	3	3 075
2a	Suspended Dust	462	2	460
2.	Sulfur Dioxide	1 861	145	1 716
3.	Nitrogen Dioxide	248	40	208
4.	Carbon Monoxide	7 434	3	7 431
	Equivalent EMISSIONS	15 224	279	14 945

status of the city. The impact of carrying out this subproject on gaining an overall picture of air pollution in town should be emphasized in assessing the expected effects.

This task does not cover the Old Town district (district 4 - conversion to natural gas) and the Łobzów area (district 3 - conversion to electric heating). Even with the expected "average" improvement, these important areas still will reach about 10 $\mu g/m^3$, signifying the need to carry out comprehensive, complementary activities; otherwise, attempts to follow the concept of "cleaning the hot spot" in the city center, without backing them up with measures in adjacent areas, will not translate into a comprehensive improvement. For example, as can be seen from a sum of the effects expected from subprojects 1 and 2, the total effect in the Old Town could reach nearly 40% of the current pollution concentrations there.

As for the suspended particulates, effects are relatively small. The average reduction in ambient concentrations for the whole town is a mere 1 $\mu g/m^3$. Within the regions where more intensive activities are planned, there will be some places where the expected reductions could be 5 $\mu g/m^3$ during the heating season (Podgórze, Prokocim, Grzegórzki).

Thus, the expected results are not great, and by any means, do not match the hopes and requirements.

This analysis points to the following elements as having important effects on background particulate pollution:

- apart from emissions sources generating energy, other sources including traffic have their impact, and
- there is the important phenomenon of "secondary emissions," underestimated by the imperfect model for urban conditions.

4.8 BASIC EFFECT OF INTRODUCING ALL THE OPTIONS OF ABATING LOW EMISSIONS

The series of analyses for partial engineering options which determined the technical feasibility of eliminating and reducing harmful effects of low emissions sources allows an evaluation of the environmental effects which could be obtained by eradicating all low emissions sources within the city. This example analysis shows the impact of the most capital-intensive options available to the city. As discussed in other sections, significant improvement can be attained with less capital outlay.

Table 4-11 shows the model's assumptions for this kind of scenario. The calculations of the present state of pollution are reviewed in Table 4-12, and those for the improved state are shown in Table 4-13.

The calculations showed that the expected result of a given scenario is markedly different, depending on the area to which it is applied. The highest environmental benefits (in per cent) were found for the so-called second circular road area. They include almost complete elimination of particulates, sulfur dioxide, and carbon monoxide emissions, and a large reduction in nitrogen oxides. This improvement stems from assuming a marked extension of the municipal district heating system.

Some of the engineering options involve imposing more load on the CHP Plant, Kraków S.A., so creating an increase in emissions from this central source. Table 4-14 gives the balance sheet of "profits" (elimination of low emissions) and "costs" (increases in high emissions). Notably, the environmental costs of the project (i.e. the increase in emissions in the central source) is relatively low, due to two basic factors:

- a higher efficiency of combustion in the central source, and
- the use of highly efficient pollution control devices not available in individual systems.

From calculations of the state of air pollution, the following points emerged:

1. At present, low emission component is responsible for the following proportions of ambient concentrations in the central part of town (within the 2nd circular road):

Suspended Particulates

- Between 15 to 30 $\mu g/m^3$, locally up to 42 and 60 $\mu g/m^3$, on average during a year. This value is 30 to 60% (locally 84 to 120%) of the standard value (D_a = 50 $\mu g/m^3$). In this area, the concentrations of suspended particulates are between 110 to 180% of the permissible value. Thus, the low emissions component is responsible for 30 to 60% (depending on area concerned) of the present pollution by particulates.

Sulfur Dioxide

- Between 10 to 33 $\mu g/m^3$, locally up to 43 and 56 $\mu g/m^3$, on average during a year. This value is 31 to 103% (locally 134 to 175% of the standard value (D_a = 32 $\mu g/m^3$). In this area, the concentrations of sulfur dioxide are between 320 to 375% of the permissible value. Thus, the low emissions component is responsible for 10 to 50% (depending on area concerned) of the present pollution by SO_2.

Further, the average concentration of SO_2 produced by low emissions is close to the difference between levels measured in winter and summer. This fact immediately confirms the importance of the low emissions component as the factor which determines the status of local air pollution in urban areas.

2. Under the modernization scenario, the low emissions component will be responsible for the following average concentration levels:

Suspended Particulates

- Between 1 to 4 $\mu g/m^3$, locally up to 6 $\mu g/m^3$, on average during a year. This value is 2 to 8% (locally 12%) of the standard value (D_a = 50 $\mu g/m^3$).

Thus, implementing the modernization program should decrease by nearly tenfold the participation of the low emissions component in the present background. However, several other sources also are responsible for polluting by suspended particulates, among which low emissions of energy sources is not the most significant. Relatively, the implementation of the program will not cause such a palpable improvement as is expected for sulfur dioxide. We note that the term low emissions of energy sources has been underscored here, to emphasize the restricted scope of the program - traffic-related sources and secondary particulate pollution are outside this scope.

Sulfur Dioxide

- Between fractions less than one and up to 2, locally up to 4 $\mu g/m^3$, on average during a year. This value is 12% of the standard value. With full implementation of the measures, a marked improvement in the status of air pollution in the city will be felt. A combined effect can be expected, depending on the part of town, as a drop in concentrations even down to 100% of the permissible level (and, in the most affected central region of Lubicz Street and Mogilskie roundabout - a drop of about 150%). In the most affected areas, a decrease of about 40% from present levels can be expected. At present, the standards for sulfur dioxide concentration are exceeded by a factor of 2 to 3 (depending on the part of town). Thus, pollution levels can be expected to drop to near the permissible values, and in the most affected areas, these levels will not exceed standards by more than about 1.5 to 1.6 times.

Table 4-11. Modernization of Heating Systems in Kraków

AREA	GROUP OF SOURCES	EXAMPLE TECHNICAL MEASURES
I OLD TOWN	Coal-fired Boilers	Conversion to natural gas.
	Home Stoves	Conversion to gas or electricity in the same proportion as this "clean" equipment has been distributed till now.
II SECOND CIRCULAR ROAD	Fixed-Grate Boilers Output up to approx. 0.3 MW	Connection to the district heating network when feasible; remaining ones converted to gas.
	Home Stoves	ŁOBZÓW area - electricity in remaining part of the area - conversion to gas or electricity in the same proportion as this "clean" equipment has been distributed till now.
III REMAINING PART OF TOWN "OUTSIDE"	Fixed-Grate Boiler Output up to approx. 0.3 MW	Connection to the district heating network when feasible; remaining ones firing coke.
	Large-Output Boilers	When feasible, connecting to the district network (at least the heat-producing parts); remaining ones modernized according to KRZESŁAWICE scenario.
	Home Stoves	Conversion to gas or electricity in the same proportion as this "clean" equipment has been distributed till now.

During these analyses, there were several cases (reception points) found for which the calculated effects raised pollution levels above the present one, which is nonsensical. It is relatively easy to explain this contradiction.

Table 4-12. Summary of Low Emissions - Present

Category	Particulates	SO_2	NO_x	CO	Equivalent
	[Mg/year]				
OLD TOWN	PRESENT STATE				
Existing and Remaining Gas Installations	1	0	14	1	44
Existing, Small - to Gas	115	73	7	208	531
Home Stoves	150	46	37	183	680
Total	**266**	**119**	**58**	**392**	**1 255**
2ND CIRCULAR ROAD	PRESENT STATE				
Existing and Remaining Gas Installations	2	0	15	2	50
Existing Small - to Network	215	130	17	520	1 063
Existing, Small - Gas	261	247	93	835	1 691
Home Stoves	1 542	473	370	1 892	6 964
Large Boiler House ("K")	3	16	4	23	48
Total	**2 023**	**866**	**499**	**3 272**	**9 816**
"OUTSIDE"	PRESENT STATE				
Existing and Remaining Gas Installations	2	0	15	2	50
Existing, Small - to Network	2 863	1 731	231	6 914	14 161
Existing, Small - Coke	685	668	219	1 974	4 277
Mechanical Grate - Coal	155	166	28	46	720
Large Boiler House ("K")	322	1 873	457	2 668	5 466
Home Stoves	1 810	625	488	2 512	8 545
Total	**5 837**	**5 063**	**1 438**	**14 116**	**33 219**
TOTAL FOR KRAKÓW	**8 126**	**6 048**	**1 995**	**17 780**	**44 289**

Table 4-13. Summary of Low Emissions - with Improvements

Category	Particulates	SO_2	NO_x	CO	Equiv.	Equiv.
	[Mg/Year]					
OLD TOWN	Improved State					Net Effect
Existing and Remaining Gas Installations	1	0	14	1	44	0
Existing, Small - to Gas	1	1	12	1	39	492
Home Stoves	0	0	3	0	9	671
Total	**2**	**1**	**29**	**2**	**92**	**1 163**
2ND CIRCULAR ROAD	Improved State					Net Effect
Existing and Remaining Gas Installations	2	0	15	2	50	0
Existing, Small - to Network	0	0	0	0	0	1 063
Existing, Small - to Gas	4	0	38	4	124	1 567
Home Stoves	3	0	26	3	86	6 878
Large Boiler House ("K")	0	0	2	0	6	42
Total	**9**	**0**	**81**	**9**	**266**	**9 550**
"OUTSIDE"	Improved State					Net Effect
Existing and Remaining Gas Installations	2	0	15	2	50	0
Existing Small - to Network	0	0	0	0	0	14 161
Existing, Small - Coke	542	506	201	1 807	3 564	712
Mechanical Grate - Coal	155	166	28	46	720	0
Large Boiler House ("K")	22	194	223	35	922	4 544
Home Stoves	19	0	167	19	549	7 996
Total	**740**	**866**	**634**	**1 909**	**5 805**	**27 413**
TOTAL FOR KRAKÓW	Improved State					Net Effect
	751	**867**	**744**	**1 920**	**6 162**	**38126**

Table 4-14. Balance of Reduced Low Emissions and Increased High Emissions After Modernization

POLLUTANT	REDUCTION IN LOW EMISSIONS	INCREASE IN HIGH EMISSIONS	IMPROVEMENT
	[Mg/year]		
TOTAL PARTICULATES	7 357	15	7 342
SULFUR DIOXIDE	5 181	750	4 431
NITROGEN DIOXIDE	1 251	210	1 041
CARBON MONOXIDE	15 860	10	15 850
EQUIVALENT EMISSIONS	38 126	1 412	36 714

- The present state of pollution was adopted on the basis of digitalized measurements from 32 control stations, situated mostly in the central part of the town.
- According to our stated reservations, the accuracy of calculations decreases with increasing distance from the center of Kraków.
- Because of insufficient control measurement stations in peripheral parts of the city, some local assessments of the present state of pollution could be wrong.
- The existing measurement network allows only general conclusions to be drawn, while some local extreme cases may escape our attention.
- A negative value given by analysis usually ranges from 1-2% of the standard which is within the range of error of the mathematical model.
- A slightly greater error appears in calculations exclusively for the borderline of the city and the Nowa Huta district. This means that there are areas where the low emissions could be the main component of the background, giving local maximum concentrations not relayed by the existing network. The absence of the measuring station in the Nowa Huta district provides one more proof of the real distinction between the two urban entities of Kraków and Nowa Huta.

Finally, the expected picture of air pollution in Kraków if all of these options were implemented can be compared to current summer values. Summer concentrations reflect sources operated throughout the year, emissions from technological processes, and the influx of pollution from outside. A remarkable decrease in the concentration of sulfur dioxide in winter can be expected, bringing it to levels only slightly higher than the summer values. A similar effect on the concentration of particulates cannot be expected, although the environmental improvement achieved will be significant.

5.0 PUBLIC OPINION AND SOURCES OF LOW EMISSIONS

The aim of activities in the public relations field, which was one element of the Polish-American program to eliminate low emissions sources, was to acquaint the public with the scale of pollution from these burdensome sources, as well as with the entire program that was planned. The objective of the program was highlighted, i.e. the prospects for improving air quality via various engineering measures that eliminated the combustion of solid fuels, and also by using improved fuels with far fewer polluting emissions.

We assessed the responses of residents of Kraków towards the suggested program, the new prices of energy substitutes, and the new methods of heating, as well as their willingness to participate in the program. The next element in the program was that of educating the public, and demonstrating to them how these low emissions degrade their health and quality of life, as well as their cultural heritage.

The following steps were included in the plan of action:

- surveying public opinion
- distributing publications, brochures, leaflets
- organizing public seminars
- holding press releases and press conferences
- producing documentary films

5.1 FOCUS GROUP STUDIES

Focus groups (intensive discussions with small groups of representative citizens) were conducted in September 1992. The aim was to ascertain the residents' level of awareness about the various issues related to air pollution, and the decision-making process for change, and, using this knowledge, to develop a questionnaire for a quantitative survey of the public. The answers would provide us with timely information on the major issues involved in implementing the project. This part of the project was conducted by VRG Strategy Co., Ltd.

5.1.1 Methodology

The material was collected by means of the Focus Group Interview technique. Each group was involved in a discussion lead by a qualified moderator. These discussions were conducted in the club rooms of the Central City Cultural Center at ul. Mikolajska 2, and were recorded on audio tape.

Four focus groups were used, each with seven to ten participants.

Group 1 consisted of landlords of apartments buildings located in the "Krowodrza" district and in the Old Town. Group 2 included those respondents who, as tenants, have applied to the Electricity Department for an allocation of energy for "night-store space heating" and have already made some investment in this direction. Group 3 consisted of those tenants who live in the Old Town and declared that they had not considered changing their heating mode. Group 4 was composed of those tenants who declared that they had not considered changing their heating mode but live just outside of the Old City boundary in the "Krowodrza" district.

5.1.2 Focus Group Results

The questions put to the respondents, as perhaps the whole subject, brought out pent-up emotion and in some instances anger. Many of the respondents became angry during the discussions and sometimes "arguments" were observed with both sides expressing precisely the same views. Such frustration and anger often was directed at the communist system which was blamed for devastation of the environment. The communist system was also held responsible for the near tragic individual consciousness of ecological issues which is demonstrated in the everyday behavior of the average person.

It seems that the current assessments gave these people their first opportunity to make their voice heard on a topic about which they feel very strongly. Differences in responding, generally, did not run along class, educational, economic, sex or age divisions.

There are nine major issues which are clearly evident from the focus group discussions. Generally, while differences between groups do exist, on the whole they do not profoundly distinguish the individuals in relation to the problems faced. Instead the issues discussed are more inclined to unite the respondents in the face of common difficulties. The situation is, however, susceptible to change as private ownership laws change.

1) Respondents on the whole do not easily distinguish between the effects of low emission pollution and the effect of other sources of pollution. This is particularly true as it relates to health issues. There are those who blame all possible ailments on pollution irrespective of the origin of pollution or the etiology of the illness. On the other hand, some respondents considered that low emission pollution from coal burning does not effect health at all. Both views are usually considered by residents to be well founded in some kind of "corroboratory evidence.""

2) The current report shows the need for people to be better informed in the whole subject of pollution; its origin, effects and solution. There appears to be too much tentative argument, gossip, and hearsay in relation to the dangers or lack of them arising from ecological pollution. Information about the actual costs of conversion to alternative heating methods would also be helpful.

3) People interviewed in the course of this research were more interested in having a convenient form of heating than they were in reducing the effects of the pollution caused by the heating which is currently in use. This view prevailed despite the emotion expressed at the beginning of each group discussion about the state of the city.

4) There appears to be a polarization of attitudes with respect to the willingness/ability to carry out or contribute to the costs of improvements. While there are those who are willing to pay for improvements and even go ahead at their own cost, some residents think that something should be done for them rather than doing something themselves. While this view was rarely stated openly, it is shown in the actual amounts (%) that people are willing to spend on improvements.

5) The state of the current infrastructure, both technical and administrative, according to the opinion of those interviewed is unsatisfactory. This makes any attempt to change home heating systems even more difficult.

6) Respondents criticized those in authority, blaming them for not providing opportunities favoring changes in heating systems. The attitude of Electricity Department staff was also estimated negatively.

7) In general, respondents appeared to be tolerant of changes if they could be convinced that something positive is being done.

8) Willingness to pay for any improvements in heating methods is, in most cases, connected directly to the income of the respondents. However, before any investment is initiated, the question of guaranteed long-term leases is seen as a crucial issue. There appears to be a need to conduct a quantitative study assessing the direct relationship between income and investment intent.

9) Only several respondents mentioned the U.S. fund, which was allocated for the improvements to the ecology of Kraków. However, foreign experts were seen as the best form of control for the appropriate use of credits. The idea expressed by some members of groups that "someone should do something" for them was not generally connected with foreign help.

5.2 PUBLIC OPINION SURVEY BY QUESTIONNAIRE

The analyses of the results obtained from the focus groups became the material for the next step in the survey of public opinion in Kraków i.e., a questionnaire.

5.2.1 Studies of the Present State of Public Opinion on Environmental Pollution

So far, no studies of this type had been conducted in Kraków, although there are a few at the national level. A comparison of some surveys from the 1980's on the level of environmental awareness with the results obtained in 1993 support the view that the level of environmental awareness has increased significantly.

The main impact on public awareness was made by:

a) The development of the mass media and the associated increase in environmental information.
b) The development of environmental movements.
c) The more widespread fashions involving ecological issues (e.g., health food).
d) The increased confidence in measures taken by authorities.

5.2.2 The Goal of the Studies

The main goals of the studies were:

1. To estimate the extent to which Kraków inhabitants are willing to participate financially in activities aimed at eliminating low sources of emissions.
2. To estimate the potential and willingness to finance conversion of coal-fired heating to other (cleaner) systems.
3. To determine interest among the residents and their willingness to purchase energy-efficiency equipment.
4. To provide data for preparing effective informational and promotional campaigns.

5.2.3 Study Methods and Implementation Procedures

The studies included:

- The entire population of Kraków within its administrative borders; sample number = 300 residents.
- Residents of "Łobzów" and "Old Town" Quarters who have coal, electric- or gas-fired heating; sample number = 100 residents.

The respondents were drawn randomly from a list held by the Voivodship Office. The n = 300 sample was drawn from particular quarters in proportion to their population figures. The sample n = 100 was drawn in a way which assured that the requirement of having a particular type of heating system was met.

The survey was carried out by survey takers using questionnaires at respondents' homes from April 14 to 25, 1993. The questionnaire was developed on the basis of the preliminary results of the focus group studies and after consultation with the American company WESTAT, who helped to edit the questions and make them more readable.

5.2.4 Selected Results of Questionnaire Study

Willingness Among Residents to Participate in the Costs of Eliminating Sources of Low Emissions in Kraków

Fifty-four percent of Kraków residents (sample = 300) agree to taxation aimed at covering the cost of eliminating low emissions. Only 25% of the residents of "Łobzów" and "Old Town" areas (sample = 100) who have coal stoves do not consent to taxation to cover the cost of reducing emissions; this represents half of the number found for the whole city, where almost 50% of those surveyed do not want to pay towards reducing emissions.

Half of the people in the 300 surveyed declared that they can pay about PLZ 100,000 per month. More than half of all those surveyed in the smaller sample (n = 100) declared that payments of PLZ 100,000 - 300,000 per month would be feasible.

Willingness to Participate in Purchasing Energy-Saving Equipment

A half of the 300 residents sampled do not plan to purchase energy-saving equipment; about 30% had no opinion, while 20% expressed interest in buying such equipment. About half of the residents in the smaller sample do not want, or do not know if they want, to purchase energy-saving devices. Those few who want to spend money on the energy-saving equipment are willing to pay sums in the range of PLZ 3.5 million.

Relationship Between Family Income and the Willingness to Participate in the Costs of Eliminating Low Emissions

The level of family income affects significantly the willingness to participate in the costs of eliminating low emissions. Only 30% of those having incomes up to PLZ 2.0 million want to bear such costs. The level of income above which many more people are willing to pay to eliminate emissions is PLZ 5.0 million per family. Thus in the PLZ 7.5 - 10.0 million income bracket, more than 80% are willing bear such costs.

Relationship Between the Level of Education and the Willingness to Participate in the Costs of Eliminating Low Emissions

The level of education is coupled with the willingness to bear the costs of eliminating low emissions. About 70% of the least educated people refuse to pay, while about 72% of persons with degrees are willing to contribute towards the costs of eliminating low emissions.

Relationship Between the Place of Residence and the Willingness to Participate in the Costs of Eliminating Low Emissions

Table 5-1. Willingness to Pay and Place of Residence

	QUARTER				
	TOTAL %	Central Quarter %	Krowodrza %	Podgórze %	Nowa Huta %
Willing to pay	54	52	60	55	48
Not willing to pay	46	48	38	45	52

The residents of the "Krowodrza" Quarter declare their financial support for eliminating low emissions more than do the others. Here, the indices of education and income are high and these determine, in the first place, the level of willingness.

Relationship Between Views on the Sources of Air Pollution and the Willingness to Participate in the Costs of Eliminating Low Emissions

People's views on the degree to which low-emissions sources are responsible for air pollution affect their willingness to pay taxes towards their elimination. The percentage of those refusing to pay for clean air drops as opinions expressed on the high impact of coal-fired boiler houses increase. For air pollution caused by coal-fired stoves, there are no evident relationships between the groups declaring or refusing financial support.

Relationship Between the Assessment of the Impact of Air Pollution on Various Aspects of Life and the Willingness to Participate in the Costs of Eliminating Low Emissions

People opposing the tax are almost always those who regard air pollutants as having a less serious impact on various aspects of life. Willingness to pay more towards eliminating low emissions are coupled with the opinion that air pollution imposes a major threat to the quality of life.

Relationship Between Confidence Towards Authorities and the Willingness to Participate in the Costs of Eliminating Low Emissions

More than 60% of those surveyed maintain that the municipal authorities should tackle the issue of air pollution, and hence, should have funds for this purpose at their disposal.

Relationship Between the Type of Heating System and the Willingness to Participate in the Costs of Eliminating Low Emissions

Declared intentions of converting to natural gas or electricity heating coincide with the willingness to pay taxes towards eliminating low emissions.

Assessment of the Degree of Air Pollution in Kraków

The following table shows the distribution of opinions expressed by respondents with various levels of education about a statement that Kraków is one of the most polluted towns in Poland. About 80% of the surveyed residents of Kraków reject the statement that Kraków's problem with air pollution is not all that serious, and that one can live here without much risk to one's health. Seventy-one percent of respondents consider Kraków is one of the most polluted towns in Poland and that living there is very dangerous to health; only 6.3% of respondents regard opinions that there is a link between air pollution and health risks as totally false.

Table 5-2. Degree of Air Pollution and Education

Kraków is one of the most polluted cities in Poland	EDUCATION						
	TOTAL	Primary	Vocational	High School	University	Below Graduate	Graduate
Number	300	27	51	11	122	22	67
Do not know (%)	3	4	4	18	3	0	0
False (%)	6	15	4	18	3	9	8
Partially true (%)	20	22	29	9	13	23	24
Completely true (%)	71	59	63	55	81	68	69

Relationship Between the Place of Residence and the Opinion on the Degree of Air Pollution

The place of residence does not greatly influence opinion about the degree of pollution and its sources. The most acute perception of the problem was noted in the Podgórze Quarter (and not in the Nowa Huta Quarter, as could be expected). These opinions are shown in Table 5-3.

Assessment of Pollution by Users of Home Stoves

A more critical attitude to pollution in the city and the hazards caused by it was exhibited by those using coal stoves compared with those using other systems.

Air Pollution from Low Emission Sources Against the Background of Other Pollutants

Residents were asked to rank various pollutant sources as causing very little, mild, considerable, or extreme pollution. The percent of responses ranking each source as causing extreme pollution are given in Table 5-4.

According to the views of the residents of Kraków surveyed, the main sources of pollution are the Sendzimir steel works and car exhausts. A remarkable number (approximately 40%) of the respondents pointed at coal furnaces as causing extreme pollution, 35% point at local boiler houses, and 32% at boilers in buildings.

Table 5-3. Degree of Air Pollution and Place of Residence

QUESTION	CENTRAL QUARTER		KROWODRZA		PODGÓRZE		NOWA HUTA	
	True	False	True	False	True	False	True	False
The problem of pollution is not great, one can live here without any risk for one's health	7	76	12	82	4	85	4	69
Air is seriously polluted, but in comparison with other areas, the situation is not yet the worst	30	24	24	46	9	59	26	27
Air pollution varies in different parts of the city	38	13	37	18	20	23	36	22
Kraków is one of the most polluted cities in Poland, and living here is very dangerous to health.	72	4	72	7	76	4	65	10

Table 5-4. Opinion on Pollution Sources

SOURCE OF POLLUTION	CAUSES EXTREME POLLUTION
Sendzimir Steelworks	69.3
Car exhaust	67.7
Combined heat and power plants	40.3
Coal-fired stoves	38.0
Silesian industry	37.0
Rubbish dumps	37.0
Local coal-fired boiler houses	35.3
Boilers in buildings	31.7
Local industry	24.0
Czech, Slovak and German industry	17.7

The perception of low emissions as the main source of pollution in the neighborhood differs significantly among the quarters where the respondents live. It is illustrated in the Table below:

Table 5-5. Pollution Sources and Place of Residence

THE MAIN SOURCE OF POLLUTION WHERE YOU LIVE	QUARTER OF RESIDENCE				
	TOTAL	CENTRAL QUARTER	KROWODRZA	PODGÓRZE	NOWA HUTA
NUMBER OF PARTICIPANTS	300	71	68	80	81
LOW EMISSIONS COMBINED, %	8.3	19.7	8.8	5.0	1.2
REMAINING SOURCES OF POLLUTION COMBINED, %	91.7	80.3	91.2	95.0	98.8

In total, 8.3% of the residents of the whole Kraków believe that low-emissions sources are the main source of pollution in the region they live. In the Central Quarter, about 20% of residents regard low emissions as the main source of pollution.

Eighty-three percent of the owners of coal-fired stoves regard them as the main or as a significant source of pollution. Among those using other heating systems, such views are expressed by 62% of those surveyed.

In the view of Kraków residents, the share of low emissions in overall air pollution is significantly lower than those of the Sendzimir Steelworks, car exhausts, and high emissions (CHP). These opinions also predominate in regions of the city where the sources of low emissions are very numerous.

The Effect of Air Pollution on Various Aspects of Life of the Residents

A great majority of those surveyed stated that air pollution has adverse impact on all aspects of life in Kraków; the only exception was the assessment of its effect on the number of tourists in the city.

Table 5-6. Opinion About Air Pollution Effects

ASPECT	AIR POLLUTION:	
	Has serious or very serious effect (%)	Has no effects (%)
The health of adults	84.0	0.3
The health of children	95.4	0.0
The state of historic buildings	88.3	0.0
The quality of the air	90.4	0.3
Cleanliness of the streets	87.7	0.3
The state of the vegetation in the city	85.7	0.0
Number of tourists	35.0	13.7

Sources of Information About Air Pollution

The preferences among Kraków residents for obtaining information about air pollution are illustrated by the following breakdown:

1. Local TV 40.7%
2. Radio Broadcasts 19.3%
3. National TV 15.7%
4. Daily Press 8.0%
5. Brochures 5.0%
6. Public Lectures 2.7%
7. Weekly Press 0.0%
8. Other Means 2.3%
9. Don't Know 6.3%

Thus local TV is the best way to inform residents about environmental conditions in Kraków.

Views on the Best Ways to Abate Emissions of Pollution

The following breakdown shows the degree of support the residents give to concrete options aimed abating or eliminating air pollution:

QUESTION

	SUPPORT
• Introduce a system of refunds and tax deductions to assist in purchase and installation of environmentally sound equipment.	92.3%
• Introduce strict controls on emissions by industrial polluters.	91.0%
• Reduce heat losses by insulating buildings, installing thermostats and radiator-control valves.	90.0%
• Introduce regulatory restrictions on car exhausts.	88.0%
• Introduce high fees and fines for local boiler houses.	76.3%
• Prohibit the use of low-quality coal.	71.0%
• Eliminate low emissions by converting 100,000 coal stoves and 1,000 boiler houses, even if the cost for converting a single coal stove is in the range of PLZ 3-15 million.	43.3%
• Make the use of briquettes obligatory in coal stoves and boiler houses, which costs twice as much as coal but causes one-fifth of its pollution.	32.0%
• Eliminate low emissions by converting 100,000 coal stoves and 1,000 boiler houses, even if the new sources of energy would require 5-10 times more capital investment, and the energy prices in the 1990's would be brought to world levels.	22.7%

These above figures allow us to conclude that residents of Kraków are willing to accept the great majority of modernization and administrative measures aimed at abating pollution, and also are willing to pay more for operating cleaner heating systems.

The following table shows the respondents' views on the suggestions of legal measures and financial help presented towards converting heating systems and conserving energy.

Table 5-7. Assessment of Implementation Options

Preferred Legal Solutions	ASSESSMENT - THE SOLUTION IS				
	Very Good	Good	Averag e	Rather Poor	Definit ely Poor
Providing low interest credits for tenants towards purchasing electrical installation or heating devices	21.0	37.3	19.7	9.0	6.7
Providing the landlords and apartment owners with special loans towards installing clean heating systems in apartments and houses	23.0	41.3	17.3	6.7	3.3
Giving tax incentives and rebates for the tenants who install clean heating systems	34.3	43.3	10.3	3.3	2.0
Giving tax incentives and rebates for the landlords who install clean heating systems	33.7	42.7	11.0	3.3	1.7
Giving subsidies (or part payments) for tenants to cover the cost of changing heating systems	40.3	36.0	8.3	2.7	5.0
Giving subsidies (or part payments) for landlords to cover the cost of changing heating systems	37.7	32.7	12.3	4.7	4.0
Imposing tariffs for particular use of heat, and not a flat rate calculated on the unit of floor area	67.3	17.3	3.3	1.3	1.3
Making obligatory the installation of insulation in buildings, and introducing other energy- efficiency measures	45.7	30.3	8.7	4.7	2.7
Levying a special tax on those burning coal for heating	6.7	10.3	20.7	14.7	33.0

The highest rate of support was obtained for tariffs for particular use of energy; about 85% of respondents regard this as a good or a very good solution. The obligatory installation of insulation was accepted by 76% of the respondents.

Preferences Expressed by Residents About the Selection of Institutions Most Qualified to Deal with the Issue of Air Pollution

The responses to the question on who is qualified to work on pollution abatement in Kraków were as follows:

1.	City Council	61.7%
2.	Joint Commission with sponsors of foreign assistance projects	10.7%
3.	Voivodship Authorities	8.3%
4.	Independent Polish Commission	5.0%
5.	Government	4.7%
6.	Other	3.7%
7.	Hard to Say	6.0%

The great majority of respondents believed that the problem of air pollution should be solved by the city authorities. However, as many as 44% of the respondents view their past actions as ineffective, and 43% of those surveyed think that the authorities have achieved little. Almost one-third of the respondents think the local authorities will be more successful in the future.

Preferences on Heating Systems

The following table shows the preferences, expressed as percentages, towards various methods of heating and their relationship to the type of system currently used.

The respondents generally support district (central) heating, using gas fuel or a non-specified fuel. None of the respondents wanted coal-fired stoves in their apartment.

The decisive reasons for selecting a heating system:

1.	Clean in Use	20.3%
2.	Cheapest to Operate	19.3%
3.	Not Harmful to the Environment	15.5%
4.	Easy way to Control Temperature	9.7%
5.	Provides Appropriate Temperature	8.0%
6.	Produces Little Pollution	3.0%
7.	Other	15.3%

Table 5-8. Heating System Preferences

Preferred Heating System	Present Heating System - Coal-Fired Stove		
	Total	Yes	No
(Numer of Participants)	300	40	260
Do not know	6.3	10.0	5.8
Coal-fired stoves	1.0	0.0	1.2
Individual gas-fired boiler for a single apartment	8.0	5.0	8.5
Electric inserts	1.7	5.0	1.2
Electric storage heaters (accumulation heaters)	9.0	17.5	7.7
District heating coal-fired boiler	9.3	7.5	9.6
District heating gas-fired boiler	22.7	25.0	22.3
District heating fuel not specified	35.3	27.5	36.5
Other	6.7	2.5	7.3

Existing Installations of Heat-Saving Equipment

The following table shows the existing heat-saving devices in apartments; the values are expressed as percentages.

Table 5-9. Existing Conservation Measures

Existing heat-saving installations	QUARTER				
	Total	Central Quarter	Krowodrza	Podgórze	Nowa Huta
Window weather-stripping	64.3	73.2	51.5	65.0	66.7
Double-frame windows	89.3	94.4	73.5	92.5	95.1
Insulation of ceiling	7.0	2.8	5.9	10.0	8.6
Insulation of walls	9.7	7.0	10.3	11.3	9.9
In winter there is a draft from windows and doors	73.3	78.9	80.9	68.8	67.9

The double-frame windows are standard. More than 70% of respondents report that during winter there is a draft from windows and doors. The same percentage open windows in winter to regulate the temperature inside. Window weatherstripping is applied more often by the users of individual systems compared with the users of central heating systems.

Planned Change of Coal-Fired Heating System to Other Systems

The following are the responses to the question about planned change of heating:

- Definitely Yes 10.0%
- Probably Yes 10.0%
- Probably Not 37.5%
- Definitely No 35.5%
- Don't Know 7.5%

The change of heating system is planned by 20% of the present users of coal-fired stoves; about 37% already have taken steps in this direction. A unanimous motive is the inconvenience of their present system. Sixty-five percent want to change to electricity, and 35% to gas. When asked to identify the main obstacles and difficulties in changing to other systems, 70% of the respondents answered that lack of their own funds is the main obstacle.

Preferences About Persons and Institutions Which Should Cover the Costs of Converting Heating Systems

The following are the opinions of respondents about who should cover the costs of conversion:

• The private owner of the building	42.5%
• The state, in state-owned buildings	65.0%
• The tenant, with a guarantee of a long-term tenancy	30.0%
• The tenant, but with some form of help (tax deductions, grants)	52.5%
• The owner, but with some form of help (tax deductions, grants)	52.5%

5.3 DESCRIPTION OF PUBLIC RELATIONS ACTIVITIES

Public relations were part of the U.S. - Polish program to eliminate low-emissions sources in Kraków. These activities were mostly implemented by National Business Services (NBS) Holding Poland Ltd.; the aims were the following ones:

- To inform Kraków residents about effects of low emissions.
- To inform Kraków residents about the Program to eliminate sources of low emissions, its objectives, and the results achieved.
- To inform Kraków residents about modern methods of energy generation, and ways to save energy.
- To encourage municipal institutions, enterprises, and the residents of the areas included in the program to adopt and apply the planned options.

To implement these goals, some studies of public opinion were first carried out:

1. Qualitative studies - focus groups
2. Quantitative studies - statistical surveys of two groups:
   - 300 residents from all over the town
   - 100 residents of the Old Town and Łobzów areas

Apart from other purposes, the results of the studies were used to develop a Public Relations campaign.

5.3.1 Press Releases

The aim of the press releases was to stimulate the media to present information on the program and on its findings. The scope of the press releases was prepared by NBS, in cooperation with the Kraków Development Office (BRK) and approved by the Steering Committee.

The following is a list of the topics in the press releases:

1. The results of the questionnaire given to the residents of Kraków.
2. The improvement in air quality due to implementing some options developed under the program ("Ekopol" studies).
3. The Demonstration Project on Energy Efficiency (four buildings at Battalion AK Skala Street).
4. The possibilities of eliminating low-emission sources by converting coal-fired heating devices to gas-fired systems.
5. The possibilities of eliminating low-emission sources by connecting them to the municipal district heating network.

5.3.2 Brochure

A brochure was prepared giving information about the U. S. - Polish program to eliminate sources of low emissions and describing the benefits resulting from its implementation.

5.3.3 Seminars

Under the Public Relations campaign, the following seminars were organized:

<u>November 9, 1993 Seminar at the Polish Academy of Sciences</u>

Topics:

- Effects of pollutants from low-emission sources on health, historic buildings, and vegetation.
- U.S. - Polish program for eliminating low-emission sources, and the results of some analyses.

Positive effects of the seminar:

- Press articles were published on harmful effects of pollution.
- Press articles were published informing people about the Program.
- Radio Kraków had a broadcast devoted to the topics discussed during the seminar.

<u>March 10, 1994 Seminar at Kraków Forum Hotel</u>

Topic of the seminar:

- International experience in air quality improvements - technical, legal, and economic solutions.

The topics discussed:

- The policy for abatement and control of pollution from low emission sources - examples of London, England, Finland, and Pittsburgh, U.S.A.
- Methods of reducing concentrations of SO_2 - a hazardous component of air pollution.
- Improvement in air quality by extending district heating systems.
- Production and distribution of energy under market economy conditions - a system of incentives for promoting energy produced in ways which are safe to the environment.

On the Polish side, the seminar was attended by representatives of the Ministry of Environmental Protection, representatives of voivodship and municipal authorities, and also by firms producing and distributing energy. The foreign guests represented the largest energy-generation companies such as IVO, EDF, Vattenfall, PowerGen, and the Dutch Board of Electricity Generation.

<u>April 22, 1994 Seminar at Kraków Forum Hotel</u>

The topic of the seminar was a presentation of the U. S. program, and also presentations by companies which won awards for work under Phase III of the Program, about the tasks to be undertaken by these firms.

The Seminar was attended by the following American companies:

- Tecogen, Inc.
- LSR Technologies
- Shooshanian Engineering Associates, Inc.
- EFH Coal Company
- Honeywell, Inc.
- Acurex Environmental Corporation
- Control Techtronics
- TSC, Inc.

The conference was attended by representatives of Polish firms cooperating with these U. S. firms, representatives of the Kraków authorities, and invited guests from other Polish cities interested in issues connected with the elimination of low emissions sources.

These seminars were part of the information dissemination activities organized under a contract from the Kraków Development Office (BRK).

In April 1994, at Pilzen, Czech Republic, a conference was held on Alternatives for Pollution Control from Coal-Fired Low Emission Sources, organized by the U. S. Department of Energy. During that seminar, the results of the Kraków Program were discussed thoroughly in four presentations. The papers were prepared by researchers from BNL, PNL, Kraków Development Office, Academy of Mining and Metallurgy, Kraków Technical University, Polinvest, and others.

5.3.4 Press Conferences

Several press conferences were organized, principally following each of the seminars mentioned earlier. They provided journalists with an opportunity to learn more about the Program itself, as well as its results.

The results of the conferences were articles in the Kraków press on low emissions within the context of the U. S. - Polish Program. We have found that the tone of the articles has undergone a gradual improvement. At the beginning, some articles voiced resentment that financing from the United States was not channelled directly into implementing projects. Later, journalists accepted the reasoning in favor of the project, and concentrated on describing its results.

This positive shift in the attitude of the media was very significantly affected by the press conference organized in 1993 by the United States Consulate in Kraków involving representatives of the Steering Committee, and by the interview given by Dr. Howard Feibus to *Czas Krakowski*.

5.3.5 Film

Owing to the efforts of, and financing from, the Department of Environmental Protection of the Voivodship Office, Kraków, a video film was produced to inform the public in Kraków of the sources of low emission, harmful effects of combustion products, and the possibilities of improving the present situation. The film was aired on local TV, and also was shown at various conferences and meetings.

6.0 ANALYSIS OF INCENTIVES

6.1 SCOPE OF WORK AND METHODS USED

6.1.1 Scope and Objectives of the Work

The following is the scope of work performed by Polinvest from January 1992 through November 1994:

a) forecasting the growth in the prices of gas, power, coal, coke, briquettes, heating oil, and district heat prices in Poland through 2020;

b) economic feasibility studies of the following types of capital projects intended to reduce low emissions:

- connecting district heating to areas where the local boiler houses are shut down;
- converting coal/coke-fired boiler houses to gas firing;
- replacing coal-fired tile stoves in the "Łobzów" substation area with electric heating;
- using briquettes in coal-fired tile stoves;

c) comparative studies of current and future operating costs of various heating systems and equipment using various types of fuel;

d) legal studies of program-related issues, such as:

- methods of energy price generation;
- effects of price controls;
- ownership issues;
- environmental regulations;
- financial and tax regulations;
- administrative law and local ordinances;
- statutes regulating local government;

e) study of incentives for possible actions to be undertaken by the municipal authority to promote the program's capital projects among the users of current heating systems and equipment.

The following were the objectives of Polinvest's work:

a) determining the feasibility of the capital projects intended to reduce low emission in various parts of Kraków, using various fuels and technologies;

b) determining the amount of money the City would have to allocate to the incentive program promoting these capital projects;

c) identifying the mechanisms the city must create to ensure the program is carried out.

6.1.2 Methods Used by Polinvest

Methods Used to Forecast Prices

Initially, Poland's retail, wholesale, and industrial energy and fuel prices were determined. The mechanisms and dynamics of energy pricing were established. Research institutions studying energy prices in Poland were identified. Next, fuel prices were forecast, based on the prognosis of the desired ultimate price-relationship developed by the Warsaw Energy Institute (Instytut Energetyki w Warszawie), and on Polinvest's own forecast of coal prices. Forecasting was done using a relational method, relating future fuel prices to the base fuel price.

Next, prices forecast in this way were compared with the global price forecasts developed by the U.S. Department of Energy. These prices are based on market energy prices in Western Europe which are eventually expected to prevail in Poland. The price growth over time is based on projections of the U.S. Energy Information Administration. The two forecasts were different, as discussed in Section 6.2, below.

Both price levels were used to calculate the feasibility of establishing the projects, since they illustrate two different scenarios for the conditions under which they are to be carried out.

Methods Used to Calculate Capital Project Data

Polinvest studied the following types of capital projects:

a) connecting district heating to select city areas where local boiler houses are shut down (a total of 101 boiler houses);

b) converting coal/coke-fired boiler houses in Old Town to gas firing;

c) replacing coal-fired tile stoves in the "Łobzów" substation area with electric heating;

d) using briquettes in coal-fired tile stoves.

Polinvest's capital-project studies included the following principal elements:

a) cash flow calculations;

b) net present-value calculations;

c) return on investment (payback) calculations;

d) sensitivity tests.

Cash flow calculations required that the expense levels for generating heat, and the revenue from such sales, were calculated over the life of each project. Therefore, the following values had to be determined:

a) forecast fuel and energy prices;

b) growth indices for heat generation cost elements;

c) forecast prices for district heat sales.

Polinvest developed a model for calculating the heating costs for systems in the range of projects. The cost of generating 1 GJ of heat could be estimated with this model, in turn, making it possible to compare the costs of energy generation for various systems. Revenues from heat sales may be determined once sales prices per GJ of heat are calculated and that, in turn, makes it possible to calculate pro-forma cash flows for each project.

Net present value (NPV) calculations were carried out to estimate the project's feasibility. For a project to be economically feasible, in banking practice it is assumed that its net present value must be positive. This value was calculated for each project in U.S. dollars, using exchange rates appropriate for the specific time to which each particular set of data relates. A discussion of conditions assumed for the calculations, i.e., expected project life and the discount rate used, precedes each report on net present value calculation.

Payback calculations were performed using net cash flow for individual years over the life of the project. The period necessary for the net present value to rise to a positive value is the payback period. **Project capital cost was assumed at the level given in the data delivered by the Kraków Development Bureau, BRK.**

Sensitivity tests were undertaken to study the range of fluctuations in net present value in relation to the fluctuation of input conditions. Foremost, project sensitivity to the following variables was studied:

- capital cost;
- overall output of the connected (converted) boiler houses;
- heat output; and
- levels of environmental fees.

In individual cases, project sensitivity to specific, individual variables also was studied, e.g., MPEC S.A. district heating utility's fixed fee in the projects relating to connecting heating customers to the district heating network in places where the local boiler houses are to be shut down.

Also it should be emphasized that the results of studies of approximately 100 local boiler houses were influenced by parameters related to individual sites, ownership (individuals, corporations), types of business the owners engage in, and their willingness to participate in the program.

When studying projects involving the connection of heating customers to the district heating network in lieu of closed local boiler houses, and converting coal/coke-fired boiler houses to gas firing, Polinvest developed calculation models for cost, cash flow, and project effectiveness. The studies of individual boiler conversions of district heating connections make comparisons possible. The following section presents an overview of one such model.

Boiler House Connection to the MPEC S.A. District Heating Network: Effectiveness Calculation Model for the Project

GENERAL PARAMETERS

a) U.S. dollar exchange rate	average exchange rate for a given period
b) discount rate	5%
c) payback period, years	20 years
d) "A" component of the MPEC S.A. price	this is the MPEC S.A. price component intended to cover the current cost of operating the network, taken as per Polinvest forecast (see Section 6.4.1 for discussion of A, B, and C cost components)

OTHER

a) amount of heat	annual heat generation of a local boiler house, GJs
b) cash revenue per each GJ of heat	expected cash revenue from the heat generation of a local boiler house
c) present value	present value of the boiler house's annual outflows if the boiler house were not shut down
d) customer's capital expense	capital expense for the on-site heat-distribution system

e) present value of the net cash flow	present value of revenue minus the customer's capital cost represents the upper limit of the present fees that customers would be willing to pay to MPEC S.A. district heating utility over the assumed payback period
f) maximum price per GJ	the maximum price a customer would be willing to pay MPEC S.A. per GJ of district heat in the individual years of the project life, i.e., the price corresponding to the heat generation cost in a given local boiler house
g) total MPEC S.A. price per GJ of district heat	the minimal price MPEC S.A. district heating utility could offer to customers of a given boiler house.

A project is feasible only if the minimal price that MPEC S.A. district heating utility could offer to the customers of a local boiler house under closure is lower than the maximum price per GJ of heat acceptable to the customer.

Methods for Comparative Studies of Operating Costs

The methods of study were based on the principles of computing the effectiveness of cost-saving projects developed by Sydney Reiter in *The Financial Evaluation of Energy Costs and Projects*, published by VNR, 1985. Reiter's approach is based on the assumption that the income from a cost-saving project is the discounted difference between the projected cash income for heating a given facility in a particular situation with and without the proposed improvement.

Polinvest used the following data to determine the operating costs of various heating systems and equipment:

a) information about the present coal- and coke-fired boiler houses, obtained from the owners and/or operators, collected through a questionnaire developed by Polinvest, and also through direct interviews;

b) operating data on heating equipment obtained from operators, dealers, and maintenance contractors;

c) data from studies by Kraków Development Bureau (BRK) and its subcontractors.

The cost-computation model developed by Polinvest, discussed below, was used to evaluate the cost of heat generation of the approximately 100 local boiler houses.

Local Boiler House Operating Costs: Computation Model

GENERAL PARAMETERS, identical for all boiler houses

U.S. dollar exchange rate	average exchange rate for the given year

FUEL PARAMETERS, providing the basis for determining the cost of fuel

a) fuel used	coke, coal, or culm; its price and heating value
b) fuel buying cost	cost of delivering, offloading, and storing fuel, expressed as a percentage of the fuel's purchase price
c) fuel use in tons	operator's estimate of fuel use in a given year

PAYROLL COST PARAMETERS

a) number of employees	employment expressed as the number of full-time positions
b) stoker's average pay	per operator's statement
c) type of employment contract	per operator's statement (important for calculating employment taxes)
(d) statutory employment tax	social security and other state employment taxes (*Labor Fund*)

MAINTENANCE COST PARAMETERS

a) boiler house gross value	per operator's statement
b) age	per operator's statement
c) type of operator	individual or corporation; corporations have to maintain elaborate bookkeeping and, therefore, can provide precise data on maintenance costs

ENVIRONMENTAL FEES

a) natural environment use fees	per license from Voivodship Environmental Protection Department
b) excessive emission fines	per operator's statement

DEPRECIATION PARAMETERS

a) boiler house gross value	per operator's statement
b) depreciation rate	per appropriate regulations of the Minister of Finance

WATER AND POWER PARAMETERS

a) power cost	per operator's statement and documentation
b) water cost	per operator's statement and documentation

OVERHEAD

a) markup, percent	per operator's statement and documentation
b) fuel and payroll cost	an assumed percentage of total direct cost, i.e., fuel and payroll cost was used to calculate overhead whenever documentation or operator's statement were unavailable

An analogous scheme was used for calculating the operating cost of equipment installed in apartments, such as ceramic stoves, accounting for obvious differences specific to the differing type and conditions of operation. For example, it is customarily accepted that no labor cost is incurred in operating home stoves. Polinvest estimated the value of this labor (carrying coal from storage bins, cleaning and carrying out ashes, starting the fire) based on the average time needed to carry out these tasks, multiplied by the minimum wage.

Methods Used for Calculating the Value of Incentives

The basis for the methods used to calculate the value of incentives necessary for carrying out the proposed projects were the calculations of project's effectiveness, i.e. net present value calculations. A negative net present value indicates the economic unfeasibility of the project on one hand, while, on the other, it determines the value of the financial incentive that would make the project feasible. In other words, a customer will never recoup his/her capital cost over the assumed life of the project, unless a financial incentive of a specific value is offered. This method of calculating incentives indicates, then, the recipient of the incentive, and legal studies determine legal options (also local) for applying various types of incentives.

Methods Used for Legal Studies and Proposing Recommendations

The methods used for legal studies were based on studying the current statutes on program implementation and proposing evaluations and conclusions about the following issues:

a) feasibility of implementing the program under the current conditions, in view of the legal status and financial capability of boiler house owners;

b) potential for introducing new legal models and organization, and the participation of the local government therein;

c) potential for using select incentives and stimuli necessary to implement the program;

d) potential for creating new companies and/or agencies to achieve the program's objectives; and

e) potential for using grass-roots movements to implement the program.

The studies concentrated on statutes in the following areas:

- environmental protection statutes;
- legal and fiscal statutes;
- local government regulating statutes;
- rent control and tenancy statutes; and
- administrative law.

Polinvest's recommendations on individual projects are opinions about the potential for carrying out the projects, based on the following aspects:

a) feasibility studies of the proposed models, developed by Polinvest; and

b) possibility of the municipal authorities assisting the implementation of the program.

6.2 ENERGY PRICE FORECASTS

6.2.1 General Information and Fuel Price Forecasts

The study uses the U.S. Department of Energy and Polinvest's own forecasts to ascertain the project's feasibility under varying conditions.

Figures 6-1 through 6-5 and Table 6-2 show Polinvest's and U.S. DOE's fuel price forecasts. The U.S. DOE forecast was supplied by the U.S. Department of Energy, supervising, through Brookhaven National Laboratory, the work of the Polish-American program. The objective of their forecast is to determine (global market) prices that would prevail in Poland if its fuels were bought at global rates and if these fuels were not subsidized.

The Polinvest forecast contemplates current Kraków prices and assumes such growth thereof to ensure that in the future the correct relationships will be achieved among the prices of various types of energy. In other words, the assumption made is that Poland's active energy-price policy will result in a return to the desirable price relationships which were unsettled during the period of its centrally planned economy. These desirable price relationships of coal-derived fuels in relation to coal prices were determined by the Warsaw Energy Institute (*Instytut Energetyki w Warszawie*). That study was commissioned by the government. National policy is very important to the character of fuel-price relationships. Polinvest investigated this matter and determined that there is no uniform price-relationship model, even in countries of a similar size with a similar level of development. Under the circumstances, the term "global prices", even though universally used, is not precise.

Polinvest's forecast of coal prices was based on EIA's projected growth rate in the price of coal mined in the Appalachians in the U.S.A., and also estimated the prices of coal-derived fuel (coke, briquettes), power, and MPEC S.A. district heating in relation to the forecast coal price. Polinvest believes that in Poland the future prices of the types of energy generated with gas and oil will be similar to global prices (such as those in the U.S. DOE forecast). Current gas prices in Poland are much lower than those forecast by DOE and, therefore, "catching up" to the global price levels will take in excess of ten years in Polinvest's estimation.

The following is a short glossary of terms used in the forecasts:

- coal for industrial customers refers to culm, with a heating value of 23 GJ per ton;
- gas for individual customers refers to household natural gas and gas used for heating individual apartments (homes);
- gas for boiler houses refers to the natural gas delivered to boiler houses operating only during the heating season, with average boiler output approximately 35 percent of full capacity.

Table 6-2 shows Polinvest's and DOE's forecast fuel prices. According to DOE, the quoted prices of coal for individual customers, industrial customers, and coke include the cost of delivery to the customer. According to Polinvest, these prices do not include the delivery cost to the individual customer. Accordingly, in related studies, the cost of delivery is treated separately in the corresponding studies of fuel-use feasibility.

6.2.2 Conclusions on the Energy Price Forecasts

The following are the principal conclusions from the Polinvest energy price forecast:

a) a steady, two to three percent increase in U.S. dollar prices of gas (for individual customers and boiler houses), electrical power (night rate, used for space heating) and in the district heat prices of the MPEC S.A. district heating utility will continue in Kraków over the next 10 years;

b) over the following years, the price of power and district heat will stabilize, but the price of gas, a largely imported fuel, will continue to grow.

The following are Polinvest's forecast about price relationships:

a) coal-derivative fuels (coke, briquettes) will be at least two times cheaper than coal-based energy, such as electricity and district heat;

b) the relationship between the prices of coal for individuals, briquettes, and coke will remain stable in the future;

c) in 1995, the district heat price offered by the district heating utility, MPEC S.A., will be slightly lower than the night rates for electrical power. This relationship will remain unchanged in the future. Regular power rates will be about 2.3 times higher; however, this rate is practically never used for heating.

Figure 6-1 depicts the forecast price relationships discussed under items a) through c) above.

d) in 1995, gas prices for boiler houses and individuals (these two rates are similar) will correspond to MPEC S.A. district heating utility prices and the price of power.

e) the price of gas will increase the fastest in the future and, after 2005, gas will become the most expensive fuel;

f) in 1995, heating oil will be the most expensive form of energy (oil prices do not include the price of delivery and on site storage). The rate of growth of heating oil prices will be slight in the future; however, only after the year 2005, will heating oil cease to be the most expensive fuel, as gas prices then will move to first place.

Figure 6-2 depicts the forecast price relationships discussed under items d) through f) above.

Table 6-2 Polinvest's and DOE's forecast data refer to the fuels with the heating values listed in Table 6-1.

Table 6-1 Heating Values of Fuels Used in the Polinvest and DOE Forecasts

Fuel Type	Unit of Measure	Fuel Heating Value (Assumed in the Forecast), [GJ]	
		Polinvest Forecast	DOE Forecast
Coal for Industrial Customers (Culm)	[t]	23.05	22.56
Coal for Individual Customers	[t]	27.21	22.56
Coke	[t]	28.00	27.08
Smokeless Briquettes	[t]	26.80	26.8
Electricity	[kWh]	0.0036	0.0036
Heating Oil	[t]	41.50	41.50
Gas	[1,000 m^3]	35.60	35.60

The following is the U.S. Department of Energy's forecast on price relationships:

a) in 1995, electricity prices (DOE) will be three times higher than coal prices (DOE) and twice the price of gas. In the future, the price ratio of power to coal will drop to 2.5, and power to gas will increase to 3;

b) briquettes will prove to be a fuel cheaper in relation to coal than electricity or gas, as in 1995, they will be 1.7 times the price of coal and in the future will be 1.6 times on an energy-content basis;

c) heating oil will be cheaper than both power and gas.

Figures 6-3 and 6-4 depict the forecast price relationships discussed under items a) through c) above.

d) at this time, fuel and energy prices in Poland are below the 1995 DOE estimates, e.g., gas by about 35 percent and electricity by about 40 percent. These differences are less for other fuels **(Figure 6-5)**.

The U.S. Department of Energy's and Polinvest's forecasts are close to each other for prices of gas and heating oil in ten and more years; however, Polinvest contends that the difference in price of coal-derived fuels and coal itself will be less than that given in U.S. DOE's forecast (Figure 6-5).

6.2.3 Changes in Fuel Prices During 1990 - 1995

Figure 6-6 depicts actual energy prices during 1990 - 1995 in U.S. dollars; the prices quoted are from January of each year.

There were the following changes in the prices of individual types of energy:

a) at present, night electric rate is the most expensive energy source per GJ. The fall in energy prices during 1992 - 1994 was caused by the prices lagging behind inflation (dollar exchange rates);

b) the gas prices quoted correspond to a sample boiler house in the Kraków area discussed in Section 6.2.1. The price depends on the relationship between the power ordered (maximum available hourly consumption) and the power actually used, and may differ between individual boiler houses;

c) the relatively faster growth of bituminous coal prices for individuals per GJ, (Figure 6-6) compared with the prices for the industry, is a consequence of those prices having been freed.

Table 6-3 and Figure 6-6 show that the most expensive energy source in 1995 was electrical power, and the least expensive was bituminous coal; this is inversely proportional to the convenience and ease of use of these types of energy. Delivery of electric power is a comprehensive service, while using bituminous coal for space heating requires substantial additional costs related to its on-site delivery, stoking/carrying to the furnace, labor and/or expense for operating the furnace. In this classification, gas falls somewhere between electrical power and bituminous coal.

Table 6-2. POLINVEST and DOE Forecast Fuel Prices

Year	Coal for Industrial Customers POLINVEST [U.S.$ per ton]	Coal for Industrial Customers DOE [U.S.$ per ton]	Coal for Individual Customer POLINVEST [U.S.$ per ton	Coal for Individual Customer DOE [U.S.$ per ton]	Coke POLINVEST [U.S.$ per ton]	Coke DOE [U.S.$ per ton]	Briquettes POLINVEST [U.S.$ per ton]	Briquettes DOE [U.S.$ per ton]
1995	28.39	65.96	84.21	75.55	58.64	71.81	82.86	94.43
1996	30.90	66.88	77.62	76.60	63.82	72.82	76.38	95.75
1997	33.63	67.82	71.54	77.68	69.47	73.83	70.40	97.09
1998	34.04	68.77	72.42	78.76	70.32	74.87	72.43	98.45
1999	34.46	69.73	73.30	79.87	71.18	75.92	74.52	99.83
2000	34.88	70.71	74.20	80.99	72.05	76.98	76.66	101.23
2001	35.52	71.70	75.55	82.12	73.36	78.06	78.06	102.64
2002	36.16	72.70	76.93	83.27	74.70	79.15	79.49	104.08
2003	36.82	73.72	78.33	84.43	76.06	80.26	80.94	105.54
2004	37.50	74.75	79.76	85.62	77.45	81.38	82.41	107.01
2005	38.18	75.80	81.22	86.81	78.86	82.52	83.92	108.51
2006	38.12	76.86	81.10	88.03	78.75	83.68	83.79	110.03
2007	38.07	77.93	80.98	89.26	78.63	84.85	83.67	111.57
2008	38.01	79.02	80.86	90.51	78.51	86.04	83.55	113.13
2009	37.96	80.13	80.74	91.78	78.40	87.24	83.43	114.72
2010	37.90	81.25	80.62	93.06	78.28	88.46	83.30	116.32
2011	37.90	82.39	80.62	94.37	78.28	89.70	83.30	117.95
2012	37.90	83.54	80.62	95.69	78.28	90.96	83.30	119.60
2013	37.90	84.71	80.62	97.03	78.28	92.23	83.30	121.28
2014	37.90	85.90	80.62	98.39	78.28	93.52	83.30	122.98
2015	37.90	85.90	80.62	98.39	78.28	94.83	83.30	122.98
2016	37.90	85.90	80.62	98.39	78.28	96.16	83.30	122.98
2017	37.90	85.90	80.62	98.39	78.28	97.50	83.30	122.98
2018	37.90	85.90	80.62	98.39	78.28	98.87	83.30	122.98
2019	37.90	85.90	80.62	98.39	78.28	100.25	83.30	122.98
2020	37.90	85.90	80.62	98.39	78.28	101.66	83.30	122.98

Table 6-2. POLINVEST and DOE Forecast Fuel Prices (cont'd)

Year	Electricity (night) POLINVEST [U.S.$ per Kwh]	Electricity (night) DOE [U.S.$ per Kwh]	Gas According to POLINVEST for Boiler Houses [U.S.$ per 1,000 cu.m]	Gas According to POLINVEST for Individual Customers [U.S.$ per 1,000 cu.m]	Gas Acc. to DOE for Individual and Industrial Customers [U.S.$ per 1,000 cu.m]	Heating Oil POLINVEST [U.S.$ per ton]	Heating Oil DOE [U.S.$ per ton]	District Heat POLINVEST [Zl. per GJ]
1995	0.0240	0.0425	201.07	206.20	320.00	336.55	324.6	6.11
1996	0.0261	0.0426	214.25	216.00	327.04	337.46	327.8	6.32
1997	0.0285	0.0428	224.43	226.27	334.23	338.38	331.1	6.54
1998	0.0288	0.0429	235.10	237.03	341.59	339.30	334.4	6.77
1999	0.0292	0.0430	246.28	248.30	349.10	340.22	337.8	7.00
2000	0.0295	0.0431	257.99	260.11	356.78	341.14	341.1	7.25
2001	0.0300	0.0433	270.26	272.48	364.63	344.55	344.6	7.50
2002	0.0306	0.0434	283.11	285.43	372.65	348.00	348.0	7.76
2003	0.0312	0.0435	296.57	299.00	380.85	351.48	351.5	8.02
2004	0.0317	0.0437	310.68	313.22	389.23	354.99	355.0	8.30
2005	0.0323	0.0438	325.45	328.12	397.79	358.54	358.5	8.59
2006	0.0323	0.0439	340.92	343.72	406.55	362.13	362.1	8.59
2007	0.0322	0.0441	357.14	360.06	415.49	365.75	365.8	8.59
2008	0.0322	0.0442	374.12	377.18	424.63	369.41	369.4	8.59
2009	0.0321	0.0443	391.91	395.12	433.97	373.10	373.1	8.59
2010	0.0321	0.0445	410.54	413.90	443.52	376.83	376.8	8.59
2011	0.0321	0.0446	430.06	433.59	453.28	380.60	380.6	8.59
2012	0.0321	0.0447	450.51	463.25	463.25	384.41	384.4	8.59
2013	0.0321	0.0449	471.93	471.93	473.44	388.25	388.3	8.59
2014	0.0321	0.0450	483.86	483.86	483.86	392.13	392.1	8.59
2015	0.0321	0.0450	494.50	494.50	494.50	396.06	396.1	8.59
2016	0.0321	0.0450	505.38	505.38	505.38	400.02	400.0	8.59
2017	0.0321	0.0450	516.50	516.50	516.50	404.02	404.0	8.59
2018	0.0321	0.0450	527.86	527.86	527.86	408.06	408.1	8.59
2019	0.0321	0.0450	539.48	539.48	539.48	412.14	412.1	8.59
2020	0.0321	0.0450	551.34	551.34	551.34	416.26	416.3	8.59

Figure 6-1

POLINVEST Forecast of Fuel Prices
in Relation to the Price of Coal
(Prices per 1 GJ)

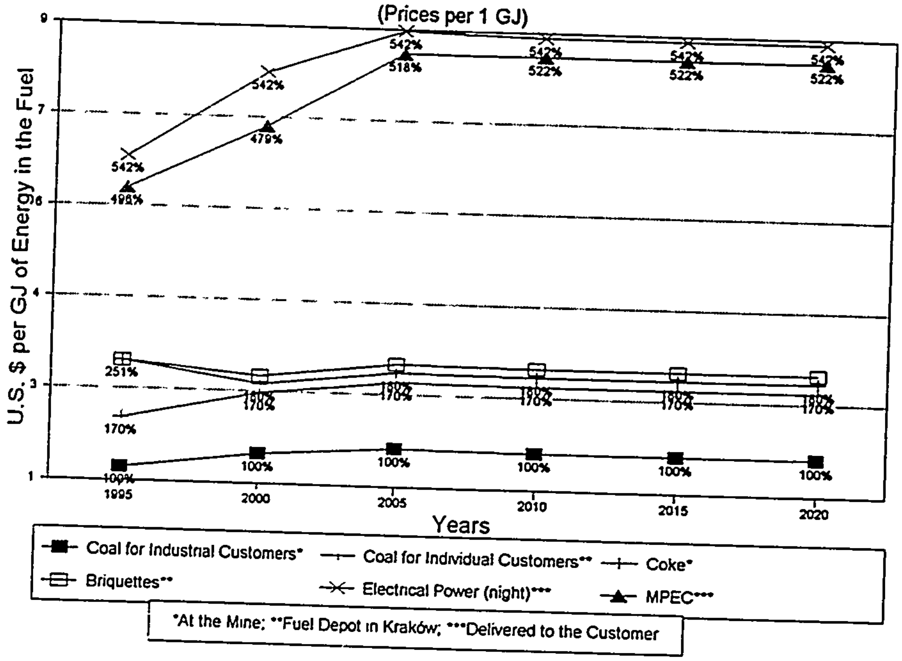


Figure 6-2

POLINVEST Forecast of Fuel Prices
in Relation to the Price of Coal
(Prices per 1 GJ)

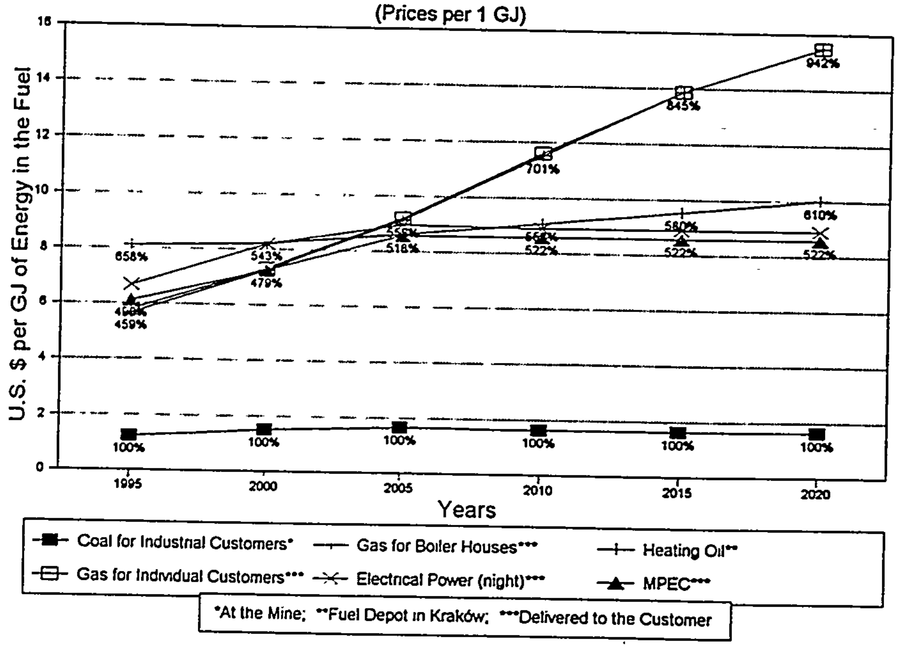


Figure 6-3

DOE Forecast of Fuel Prices Including Delivery

in Relation to the Price of Coal (Prices per 1 GJ)

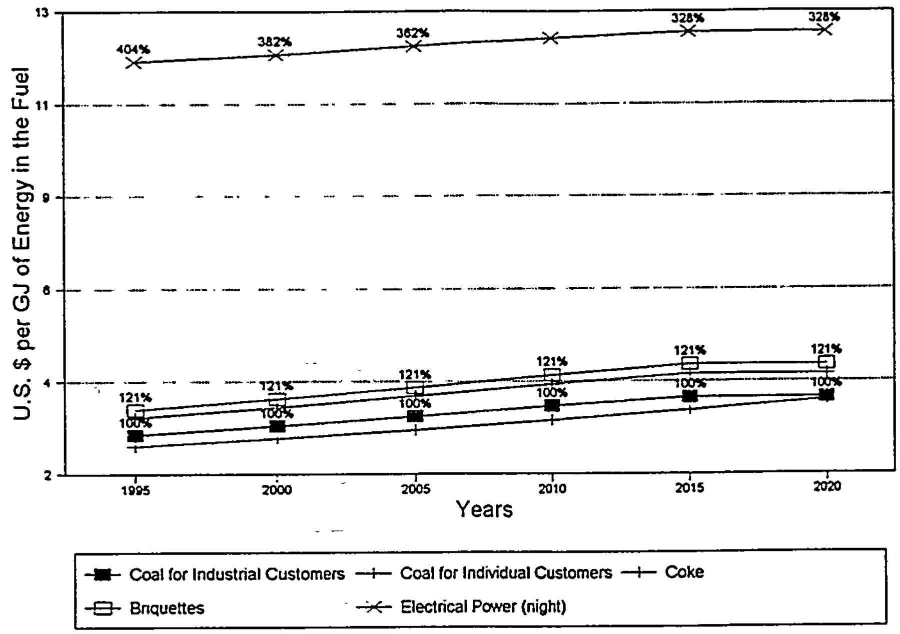


Figure 6-4

DOE Forecast of Fuel Prices Including Delivery

In Relation to the Price of Coal

Prices per 1 GJ

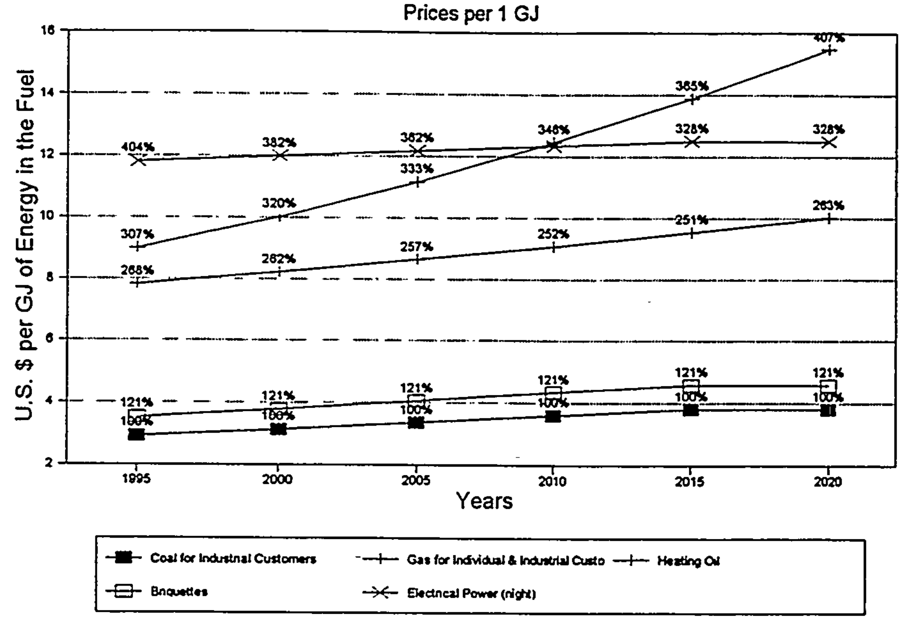


Figure 6-5
Comparison of Forecasts
(1 GJ of Energy in Fuel)

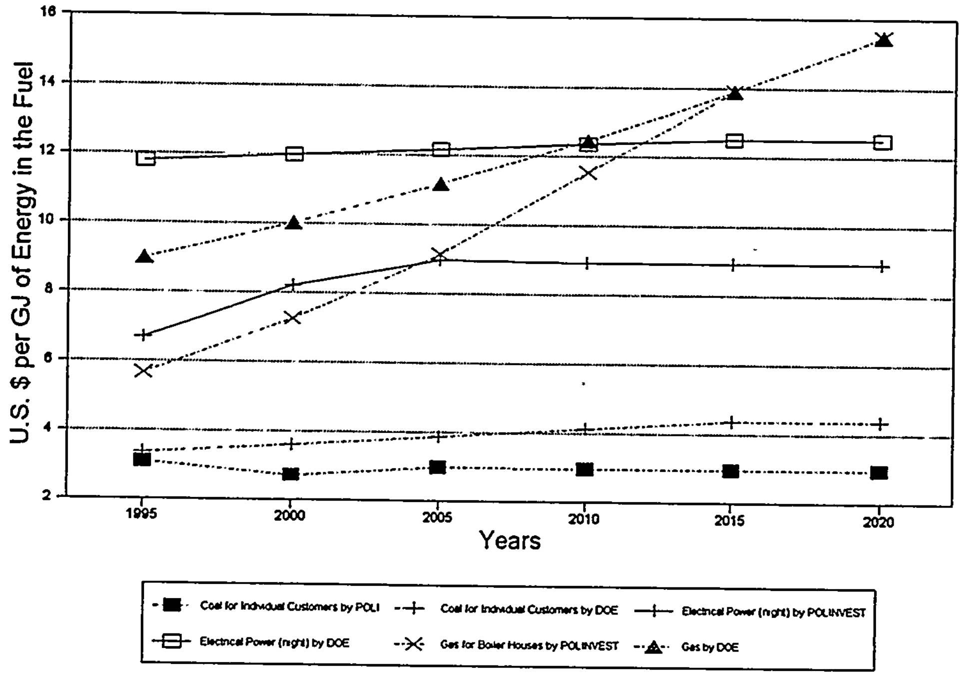


Figure 6-6
Comparison of Energy Prices in Poland
During 1990 - 1995

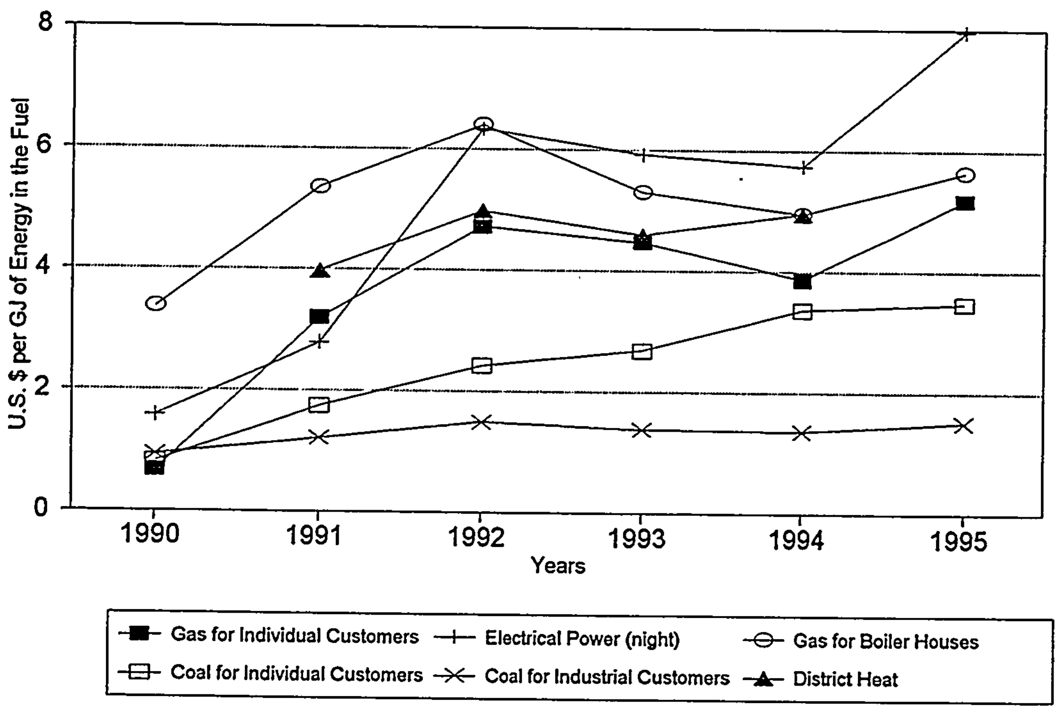


Table 6-3. Fuel Prices in Poland During 1990 - 1995

Fuel	Fuel Prices (in January each year) in U.S. $ per GJ Energy in the Fuel					
	1990	1991	1992	1993	1994	1995
Electricity (night)	1.58	2.78	6.36	5.92	5.74	7.97
Gas for Individual Customers	0.68	3.19	4.72	4.47	3.85	5.18
Gas for Boiler Houses	3.37	5.37	6.41	5.31	4.95	5.65
Coal for Individual Customers	0.82	1.74	2.42	2.68	3.36	3.46
Coal for Industrial Customers	0.94	1.22	1.50	1.39	1.36	1.51
District Heating*)	-	3.97	4.98	4.59	4.95	-

*) An average price was calculated by MPEC S.A. based on the two-tiered system (no data was available for January 1990 and January 1995).

6.3. ORGANIZATION OF THE CURRENT FUEL AND ENERGY MANUFACTURING AND DISTRIBUTION SYSTEM IN POLAND (KRAKÓW)

6.3.1 Fuel and Energy Distribution Systems

Heat. Heat production and sales take place in the following two subsystems:

a) **production** — industrial heat and power plants (such as the Kraków Cogeneration Plant, *Elektrocieplownia Kraków S.A.* and the Skawina Cogeneration Plant, *Elektrociepłownia Skawina*), industrial plants for which power is an accessory product, (e.g., Huta T. Sendzimira Steel Mill), process boiler houses, district and local boiler houses;

b) **distribution** — local utilities (e.g., Kraków Heat Utility Company, Joint Stock Corp., MPEC S.A., *Miejskie Przedsiębiorstwo Energetyki Cieplnej w Krakowie*).

Gas. Manufacturing and sales of gaseous fuels take place in the following three subsystems:

a) **manufacturing** — Polish Oil Mining and Gas Company (*Polskie Górnictwo Naftowe i Gazownictwo*) has the monopoly on mining, manufacturing, and importing gas. Russia is the principal source of Poland's gas.

b) **transport** — a joint gas network, managed by 18 District Gas Companies (*Okręgowy Zakład Gazownictwa*);

c) **distribution** — distribution companies, such as Kraków's gas utility, *Zakład Gazowniczy*.

The following gaseous fuels are distributed:

- natural high methane gas (Z tariffs);
- nitrated natural gas (Za tariffs);
- coking gas (K tariffs);
- town gas (M tariffs).

Electrical power. National production and sales of electrical power take place in the following three subsystems:

a) **generation** — 36 system power plants and cogeneration plants (industrial power generation);

b) **transport** — national high voltage grid (Polish Power Grid, Joint Stock Corp., *Polskie Sieci Elektroenergetyczne S.A.*);

c) **distribution** — 33 distribution utilities (such as the Kraków power utility, Kraków Power Company, Joint Stock Corp., *Zakład Energetyczny Kraków S.A.*).

Coal and coal-derived fuels. Poland's coal and coke demand is fully met by domestic mining and coking. Manufacturing and sales take place in the following two subsystems:

a) **manufacturing** — approximately 60 coal mines and coking plants, located primarily in Poland's Silesia (*Śląsk*) region;

b) **distribution** — mines, coal companies, fuel depots.

Smokeless briquettes have not been mass-manufactured yet in Poland for the following reasons:

a) the high cost of manufacture has put their price of out of the customers' buying range;

b) the processes presently are environmentally hazardous.

6.3.2 Subsidies to the Cost of Heating

Only **district heating** fees are subsidized. District heat distributors enter into contracts with their customers, primarily housing co-ops, associations of condominium homeowners and municipal housing management companies (*PGM*'s), for heat deliveries at **negotiated prices.**

Fees payable by individual households are based on **official prices** (centrally set). The subsidy system is intended to bridge the gap between the two prices from state (housing co-ops and condominium homeowners associations) and municipal (housing management companies) funds.

There is no such system of gas subsidies despite the fact that there are official gas prices, too. The entire fuel and power industry is being subsidized directly, e.g., by such means as state financing of power-related capital construction. Additionally, the consequence of using official, uniform price tariffs in spite of obvious differences in the cost of delivery to Poland's various regions is such that some customers are subsidizing others.

6.3.3 Fuel and Energy Price Setting Systems

Heat prices in Poland are negotiated. Prices are set up in negotiations between the distributor and the customer (e.g., housing co-ops and associations of condominium homeowners), based on each distributor's cost. Since October 1991, the Minister of Finance determines the cap on price increases for household heat. Distributors can raise prices by the specified increase, or less, at times corresponding to the times of official rate increases. Negotiated prices can be two-tiered prices (a fixed fee for ordered capacity and a fee for heat actually delivered) or a single-tier system consisting of a fee for heat actually delivered.

Fees paid by households (such as co-op tenants to a housing cooperative or a condo homeowner to the homeowners association) are based on official prices. These prices are fixed-rate fees, set in relation to the square footage of living space, in zł. per square meter. Individual households equipped with appropriate metering devices are charged at official prices calculated in relation to the actual amount of heat used, as shown on the meter, expressed in zł. per GJ, or zł. per MWh. These official prices are set by the Minister of Finance and the schedules and amounts of possible rate increases are written into the state budget (which is in the form of a congressional act).

A study of MPEC S.A. district heating utility's 1992 revenues showed that approximately 67 percent of the revenue was for ordered capacity (maximum available hourly consumption ordered), and approximately 33 percent for heat delivered.

Gas prices in Poland are official prices. Official prices for end-users are set by the Minister of Finance. These prices, and the principles of charging are set forth in the Price Schedule Z/94. Several different tariffs are offered, with prices set according to the following criteria:

a) contract capacity, i.e., contractually determined maximum hourly gas use requested by the customer and accepted by the distributor; and

b) type of meter.

The following tariffs are used, based on the above criteria:

a) for customers using more than 10 cu. m. of high methane natural gas, or over 25 cu. m. of other gas fuels — tariffs Z1, Za1, and K1 (gas meter equipped with an hourly gas-use device), or Z2, Za2, K2, and M3;

b) for customers using less than 10 cu. m. of high methane natural gas or under 25 cu. m. of other gas fuels — tariffs Z5, Za5, K5, M5, and service fees.

The following fees are included in the tariffs:

a) fixed fee, in zł. per cu. m. per hour, for maximum available hourly consumption ordered;

b) fee for heat actually delivered, in zł. per sq. m.; and

c) service fee, in zł. per month.

The following tariffs are used for space heating:

a) Z1[1] (fixed fee: zł. 600 per cu. m. per hour; variable fee: zł. 2,400 per cu. m.);

b) Z2 (fixed fee: zł. 500 per cu. m. per hour; variable fee: zł. 2,400 per cu. m.);

c) Z5 (service fee: zł. 19,000 month; variable fee: zł. 4,500 per cu. m.).

Electric power prices in Poland are the official prices. The price-setting system consists of a price-determination system and account settling principles between industrial power manufacturers, distributors, and end-users (consumers).

Official (transfer) prices, used for settling accounts between the manufacturers and the grid (*PSE S.A.*), and between the grid (*PSE S.A.*) and the distributors, are set by the Minister of Industry and Trade. These prices, and principles of account settling, are set forth in an official publication *Principles of Settling Accounts Between Manufacturers, the Grid (PSE S.A.), and Power Utilities in 1994*, developed by the Ministry of Industry and Commerce. Official prices for end-users are set by the Minister of Finance. These prices, and the principles of charging are set forth in the Price Schedule 7-Z/92. Several different tariffs are offered, with prices set according to the following criteria:

a) power voltage level (tariff groups A - high voltage; B - medium voltage; C and G - low voltage);

[1] Gas and power prices quoted are in effect from January 1, 1995.

b) power consumption, momentary or overall (two- and single-tiered tariffs);

c) daily variable rates (24-hour rate, night/day, and three daily period rates).

For each of these rates, fees for power use are set in zł. per Kwh. Price propositions for end users and transfer contracts are developed by the power grid (PSE S.A.) and submitted for approval to the Finance and Industry and Commerce Ministries. Planned increases in prices are written into the state budget (which is in the form of a congressional act).

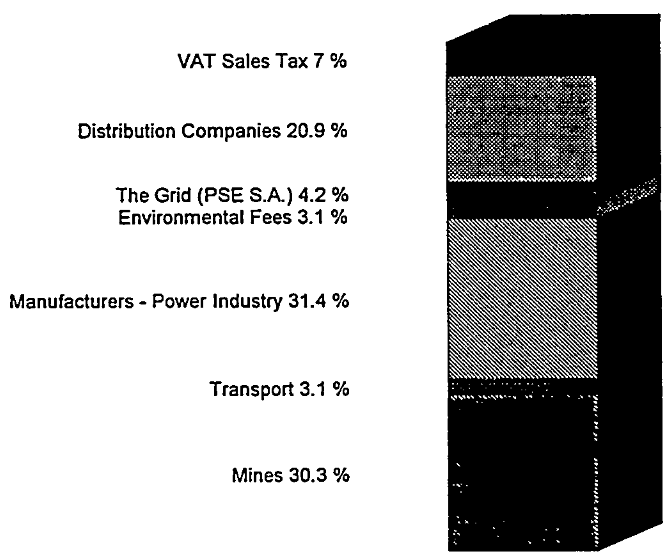
The following tariffs are used for space heating:

a) G11 - single, 24 hour rate of zł. 1,500 per Kwh; and

b) G11 - night rate of zł. 700 per Kwh; day rate of zł. 1,700 per Kwh; service fee of zł. 18,000 per month.

Official power prices are used by the state to limit inflation and reduce (prevent) social unrest (tension). In 1992, a "creeping" price system was introduced. Its evaluation, published in June and September by the power grid (PSE S.A.) indicate that the system helped to reform and improve the rate tariff structure (particularly the price relationships between the prices for industrial and residential customers) and transfer prices. The makeup of the end-user electricity price is shown in Figure 6-7.

Figure 6-7
End User Electricity Price Makeup



Coal and coal-derivative fuel prices are free, market prices. However, the price of coal for power companies is regulated. This is closely related to the use of coal as the principal fuel in generating electricity and to the existence of official power prices.

6.4. RESULTS OF CAPITAL PROJECT STUDIES

6.4.1 Feasibility of Developing the MPEC S.A. District Heating Network in Areas of Local Boiler House Closure

Study Objectives and Initial Assumptions

The objective of the first study, developed by Polinvest under subproject 1, March through June 1993, was to create a model for developing business plans for select Kraków neighborhoods, where local boiler houses are to be replaced with district heating provided by MPEC S.A.; this model also was intended to identify those parties for whom the conversion to district heating would not be feasible without express incentives and stimuli. **It was assumed that such a project may be carried out only when replacing heat generated by the local boiler houses with MPEC S.A. district heating is economically viable (profitable) for all parties involved.**

A total of 101 boiler houses were included in the study. Twelve of these were selected for development of individual feasibility study models and operating cost calculation models. A further 70 boiler houses were included in a feasibility study, which showed that connecting the remaining 19 is not possible.

Another, parallel objective of the study was to present to potential lenders the initial conditions and the range of municipal programs required to make the projects feasible.

The following assumptions were made in the project's feasibility studies:

a) the following parties are to participate in the subject projects:

- always MPEC S.A.;
- owners of local boiler houses who will be the future district-heating customers;
- customers in the area previously supplied with heat by local boiler houses;

b) participation in the project must be economically viable for each of the parties involved;

c) the value of municipal incentives to be applied to a project was calculated whenever it did not prove economically viable for one or more parties thereto;

d) projects may be co-financed by interested parties, such as MPEC S.A. district heating utility or EC Kraków S.A. Cogeneration Plant.

The following qualifications were made in the project feasibility studies:

a) Polinvest accepted data from the Kraków Development Bureau (BRK) at face value and did not verify it;

b) calculations were based on data from the 1991/1992 heating season, updated, whenever possible, to 1992/1993 conditions;

c) the 12 boiler houses studied were selected from BRK's database of 1,344 boiler houses. All categories of boiler house, according to study's criteria, were fully represented in the study.

The following were criteria for selecting the boiler houses:

a) the boiler house's capacity, as a criterion of its size and expected scale of heat generation;

b) the owner or operator of the boiler house, as a criterion significant for marketing issues and the way cost is incurred;

c) the type of fuel used, as a criterion significant to environmental protection issues and the current cost of using heat generated by local boiler houses;

d) the number of boilers and their mean operating output, as an economic criterion, governing current costs of heat generated by local boiler houses;

e) particulate emissions, as the criterion of levels of environmental fees;

f) neighborhood location, for the potential connection to the MPEC S.A. district-heating network.

The following groups of customers are represented in the selected sample of boiler houses:

- state-owned businesses
- municipal businesses/public utilities
- privately owned businesses
- public and state agencies and organizations
- housing co-ops and associations of condominium homeowners
- individuals.

Conclusions and Possible Strategies for the MPEC S.A. District Heating Network Development/Enlargement

General

Over the next few years, as current MPEC S.A. customers undertake energy-conservation measures, MPEC S.A.'s heat sales are expected to fall. Data presently available to Polinvest do not permit a precise determination of savings resulting from these expected energy conservation measures[2]. At the same time, with the World Bank's assistance, MPEC S.A. district-heating utility began implementing a program for containing the network-incurred heat loss. The 1992 ordered capacity (maximum available hourly consumption ordered) was approximately 1,650 megawatts, and more than 12 million gigajoules (GJ) of heat actually were delivered. From 1994 through 2005[3], as a consequence of implementing the modernization program and development strategy in cooperation with the World Bank, the following fall is expected in the maximum available hourly consumption ordered, and in the actual heat deliveries:

a) capacity for the currently existing substations — 23 percent;

b) capacity for the newly connected boiler houses — 35 percent;

c) capacity for new construction — 16 percent;

d) heat for all customers — 26 percent.

Heating cost is settled between MPEC S.A. and its customers using a two-tiered rate tariff. This tariff consists of a fixed fee for the maximum hourly consumption available to the customer at any time, expressed in megawatts, and a variable fee for the heat actually delivered, accounted for in gigajoules (GJ). The construction of this tariff does not reflect the differences in capital cost necessary for connecting customers to the district heating network. A cap on both these above rates is set by Poland's Ministry of Finance. The mean heat price, per 1 GJ, calculated in accordance with the above discussed tariff, was $6.89 per GJ in 1992.

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[2] In 1993, MPEC S.A. ordered capacity (maximum available hourly consumption ordered) for the 1993/1994 heating season fell by 5.8 percent relative to the preceding, 1992/1993 heating season. However, it is not possible to determine to what extent energy-conservation measures undertaken by the consumers were responsible for this drop in sales.

[3] Once MPEC S.A.'s network reduction program for network-incurred delivery heat loss is established, the actual heat demand should fall; it also will provide the grounds for re-negotiating ordered peak capacity.

In 1992, MPEC S.A. district-heating utility purchased heat from four suppliers, the largest of which was EC Kraków Cogeneration Plant at 87.02 percent of the whole. The remaining three suppliers were: EC Skawina Cogeneration Plant, at 7.96 percent; Solvay Soda Works, at 3.08 percent; and Sendzimira Steel Mill, at 1.94 percent. Heat fees were calculated in accordance with a two-tiered tariff, except for the Sendzimira Steel Mill, who used a single-tier, variable rate tariff. The mean 1992 price paid by MPEC S.A. district heating utility was $4.66 per GJ.

The following table illustrates 1992 heat purchase prices at the levels from June 1992.

Table 6-4. MPEC Heat Purchase Prices, 1992

Heat Supplier	Price, zł. per GJ	Price, U.S. $ per GJ	Price, zł. per MW	Price, U.S. $ per MW
EC Kraków Cogeneration Plant	30,400	2.21	21,234,750	1,539.42
EC Skawina Cogeneration Plant	28,977	2.11	26,411,722	1,914.73
Solvay Soda Works	35,780	2.60	57,212,400	4,147.63
Sendzimira Steel Mill	61,000	4.44	-	

The 1994 maximum hourly available capacity ordered was approximately 1,700 MW. Over 90 percent of this heat was purchased by MPEC S.A. district heating utility from 3 outside suppliers, i.e., EC Kraków Cogeneration Plant (84.5%), EC Skawina Cogeneration Plant (13.6%), and Sendzimira Steel Mill (1.9%).

Table 6-5 illustrates 1994 heat purchase prices, at the levels from November through December 1994.

Table 6-5. MPEC Heat Purchase Prices, 1994

Heat Supplier	Price, zł. per GJ	Price, U.S. $ per GJ	Price, zł. per MW	Price, U.S. $ per MW
EC Kraków Cogeneration Plant	61,431	2.55	34,531,784	1,431.49
EC Skawina Cogeneration Plant	64,059	2.66	32,459,876	1,345.60
Sendzimira Steel Mill	129,470	5.37	-	-

Strategies for the Development/Enlargement of MPEC S.A. District-Heating Network

There are two possible scenarios for future development:

a) MPEC S.A. district-heating utility will lose district heat sales, thereby decreasing its gross margin, and possibly, becoming insolvent. This constitutes a danger for its owner, the Municipality of Kraków, 70 percent of whose residents depend on MPEC S.A. for heating. With a decrease in heat sales to its end-users, MPEC S.A. district heating utility would reduce its purchases from EC Kraków Cogeneration Plant. Recovering the eventual loss of revenue by increasing sales prices must be deemed impossible. As a consequence of a gradual reduction of subsidies, the customers' net available income actually may decrease relative to its present level, making significant rate increases unfeasible.

b) MPEC S.A. district-heating utility will connect/acquire additional network customers, thereby avoiding a decline in heat sales. Currently, there are approximately 1,100 local coal-, coke-, or culm-fired boiler houses in Kraków, 600 of which are located near existing MPEC S.A.'s mains. This strategy would definitely benefit Kraków's program of eliminating low emission sources within the city bounds. Additionally, favorable are the arguments for the possibility of eliminating of MPEC S.A.'s local boiler houses, an expensive way of space heating, and of the advantageous use of the excess heat generated by the power houses and conserved within the network itself - all achievable through these conservation programs.

Polinvest suggests that scenario b) is the strategy that will substantially reduce Kraków's low emission sources.

To carry out the proposed project, Kraków's Municipal Offices, the *Voivod*'s (local governor's) office, MPEC S.A. district-heating utility, and EC Kraków Cogeneration Plant all will have to work together. Each entity will benefit from the project.

Possible measures for creating circumstances favorable for successfully carrying out the program are discussed below.

a) MPEC S.A. district-heating utility could offer a three-tier (rate) tariff to the new heat customers connected to the network. Component (A) of the tariff will correspond to the recovery of MPEC S.A.'s capital cost expended for connecting the customer to its district-heating network, and will be payable only until such cost is fully recovered. Components (B) and (C) will correspond to the recovery of current operating cost of heat deliveries from the district-heating network and, specifically, will help recover MPEC S.A.'s fixed and variable fees, respectively, paid to the suppliers of heat to the network (heat sources, or the power plants).

b) MPEC S.A. could offer its newly connected customers a lower price. A cost analysis for the 1992/1993 heating season indicates that the average revenue to a local boiler house for 1 GJ of heat ranged from U.S. $4.5 to $6.5.

MPEC S.A.'s 1992 price for customers previously connected to the district-heating network, in accordance with the two-tiered tariff, uniform for all customers, was approximately U.S. $6.9 per GJ. Polinvest's calculations suggest that the cost of delivering 1 GJ of heat, calculated from district-heating network data (excluding the cost associated with operating the local and neighborhood boiler houses) could be circa U.S. $4.64 per GJ of heat. This number excludes any possible MPEC S.A. capital cost recovery; it was calculated assuming that all additional heat deliveries for the newly connected customers would be from heat purchased from EC Kraków Cogeneration Plant (Łęg).

Polinvest also assumed that the capital cost fee will be paid by boiler house owners relative to the capital cost of connecting the respective boiler house to the district-heating network. Polinvest developed a model permitting a precise computation of the capital cost share of each of the project's participants. Attention must be given to the fact that the capital-cost recovery component of the heat fee will vary widely among individual customers, relative to the following variables:

- maximum capacity needed;
- location;
- overall number of project participants in the area.

c) The *Voivodship* (Governor's) Office could undertake active measures to assess the local boiler house owners with the cost of using the natural environment, through levying and collecting fees and fines, and closing particularly hazardous installations.

d) The municipal authorities could rigorously apply their authority mandated by the environmental protection statutes to develop programs to improve air quality that will locally and realistically do so. If, in spite of fines and other administrative measures, an owner or operator of an environmentally hazardous boiler house willingly fails to comply with administrative orders or violates the statutes, the municipal authorities could force such an owner/operator to replace the boiler house, or to close it altogether[4].

e) The *Voivodship* (Governor's) Office and the Municipal Offices could coordinate with each other on all actions related to financing the cost of heating, and of the capital cost expended

[4] Articles 76.1 and 76.2 of the January 31, 1980 Environmental Protection Act (uniform text including subsequent amendments of March 21, 1994, is published in the April 15, 1994, *Congressional Reports*, or *Dziennik Ustaw*, #49).

for the public utilities in such a way that these funds are used rationally to connect these public utilities to the MPEC S.A. district-heating network.

f) Municipal and state land could be made available for developing and enlarging the MPEC S.A. district-heating network.

g) The *Voivodship* (Governor's) Office could assist individuals closing their local boiler houses by forgiving environmental fees and fines (in favor of applying the funds generated to the program), and the Municipality could assist these individuals through local tax exemptions.

h) In consultation with the *Voivodship* (Governor's) Office and the Municipality of Kraków, MPEC S.A. could develop long-term draft contracts for heat deliveries to an area. Such contracts would be entered into for a term equal to the payback period of the capital cost incurred by MPEC S.A. and its customers. The precise amount of the heat capacity ordered (maximum hourly available capacity), expressed in megawatts, should be specified in such contracts. MPEC S.A.'s proposed clause regulating the principles for charging for heat deliveries should be based on the three-tier tariff discussed under item a) above. Increases in the heat rate should be indexed to a variable, independent of MPEC S.A. district-heating utility and EC Kraków Cogeneration Plant (such as coal prices, exchange rate for U.S. dollars).

The models discussed in Section 6.1.2 were used by Polinvest in feasibility studies of connecting the MPEC S.A. district-heating network to the following four areas where local boiler houses are intended to be closed down:

- Halicka and Szeroka Streets area;
- Karmelicka and Krupnicza Streets area;
- Zwierzyniecka and Świerczewskiego Streets area;
- Wrocławska Street area.

These areas belong to a group consisting of approximately 600 boiler houses where the MPEC S.A. district-heating utility has adequate standby capacity to connect all existing boiler houses in the given area. The 4 sample areas were selected by the Kraków Development Bureau (BRK).

Economic Viability of Connecting the MPEC S.A. District-Heating Network to Areas of Local Boiler House Closure

Polinvest performed an initial study of the economic viability (profitability) of converting 70 coal/coke fired boiler houses in the four areas discussed above. What follows is a list of general conclusions on the issue of economic viability of converting coal/coke-fired boiler houses to the MPEC S.A. district-heating network:

a) The current, uniform MPEC S.A. tariff may prove a hindrance in the project, as it requires the owners of local boiler houses to incur relatively high *participation* fees to make the project viable for the MPEC S.A. Thus, even if a conversion proves viable for the local boiler-house owners, Polinvest contends that the payment of these *participation* fees at the proposed level will render the projects unfeasible, as the owners do not have enough money to meet these charges.

b) Under the circumstances discussed under item a) above, MPEC S.A. itself will have to incur some of the capital cost, and gradually pass it on to the customer by levying a capital-cost fee rate.

c) Boiler houses should be connected in groups that could jointly use parts of the network (such as local mains and stations).

d) Polinvest's studies show that the ongoing operating costs of heat generation in the local boiler houses usually ranges from U.S. $5 and $6.5 per GJ. Assuming that MPEC S.A. in 1992 offers Polinvest's recommended price of U.S. $4.64 per GJ of heat as a sum total of the (B) and (C) components of a three-tiered tariff, then the level of the (A) component, intended to permit the recapture of the capital cost[5], would have to fall between U.S. $.36 and $1.84 per GJ. Charging of higher capital-cost fees by the utility would render the conversion of local boiler houses economically inviable for their owners.

e) Conversion viability depends most on the mean capital investment per each kilowatt of capacity (maximum hourly heat capacity available) ordered by the local boiler-house customers after converting to district-heating. This should be the principal parameter for initially selecting the project's groups of boiler houses.

f) Among the 70 boiler houses studied, with the joint total capacity of 17,919 kW[6], converting 26 of them, i.e., 37.1 percent, with a joint total capacity of 4,561 kW, did not require incentives and stimuli.

g) In the situation where each boiler house is considered separately, converting the remaining 44 local boiler houses (62.9%) with a joint total capacity of 13,358 kW, i.e., 74.6 percent, would require municipal incentives and stimuli to a joint present 1992 value of U.S. $2,210 thousand (i.e., the sum total only of the project's negative net present values).

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[5] i.e., the additional capital cost fee, as discussed under item b) above.

[6] Heat-capacity demand refers to such capacity that the customers would order following the conversion of a given local boiler house to district heat.

h) When each boiler house in the four sample areas is considered separately, converting each megawatt of boiler house capacity to district-heating would require municipal incentives and stimuli valued in 1992 dollars at U.S. $123,333.

i) From the point of view of the Municipality, it is particularly worthwhile to apply incentives and stimuli to converting to district-heating of those local boiler houses belonging to the groups where most conversions are viable (such as the group of eight local boiler houses in the Podwale Street area, of which seven are economically viable without incentives and stimuli, and the conversion of the one inviable on its own would require incentives of net present value of ca. U.S. $11 thousand).

j) **In the situation where converting the 70 boiler houses is carried out by MPEC S.A. as a single capital construction project, the net present value is approximately negative $198 thousand[7]. Therefore, to carry out this project, the City would have to offer incentives valued in 1992 dollars at $198,005 (i.e., approximately $11,050 per each megawatt of the capacity of those boiler houses connected to the district-heating network).** The reduction of emissions per dollar of incentives also is high (see Section 6.4.6) for this project.

k) **Therefore, if the City chooses to support district heat connections, it would be particularly worthwhile to financially support the projects that include the most boiler houses, and particularly, those that have groups of boiler houses for which the conversion is economically viable (in accordance with the example in item i above).**

l) To avoid the increase of the subsidies needed to carry out these projects, the City could support them by creating non-financial incentives for boiler house owners to connect to the municipal district-heating network. Additionally, the City could support these future MPEC S.A. customers who will have to incur some of the capital cost of conversion (such as the cost of on-site system modernization). These costs were not studied.

6.4.2 Economic Viability of Converting Coal/Coke-Fired Boiler Houses in the Old Town

Study Objectives

The objective of this study was to assess the following aspects:

a) economic and legal conditions for the feasibility of converting coal/coke-fired boiler houses in the Old Town area to gas firing;

b) the amount of incentives, if any, necessary to promote the capital projects;

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[7] The total net present value of the project was calculated as the sum of all individual, positive and negative net present values for each individual boiler house.

c) the order in which boiler houses should be converted that most effectively applies municipal funds to eliminating low-emission sources.

This section of the paper discusses the findings of the economic studies found in the report *Incentive Analysis and Recommendation of Possible Actions by the City to Interest Coal Fired Boiler House Owners to Convert to Gas Firing* (*Analiza bodźców i rekomendacja działań możliwych do podjęcia przez władze miejskie dla zachęcenia użytkowników kotłowni opalanych paliwem stałym do zamiany na paliwo gazowe*). Section 6.6 has recommendations for possible actions. The study was finished in December 1993.

1993 Boiler House Operating Costs and Future Operating Costs of Gas-Fired and Coal/Coke-Fired Boiler Houses

Cost options were computed for the ten sample boiler houses with two alternative fuel-use sets of data. Fuel consumption for the first option was computed using Hottinger's formula required in accordance with Polish standard #PN-66/B-02419. Fuel consumption for the second option was computed using data reported by boiler house operators.

Assumed Economic Conditions Accompanying the Conversions

Two scenarios, representative of the most likely economic conditions, were considered under which conversion of boiler houses was expected to be carried out. These two options (Options 1 and 2) were named basic options, with the same initial assumptions, except for the predicted gas prices.

The following assumptions were made for the basic options:

a) gas price per Polinvest forecast (Option 1) or the U.S. Department of Energy (Option 2);

b) heat use considered was actual heat use;

c) discount rate was 12 percent;

d) no loans were considered;

e) no subsidies were considered;

f) capital cost was as per BRK data;

g) income tax was 40 percent;

h) revenue from heat sales was at the level of solid-fuel heating costs;

i) VAT sales tax was seven percent.

Economic Viability of Conversions for Boiler House Owners Without Municipal Assistance

The payback period is as follows:

a) **Basic Option 1,** for nine boiler houses, full payback is impossible over the project's life of 20 years, for one boiler house there is full payback after 15 years;

b) **Basic Option 2,** for all 10 boiler houses, full payback is impossible over the project's life of 20 years.

The calculations of Basic Option 1 payback terms indicate that, from the boiler-house owner's point of view, conversion to gas firing is not viable economically. The findings for Basic Option 2 are even worse (lower net present value).

The term *net present value*, or *NPV*, refers to the accumulated value of the difference between cash in- and out-flows (revenues and expenses) over the period studied, expressed in today's dollars. A negative net present value for a given project life indicates that it will lose money. Calculating the net present value makes project comparisons possible.

Municipal Subsidy Amounts Ensuring Full Payback of Capital Cost in 10 and 20 Years

Payback term was calculated using cash flows and the project's net present values.

Amounts were computed for each of the following three possible types of subsidy:

a) subsidy to the price of heat;

b) subsidy to the capital cost of converting boiler houses;

c) subsidy as property tax exemptions.

The percent amounts of subsidy to prices and capital cost ensuring full payback in 10 and 20 years were calculated. However, there were several cases where, despite a full, 100 percent capital cost subsidy, net present values are negative over 10- and 20-year project life terms. Therefore, the term *capital cost subsidy ensuring full payback in 10 and 20 years* used in this text refers also to the cases where, in spite of such a full 100 percent subsidy, the net present value in the tenth and the twentieth year of project life is negative (the project will lose money). Price subsidy refers to such fixed percent share of the subsidy in the cost of heat generation (increasing) over the payback period that will ensure a positive net present value in 10 or 20 years, respectively.

Heat Price Subsidy

A fixed percent subsidy to the assumed price level (at coal-/coke-fired boiler house costs for heat generation) will equal:

Basic Option 1

a) 43 percent of the base price, to ensure 10-year payback;

b) 31 percent of the base price, in order to ensure 20-year payback.

Basic price refers to a price set at the level of the cost of generating heat at an existing coke-fired boiler house. The basic price reflects a situation where the tenants do not bear the capital cost of conversion.

Basic Option 2

a) 82 percent of the base price, to ensure 10-year payback;

b) 69 percent of the base price, to ensure 20-year payback.

For example, the mean subsidy to the price of heat per GJ must be as follows:

Basic Option 1

a) US $3.59 in the first year, and larger amounts in the following years, e.g., $3.74 in 1995, to ensure full payback in 10 years;

b) US $2.62 in the first year, and larger amounts in the following years, e.g., $2.69 in 1995, to ensure full payback in 20 years.

Basic Option 2

a) US $6.85 in the first year, and larger amounts in the following years, e.g., $7.13 in 1995, to ensure full payback in 10 years;

b) US $5.76 in the first year, and larger amounts in the following years, e.g., $6.00 in 1995, to ensure full payback in 20 years.

The 33 operating boiler houses generate 57,351 GJ of heat per season. The following is the amount necessary if heat-price subsidies (assuming subsidies for each boiler house) are used:

Basic Option 1

a) US $205,890 in 1994, and larger amounts in the following years, e.g., $214,550 in 1995, to ensure full payback in 10 years.

b) US $150,259 in 1994, and larger amounts in the following years, e.g., $154,676 in 1995, to ensure full payback in 20 years.

Basic Option 2

a) US $392,854 in 1994, and larger amounts in the following years, e.g., $409,142 in 1995, to ensure full payback in 10 years.

b) US $330,341 in 1994, and larger amounts in the following years, e.g., $344,271 in 1995, to ensure full payback in 20 years.

These results of calculating boiler house subsidies raise the following points:

a) heat-price subsidy is progressive (increasing) over the project term. This is because the basic price increases in relation to the boiler house operating costs rise from year to year;

b) rejecting complicated calculations in favor of simplicity, it may be concluded that the subsidy to heat prices for a 10-year payback will be 10 times higher than the 1994 subsidy, and the subsidy to heat prices for a 20-year payback will be 20 times higher than the 1994 amount;

c) the amount of the subsidy to heat prices calculated in the way discussed herein will equal for the Basic Option 1:

   U.S. $2,058,900 for a 10-year payback;

   U.S. $3,005,180 for a 20-year payback;

Capital Cost Subsidy

The mean subsidy for capital cost calculated for the 10 sample boiler houses will equal:

Basic Option 1

a) 79.35 percent of capital cost, for a 10-year payback;

b) 78.03 percent of capital cost, for a 20-year payback.

Basic Option 2

In nine cases, the subsidy to the project capital cost is 100 percent, and, in one case, it is 91 percent for a 10-year payback and 98 percent of project cost for a 20-year payback. In subsequent calculations, the following capital cost subsidies were assumed for the 10 boiler houses:

a) 100 percent of capital cost, for a 10-year payback;

b) 100 percent of capital cost, for a 20-year payback.

Project capital cost subsidies will be the following:

Basic Option 1

a) U.S. $1,064,554 for a 10-year payback, or zł. 23,052 million at the January 20, 1994, mean of the National Bank of Poland's exchange rate;

b) U.S. $1,046,845 for a 20-year payback, or zł. 22,669 million at the January 20, 1994, mean of the National Bank of Poland's exchange rate.

Basic Option 2

a) U.S. $1,341,593 for a 10-year payback, or zł. 29,669 million at the January 20, 1994, mean of the National Bank of Poland's exchange rate;

b) U.S. $1,341,593 for a 20-year payback.

The capital cost subsidy for Basic Option 1 is less than for Basic Option 2. Basic Option 1 (Polinvest's forecast — prices in the project's initial years close to the current prices) illustrates a situation wherein conversion of the boiler houses occurs quickly. Basic Option 2 (U.S. Department of Energy's forecast — prices at the level of global prices; according to Polinvest's forecast, gas prices will reach this level in a dozen or more years) illustrates a situation wherein the boiler houses are converted several years from now.

The calculations of heat price and the project's capital costs indicate that:

a) a subsidy for capital cost is more effective than one for heat price as less funds are required;

b) if subsidies are provided, the subsidies needed to carry out the conversions later will be much higher.

Subsidy as a Property Tax Exemption

From the perspective of a boiler house owner who does not have funds available for the conversion, this type of a subsidy clearly is less interesting than other forms. Additionally, this incentive applies only to some owners in Old Town, as not all pay this tax. This issue is discussed in detail in Section 6.6 of this report.

Possible Subsidy Method

If the City chooses to support gas conversions and if the funds available are adequate to finance the project, the amounts needed will correspond to those quoted in the Section entitled "Capital Cost Subsidy", above.

Should the City's funds prove inadequate for financing the entire project, Polinvest proposes that they are spent to convert boiler houses that meet the following criteria:

- those that belong in the groups of boiler houses whose conversion will result in the maximum reduction of emissions;

- those in which the capital costs for eliminating emissions relative to the size of the emissions is relatively low, i.e., boiler houses for which expense effectiveness is high.

Detailed propositions on the selection criteria for boiler houses together with emissions tables can be found in the Polinvest study *Incentive Analysis and ...*

Possibilities of Diverting the Expense of Conversions to the Tenants

The studies showed that the prices paid by customers for heat will rise by approximately 30 percent over the next few years. In some cases, this increase will be even higher. These increases will take place as the official prices for heating tenant spaces are lifted, and they will occur regardless of whether or not boiler houses are converted.

In some cases, the increase in the price of heat will be limited (through subsidies) to the level of coke-fired heating costs, but in other cases, despite subsidies, the required increases will be higher. Boiler-house owners will have to ensure that the tenants in their buildings are prepared to incur higher fees, at least partially. For those owners of multi-family buildings in Old Town who can freely control the commercial space in their buildings (for example, if this space is being rented under conditions where rent control does not apply), including the higher cost of gas heating in the rent should not substantially limit the demand for such space. Some groups of current tenants who are protected by law against undue rent increases, even where such increases are justifiable, may prove to be a significant impediment to converting some boiler houses.

Results of the Feasibility Study from the Perspective of the City

a) The studies showed that the use of incentives and stimuli may be required to fully eliminate coal/coke-fired boiler houses in the Old Town area.

b) The capital expenditure for converting coal/coke-fired boiler houses in most cases is not viable economically from the perspective of the owners. However, such projects would undeniably benefit the City financially, as lot prices and rents downtown would rise after low-emission sources are eliminated.

c) The City Council might pass a resolution allocating, in 1996 and the following years, a part of the funds from the municipal environmental protection fund to subsidizing the capital expenses for converting boiler houses in Old Town. The amount of subsidy for approximately 30 boiler houses will come in fixed prices to ca. zł. 23 billion (U.S. $1,064,554). See Polinvest's study *Incentive Analysis and Recommendation of Possible Actions by the City to Interest Coal Fired Boiler House Owners to Convert to Gas Firing* (*Analiza bodźców i rekomendacja działań możliwych do podjęcia przez władze miejskie dla zachęcenia użytkowników kotłowni opalanych paliwem stałym do zamiany na paliwo gazowe*).

d) If the City abstains from supporting the conversions in the next few years, then the subsidies needed in later years will be considerably higher. For some boiler houses, even today, a 100 percent subsidy of capital costs will not ensure a positive net present value over the project's life. Postponing the conversions may necessitate subsidizing 100 percent of conversion capital costs for all boiler houses. Subsidies to the capital costs of conversion should prove the simplest to carry out, and cheaper than the other ways of subsidizing the projects (discussed in this report), and more desirable from the point of view of the owners and operators of boiler houses.

e) Equivalent emissions will be reduced by 225,400 kg per season by converting Old Town coal/coke-fired boiler houses to gas firing. Polinvest's report *Incentive Analysis and Recommendation of Possible Actions by the City to Interest Coal Fired Boiler House Owners to Convert to Gas Firing* (*Analiza bodźców i rekomendacja działań możliwych do podjęcia przez władze miejskie dla zachęcenia użytkowników kotłowni opalanych paliwem stałym do zamiany na paliwo gazowe*) has detailed data on such reductions.

6.4.3 Comparative Analysis of Replacing Coal Firing With Electrical Power for an Average Ceramic Stove

Initial Assumptions

The objective of this comparative analysis was to determine whether and, possibly, what savings could be realized by replacing coal firing with electrical power for an average ceramic space-heating stove.

The first alternative of this comparative analysis was based on Polinvest's forecast of energy prices.

Based on a study *Engineering Analysis of Ceramic Space Heating Home Furnace Tests* (*Analiza inżynierska wyników testowania pieców domowych*) developed by Witold Szewczyk, Kraków, July 1994, under the American-Polish Program of Elimination of Low Emission Sources in Kraków, it was calculated that the annual demand for coal at an average ceramic stove is 850 kg, while its annual demand for electrical power is 6,959 kWh.

Current (August 1994, Table 6-6) and future forecasts by Polinvest of the operating costs of the heating with such an average stove, and of the capital expenses required over the project's life to maintain the stove in working order, were used in the comparisons. Costs related to the user's incurred expense, and labor for operating the stove, both actually expended and representing the value of the user's labor at minimal wage, also were included in the analysis.

The expected life of a coal-fired stove is shorter than that of one equipped with an electric heating element. It was assumed that the expected life of a stove averages 20 years. Also, it was assumed that the capital cost of a new stove is U.S. $404, and that this expense will be incurred in the 11th year of operating the stove as the electric heating element is installed in an existing stove, i.e., after it has been used for an average of 10 years ((0 + 20)/2). Further, it was assumed that the capital expense of installing the element and modifying the wiring on an existing stove is U.S. $125, and is incurred at the beginning of the project.

The project's life was assumed to be 30 years.

Table 6-6. Annual Operating Costs in August 1994, Assumed as the Basis for the Study

	Coal Heating	Electric Heating	Cost Difference	
U.S. $1 = Zł. 22,500			zł.	U.S. $
Fuel	1,593,750	4,300,933	(2,707,183)	(120)
Fuel Delivery	242,000	0	242,000	11
Cleaning	90,000	0	90,000	4
Major Maintenance	188,889	250,000	(61,111)	(3)
Accessory Materials	90,000	0	90,000	4
Labor	2,152,172	0	2,152,172	96
Total	4,356,811	4,550,933	(194,122)	(9)

The sum of the difference in cost of operating a coal-fired stove and one equipped with an electric heating element, totalled over the 30-year project life, was expressed in today's dollars (present value) at a seven percent discount rate. The results reflect the savings to the stove operator due to converting a coal-fired stove to electricity.

Another alternative in this comparative analysis of a conversion was developed from the U.S. Department of Energy's energy-price forecast. The DOE alternative is based on the same cost makeup as in the Polinvest alternative, except that DOE forecast electricity and coal prices were used.

The heating value of coal used by DOE is 22,563 kJ per kg of coal, lower than that in Polinvest's forecast. To obtain the same amount of heat from this coal, an annual use of 1.1 t was assumed. Since DOE's forecast of the price of electrical power for individual customers substantially differs from that made by Polinvest, the results in this alternative are different from those of Polinvest's forecast.

Conclusions of the Comparative Analysis

The first alternative was based on forecast of energy prices by Polinvest.

Based on the assumptions and the calculations made, it was determined that operating a ceramic stove equipped with an electrical heating element is cheaper than that of a coal-fired stove if such a stove is operated a minimum of 11 years. The discounted savings (PV) over the 30-years of operation is U.S. $441.

Tables 6-7 and 6-8 illustrate the expenses related to operating a stove with an electric heating element and a coal-fired stove, respectively. Table 6-9 illustrates the difference, both in the real and discounted expense, arising from this conversion. Figure 6-8 compares the cumulative, discounted expenses of operating an average ceramic home-heating stove on coal and on electricity.

If labor costs are not included in the operating costs of a coal-fired ceramic stove, its conversion to electricity will not be viable, and will increase the cost of heating over the 30 years of project's life by U.S. $1,573 in today's dollars (PV, or the sum of the discounted cost increase).

The second alternative in the comparative analysis was based on the U.S. Department of Energy's forecast of energy prices.

An analysis based on the U.S. Department of Energy's forecast of energy prices showed that coal heating is cheaper than electric heating. Converting a coal heating stove to electric heating would, over the 30 years of the project's life, increase the cost of heating by U.S. $437 (PV, or the sum of the discounted cost increase).

Table 6-7
Expense of Operating an Electric Heating Element Equipped Ceramic Home Furnace
in U.S. Dollars, Based on the POLINVEST Energy Price Forecast
Fuel Demand:
6959 kWh

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Capital Expense						
Fuel	178	210	218	239	237	237
Fuel Delivery	0	0	0	0	0	0
Cleaning	0	0	0	0	0	0
Major Maintenance	12	13	15	19	28	28
Accessory Materials	0	0	0	0	0	0
Labor	0	0	0	0	0	0
Total Expense	189	223	233	258	265	265
Discounted Expense	177	182	155	123	64	35
Cumulative Discounted Expense	302	664	1,156	1,831	2,704	3,121

Note: Cumulative discounted expense includes the capital expense for installing an electric heating element at $125, incurred at the begining of 1995.

Table 6-8
Expense of Operating a Coal Fired Ceramic Home Furnace
in U.S. Dollars, Based on the POLINVEST Energy Price Forecast
Fuel Demand:
0.85 t

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Capital Expense				404		
Fuel	71	65	68	74	74	74
Fuel Delivery	11	11	12	13	16	16
Cleaning	4	5	5	7	10	10
Major Maintenance	9	10	11	14	21	21
Accessory Materials	4	4	4	4	4	4
Labor	100	111	128	164	242	242
Total Expense	200	206	229	680	367	367
Discounted Expense	187	168	152	323	89	48
Cumulative Discounted Expense	187	532	1,005	1,894	2,985	3,562

Table 6-9
Difference Between Expense of Operating an Electric Heating Element Equipped Ceramic Home Furnace
and the Expense of Operating a Coal Fired Furnace
Assuming the Selection if Electric Heating
in U.S. Dollars, Based on the POLINVEST Energy Price Forecast

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Expense Difference	11	(17)	(4)	422	101	101
Discounted Expense Difference	10	(14)	(3)	201	24	13
Cumulative Discounted Expense Difference	(115)	(132)	(151)	63	282	441

Note: Due to rounding, totals may differ from the sum of components

Tables 6-10 and 6-11 illustrate the expenses needed to operate a stove fitted with an electric heating element and a coal-fired stove, respectively. Table 6-12 illustrates the difference, both in the real and discounted (at 7 percent) expense, arising from the conversion. Figure 6-9 compares the cumulative, discounted expense of operating an average stove on coal and on electricity.

Analogous to the first alternative, if the cost of labor is not included in the operating costs of a coal-fired stove, its conversion to electricity will increase the cost of heating over the 30 years of the project by U.S. $2,224 in today's dollars (PV, or the sum of the discounted cost increase).

6.4.4 Study of the Profitability of Enlarging the "Łobzów" Power District

The study of the profitability of enlarging the "Łobzów" power district was intended to answer whether enlarging the "Łobzów" power district to convert the coal-fired ceramic home stoves in this area to electric heating is profitable for the Power Company (whether project PV, or the present value is positive for the Power Company, assuming a 26-year project life, and a 15 percent discount rate). This study also considered the present value of incentives that might be required to be extended to the Power Company should project present value prove to be negative.

Figure 6-8

Comparison of Cumulative, Discounted Expense

For the Two Types of Heating

Over 30 Years of Project Life

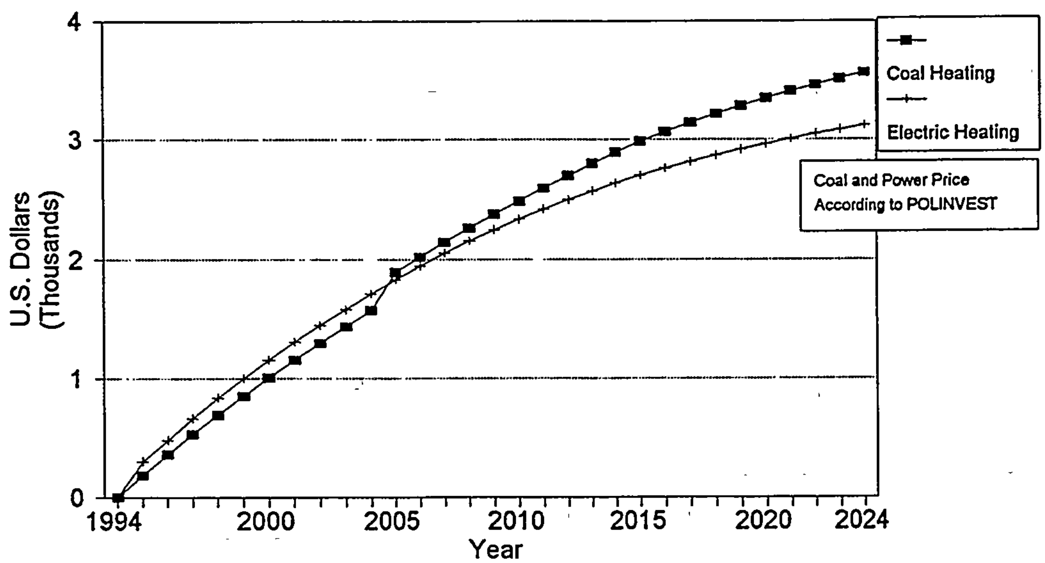
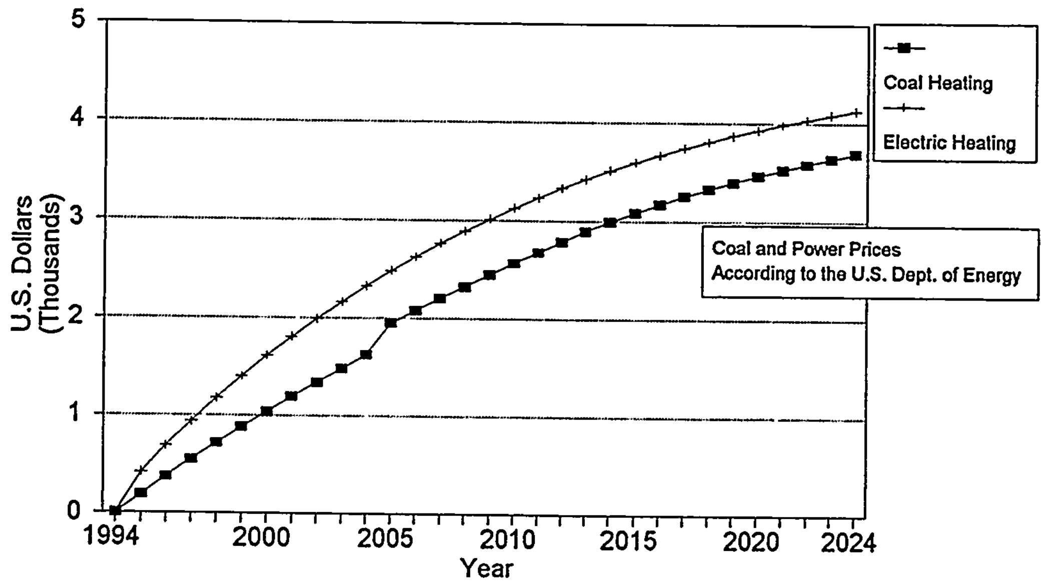


Figure 6-9

Comparison of Cumulative, Discounted Expense

For the Two Types of Heating

Over 30 Years of Project Life



Study Findings

Based on the initial assumptions drawn from the BRK engineering studies and data obtained from the Power Company staff, two present values were calculated. The first was calculated on the basis of the Polinvest developed electric power prices, with the other on the basis of the U.S. Department of Energy prices. The following results were obtained:

a) if Polinvest's price forecast is used, the project's present value is negative at zł. (23,435 million), or U.S. ($1,011,728);

b) if the U.S. Department of Energy's price forecast is used, the project's present value is negative at zł. (20,041 million), or U.S. ($864,097).

Therefore, enlarging the "Łobzów" power district is unprofitable for the power utility itself; consequently, the value of the incentives needed is equal to project's present value.

Table 6-10
Expense of Operating an Electric Heating Element Equipped Ceramic Home Furnace in U.S. Dollars, Based on the U.S. Dept. of Energy Price Forecast
Fuel Demand:
6959 kWh

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Capital Expense						
Fuel	296	298	300	305	310	310
Fuel Delivery	0	0	0	0	0	0
Cleaning	0	0	0	0	0	0
Major Maintenance	12	13	15	19	28	28
Accessory Materials	0	0	0	0	0	0
Labor	0	0	0	0	0	0
Total Expense	307	310	315	324	338	338
Discounted Expense	287	253	210	154	82	44
Cumulative Discounted Expense	413	936	1,607	2,482	3,592	4,125

Note: Cumulative discounted expense includes the capital expense for installing an electric heating element at $125, incurred at the begining of 1995.

Table 6-11
Expense of Operating a Coal Fired Ceramic Home Furnace in U.S. Dollars, Based on the U.S. Dept. of Energy Price Forecast
Fuel Demand:
1.1 t

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Capital Expense				404		
Fuel	83	85	89	95	107	107
Fuel Delivery	0	0	0	0	0	0
Cleaning	4	5	5	7	10	10
Major Maintenance	9	10	11	14	21	21
Accessory Materials	4	4	4	4	4	4
Labor	100	111	128	164	242	242
Total Expense	201	215	238	688	384	384
Discounted Expense	187	175	159	327	93	50
Cumulative Discounted Expense	187	544	1,035	1,947	3,084	3,687

Table 6-12
Difference Between Expense of Operating an Electric Heating Element Equipped Ceramic Home Furnace and the Expense of Operating a Coal Fired Furnace
Assuming the Selection if Electric Heating
in U.S. Dollars, Based on the U.S. Dept. of Energy Price Forecast

Project Year	1	3	6	11	21	30
Calendar Year	1995	1997	2000	2005	2015	2024
Expense Difference	(107)	(96)	(77)	364	45	45
Discounted Expense Difference	(100)	(78)	(51)	173	11	6
Cumulative Discounted Expense Difference	(225)	(392)	(572)	(534)	(509)	(437)

Note: Due to rounding, totals may differ from the sum of components

Project's Cash Flow

Assumptions Made for Calculating the Project's Cash Flow

The amounts and scheduling of the Power Company's capital expense and its potential growth in power sales arising from the project were assumed at levels taken from the BRK data. The initial project assumptions are shown in Table 6-13 below.

Table 6-13. Schedule, Power Company Capital Expense Amounts, and Medium Voltage Power Increase Associated with Enlarging the "Łobzów" Power District

Project Year	Capital Expense Amount, in zł. million	Medium Voltage Power Increase, in kW
1	1,075	0
2	5,650	0
3	5,775	2,107
4	6,582	2,232
5	7,264	2,947
6	7,389	5,047
7	8,196	4,755
8	9,253	2,697
9	9,550	4,886
10	0	5,239

Based on data obtained from the Manager of the Economic Department of the Power Company, it was determined that the Power Company's cost of customer servicing will not change if the project is implemented.

Further, the Power Company's data showed that the following measures should be undertaken under the project, adding to the project's capital cost:

a) purchasing additional power from the grid (PSE S.A.);

b) installing new power meters at the customers's homes;

c) employing an additional person for every 10 new transformer stations;

d) maintaining wiring and transformers at current levels;

e) undertaking major maintenance of wiring and transformers.

Based on BRK data, the mean heating season was assumed to last 180 days, and full-capacity operation of the heating elements was taken at eight hours daily.

The useful life of a transformer is 25 years, as stated by the Manager of the Economic Department of the Power Company; the first transformer stations shall be erected in the project's second year. Consequently, the project's life was assumed to be 26 years.

A 15 percent discount rate was assumed, as this is the level preferred by World Bank for heating projects.

Two power price forecasts were used; one developed by Polinvest and the other developed by the U.S. Department of Energy.

Cash Flow Tables and Sensitivity Tests for the Power Company Project

Two alternative cash flow sets were calculated based on the initial assumptions described above and the two price forecasts.

The results are displayed in Tables 6-14 and 6-15. Accordingly, project's present value for the Power Company is negative for both alternatives:

a) for Polinvest's forecast — Zł. (23,465), or U.S. ($1,011,728);

b) for the U.S. Department of Energy's forecast — Zł. (20,041), or U.S. ($864,097).

The present value of incentives that would make the project profitable equals the project's present value.

Sensitivity tests were made for each alternative for the project's present value changes in response to changes of the following variables:

a) price per kWh paid by the Power Company to the grid (PSE S.A.);

b) price per kWh paid by the customers to the Power Company;

c) power sales.

Sensitivity Tests for the Polinvest Forecast

Figure 6-10 shows that:

a) the project's present value would be null if the price, per kWh, paid the Grid (PSE S.A.) by the Power Company was equal to ca. 80 percent of the prognosticated price. The project's present value for the price at 79.8 percent is zł. 105.6 million (i.e., in 1997, the first year of power purchase, the price should be zł. 852 per kWh, and its subsequent increase should follow price increase indices from Table 6-2 above);

b) the project's present value would be null if the price, per kWh, paid the Power Company by its customers were ca. 117 percent of the price in the forecast. It's present value for the value of 117 percent is zł. 55 million (i.e., in 1997, the first year of power sales, the price should be zł. 1,780 per kWh, and its subsequent increase should follow price increase indices from Table 6-2 above);

c) the project's present value would be null if the power sales were approximately 208 percent of the amount in the forecast. The project's present value for the power sales at 208.3 percent is zł. 3.9 million (i.e., the capacity of electrical service connected in the individual project years, without any additional capital expenses and operating costs, should follow the data in Table 6-16).

Figure 6-10

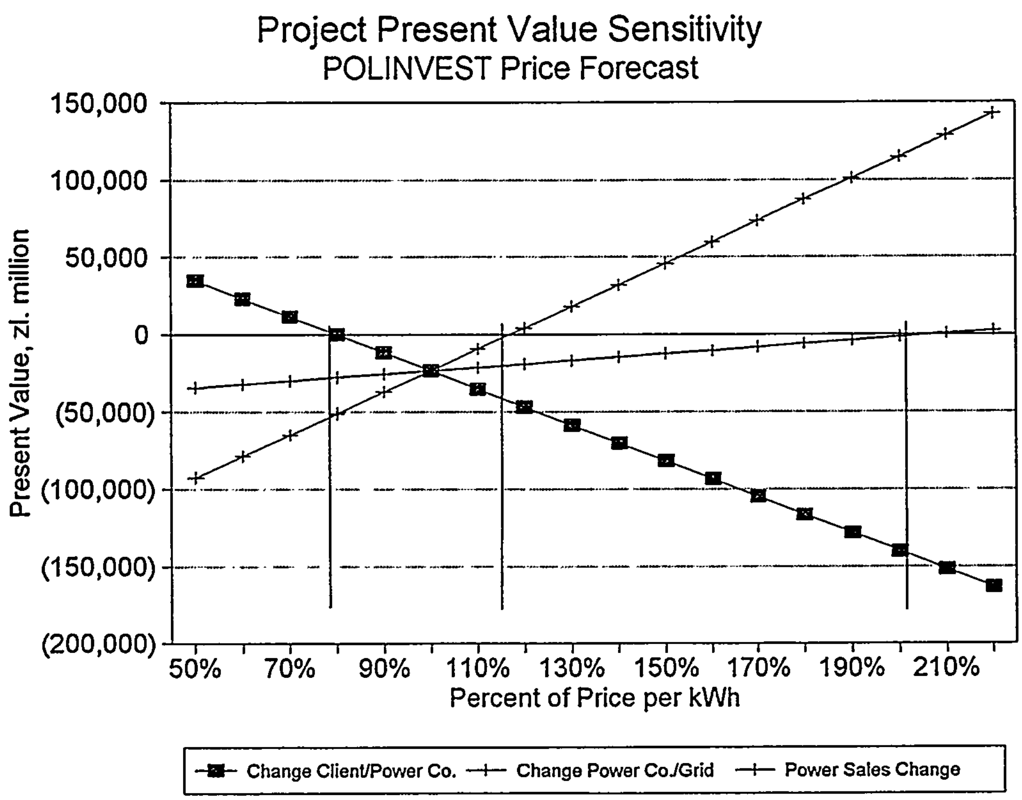


Table 6-14 Power Company Cash Flow Pro Forma
for the Enlarging the "Łobzów" Power District -
Based on the POLINVEST Price Forecast

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1. Power Sales Revenue	0	0	3,135	6,535	11,103	19,025	26,895	31,845	40,384	49,925	50,836	50,761	50,687
2. Capital Expense	1,075	6,119	6,272	7,237	8,387	8,455	8,817	10,341	10,731	0	0	0	0
2.1 Project Development Expense	375	175	200	225	225	250	275	350	0	0	0	0	0
2.1.1 Engineering and Blueprint Expense	175	175	200	225	225	250	275	350	0	0	0	0	0
2.1.2 Feasibility Expense	200	0	0	0	0	0	0	0	0	0	0	0	0
2.2 Land Acquisition Expense	700	700	800	900	900	1,000	1,100	1,400	0	0	0	0	0
2.2.1 Labor Expense	350	350	400	450	450	500	550	700	0	0	0	0	0
2.2.2 Reimbursement Expense	350	350	400	450	450	500	550	700	0	0	0	0	0
2.3 Construction and Equipment Expense	0	5,244	5,272	6,112	7,262	7,205	7,442	8,591	10,731	0	0	0	0
2.3.1 Transformer Station Construction Expense	0	3,556	3,556	4,064	4,572	4,572	5,080	5,588	7,112	0	0	0	0
2.3.2 MediumVoltage Line Expense	0	632	632	722	812	812	903	993	1,264	0	0	0	0
2.3.3 Low Voltage Line Expense	0	587	587	671	755	755	839	922	1,174	0	0	0	0
2.3.4 Power Meter Expense	0	469	497	655	1,123	1,066	620	1,087	1,181	0	0	0	0
3. Current Maintenance Expense	0	0	2,863	5,951	10,042	16,980	23,874	28,324	35,819	44,126	44,894	44,831	44,768
3.1 Station and Line Service	0	0	220	439	678	935	1,191	1,467	1,760	2,020	2,020	2,020	2,020
3.1.1 Labor and Labor Taxes	0	0	90	180	270	360	450	540	630	630	630	630	630
3.1.2 Maintenance Expense	0	0	130	259	408	575	741	927	1,130	1,390	1,390	1,390	1,390
3.2 Grid Power Purchase Expense	0	0	2,644	5,511	9,364	16,045	22,683	26,857	34,059	42,106	42,874	42,811	42,748
4. Reserve for Unexpected Expense	54	306	457	659	921	1,272	1,635	1,933	2,328	2,206	2,245	2,242	2,238
Total Cash Flow	**(1,129)**	**(6,425)**	**(6,457)**	**(7,313)**	**(8,247)**	**(7,681)**	**(7,430)**	**(8,753)**	**(8,494)**	**3,593**	**3,698**	**3,689**	**3,681**
Non-cumulative Present Value	(982)	(4,858)	(4,246)	(4,181)	(4,100)	(3,321)	(2,793)	(2,861)	(2,414)	888	795	690	598
Present Value Through the Year Before	(982)	(5,840)	(10,085)	(14,266)	(18,366)	(21,687)	(24,480)	(27,342)	(29,756)	(28,868)	(28,073)	(27,384)	(26,785)
Cash Flow Present Value	**(23,465)**												

Table 6-15 Power Company Cash Flow Pro Forma
for the Enlarging the "Łobzów" Power District -
Based on the U.S. Department of Energy Price Forecast

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1. Power Sales Revenue	0	0	4,087	8,443	14,215	24,135	33,608	39,197	48,964	59,626	59,805	59,984	60,164
2. Capital Expense	1,075	6,119	6,272	7,237	8,387	8,455	8,817	10,341	10,731	0	0	0	0
2.1 Project Development Expense	375	175	200	225	225	250	275	350	0	0	0	0	0
2.1.1 Engineering and Blueprint Expense	175	175	200	225	225	250	275	350	0	0	0	0	0
2.1.2 Feasibility Expense	200	0	0	0	0	0	0	0	0	0	0	0	0
2.2 Land Acquisition Expense	700	700	800	900	900	1,000	1,100	1,400	0	0	0	0	0
2.2.1 Labor Expense	350	350	400	450	450	500	550	700	0	0	0	0	0
2.2.2 Reimbursement Expense	350	350	400	450	450	500	550	700	0	0	0	0	0
2.3 Construction and Equipment Expense	0	5,244	5,272	6,112	7,262	7,205	7,442	8,591	10,731	0	0	0	0
2.3.1 Transformer Station Construction Expense	0	3,556	3,556	4,064	4,572	4,572	5,080	5,588	7,112	0	0	0	0
2.3.2 MediumVoltage Line Expense	0	632	632	722	812	812	903	993	1,264	0	0	0	0
2.3.3 Low Voltage Line Expense	0	587	587	671	755	755	839	922	1,174	0	0	0	0
2.3.4 Power Meter Expense	0	469	497	655	1,123	1,066	620	1,087	1,181	0	0	0	0
3. Current Maintenance Expense	0	0	3,667	7,560	12,666	21,289	29,535	34,524	43,055	52,307	52,458	52,609	52,761
3.1 Station and Line Service	0	0	220	439	678	935	1,191	1,467	1,760	2,020	2,020	2,020	2,020
3.1.1 Labor and Labor Taxes	0	0	90	180	270	360	450	540	630	630	630	630	630
3.1.2 Maintenance Expense	0	0	130	259	408	575	741	927	1,130	1,390	1,390	1,390	1,390
3.2 Grid Power Purchase Expense	0	0	3,447	7,120	11,989	20,354	28,344	33,058	41,295	50,287	50,438	50,589	50,741
4. Reserve for Unexpected Expense	54	306	497	740	1,053	1,487	1,918	2,243	2,689	2,615	2,623	2,630	2,638
Total Cash Flow	**(1,129)**	**(6,425)**	**(6,348)**	**(7,094)**	**(7,891)**	**(7,096)**	**(6,662)**	**(7,911)**	**(7,512)**	**4,704**	**4,724**	**4,745**	**4,765**
Non-cumulative Present Value	(982)	(4,858)	(4,174)	(4,056)	(3,923)	(3,068)	(2,504)	(2,586)	(2,135)	1,163	1,015	887	774
Present Value Through the Year Before	(982)	(5,840)	(10,013)	(14,070)	(17,993)	(21,061)	(23,565)	(26,151)	(28,287)	(27,124)	(26,108)	(25,222)	(24,447)
Cash Flow Present Value	**(20,041)**												

Table 6-15 (cont'd) Power Company Cash Flow Pro Forma
for the Enlarging the "£obzów" Power District -
Based on the U.S. Department of Energy Price Forecast

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1. Power Sales Revenue	60,345	60,526	60,707	60,889	61,072	61,255	61,439	61,439	61,439	61,439	61,439	61,439	61,439
2. Capital Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1 Project Development Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1.1 Engineering and Blueprint Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1.2 Feasibility Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2 Land Acquisition Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2.1 Labor Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2.2 Reimbursement Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3 Construction and Equipment Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.1 Transformer Station Construction Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.2 Medium Voltage Line Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.3 Low Voltage Line Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.4 Power Meter Expense	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Current Maintenance Expense	52,913	53,066	53,219	53,372	53,526	53,681	53,836	53,836	53,836	53,836	53,836	53,836	53,836
3.1 Station and Line Service	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020	2,020
3.1.1 Labor and Labor Taxes	630	630	630	630	630	630	630	630	630	630	630	630	630
3.1.2 Maintenance Expense	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390
3.2 Grid Power Purchase Expense	50,893	51,046	51,199	51,352	51,506	51,661	51,816	51,816	51,816	51,816	51,816	51,816	51,816
4. Reserve for Unexpected Expense	2,646	2,653	2,661	2,669	2,676	2,684	2,692	2,692	2,692	2,692	2,692	2,692	2,692
Total Cash Flow	4,786	4,807	4,827	4,848	4,869	4,890	4,911	4,911	4,911	4,911	4,911	4,911	4,911
Non-cumulative Present Value	676	591	516	451	393	344	300	261	227	197	172	149	130
Present Value Through the Year Before	(23,771)	(23,180)	(22,664)	(22,214)	(21,820)	(21,477)	(21,176)	(20,916)	(20,689)	(20,491)	(20,320)	(20,171)	(20,041)
Cash Flow Present Value	(20,041)												

Table 6-16. Timetable for an Increase in Medium Voltage Power Required to Make the Enlargement of the "Łobzów" Power District Profitable — For the Price Forecasts Developed by Polinvest and the U.S. Department of Energy

Project Year	Medium Voltage Power Increase, in kW, for Polinvest's Prices	Medium Voltage Power Increase, in kW, for the U.S, Department of Energy's Prices
3	4,382.56	3,729.39
4	4,642.56	3,950.64
5	6,129.76	5,216.19
6	10,497.76	8,933.19
7	9,890.40	8,416.35
8	5,609.76	4,773.69
9	10,162.88	8,648.22
10	10,897.12	9,273.03

Sensitivity Tests for the U.S. Department of Energy Forecast

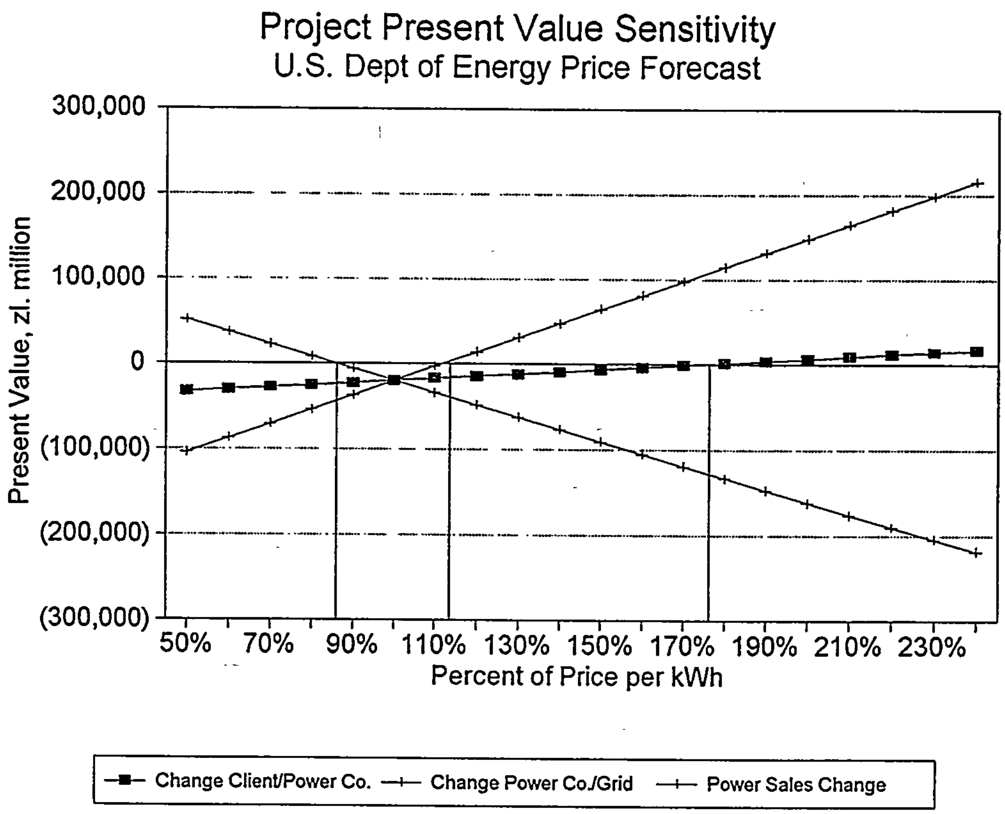
Figure 6-11 shows that:

a) the project's present value would be null if the price, per kWh, paid the Grid (PSE S.A.) by the Power Company were equal to approximately 86 percent of the prognosticated price. The project's present value for the price at 85.8 percent is zł. 112 million (i.e., in 1997, the first year of power purchase, the price should be zł. 1,194 per kWh, and its subsequent increase should follow price increase indices from Table 6-2 above);

b) the project's present value would be null if the price, per kWh, paid the Power Company by its customers were ca. 112 percent of the price in the forecast. The project's present value for the price of 112 percent is zł. 152.5 million (i.e., in 1997, the first year of power sales, the price should be zł. 2,222 per kWh, and its subsequent increase should follow price increase indices from Table 6-2 above);

c) the project's present value would be null if the power sales were approximately 177 percent of the amount in the forecast. The project's present value for the power sales at 177 percent is zł. 253 million (i.e., the capacity of electrical service connected in the individual project years, without additional capital expense and operating costs, should follow the data in Table 6-16).

Figure 6-11


Project Present Value Sensitivity
U.S. Dept of Energy Price Forecast
300,000
200,000
100,000
0
(100,000)
(200,000)
(300,000)
Present Value, zl. million
50%
70%
90%
110%
130%
150%
170%
190%
210%
230%
Percent of Price per kWh
Change Client/Power Co.
Change Power Co./Grid
Power Sales Change

6.4.5 Feasibility of Using Briquettes Instead of Coal in Heating With Ceramic Home-Heating Stoves

Objectives of Study

The objective of this study was to develop the following data:

a) conditions for the economic and legal feasibility of introducing smokeless briquettes into the Kraków fuel market;

b) the amount of money that would be needed as incentives (subsidies) to successfully carry out the project, should the City decide to support this option.

The recommendations from the study *Recommendation of Possible Actions by the City to Interest Residents in Using More Expensive Smokeless Briquettes and to Discourage Burning the Worst Grades of Coal (Rekomendacja działań możliwych do podjęcia przez władze miejskie dla zachęcenia ludności do stosowania droższych brykietów bezdymnych oraz dla przeciwdziałania spalaniu najgorszych gatunków węgla)* are quoted in this section. The study was developed by Polinvest in September 1994.

Availability of Briquettes and Their Forecast Prices

Briquettes are not available on the Kraków fuel market, and local fuel-depot customers do not inquire about briquettes. Briquettes have not been sold in large quantities to date; therefore, there is no developed price for this commodity. The Polinvest comparative analysis of the operating cost of a ceramic stove firing coal and briquettes, discussed below, showed that introducing briquettes into Kraków's fuel markets is possible if their price is similar to that of a good quality coal, such as the Wujek Mine coal.

This relationship does not refer to the price of fuel per ton, but to the price of a gigajoule (GJ) of energy available from coal, and also from the briquettes. In 1994, the price of 1 GJ of energy from the Wujek Mine coal was U.S. $3.07. The proposed 1995 price of briquettes in Kraków, calculated similarly, should be $82.86 per ton.

As in the other projects, the feasibility conditions are considered for two price forecasts, the U.S. Department of Energy's prices and Polinvest's prices. The assumptions for the two forecasts are discussed under Section 6.2, above. The project's scenarios for the two price alternatives are discussed below.

Polinvest Forecast

According to Polinvest, the price per GJ of energy contained in the briquettes for the initial period of their introduction to Kraków's fuel markets should be maintained through 1997 at the level of grade one, "cobble" size coal, i.e., U.S. $76.38 per ton in 1996, and $70.40 per ton in 1997. Accordingly, coal prices will temporarily fall. From 1998 on, coal prices should gradually rise, until they reach $76.66 per ton in the year 2000. The price of the briquettes achieved by then should correspond to the economic relationship between the prices of coal and briquettes. Briquettes manufactured out of coal (without subsidies) usually are approximately five percent more expensive. This relationship of coal and briquette prices is used in the U.S. Department of Energy's forecast.

The Institute of Chemical Processing of Coal (Instytut Chemicznej Przeróbki Węgla) in Zabrze at present is Poland's only manufacturer of coal briquettes. Manufacturing is an ancillary business at the Institute (Polish acronym ICHPW); hence, its annual output is only a few hundred tons. The unit manufacturing cost of briquettes at ICHPW is presently in excess of the proposed briquette price in Kraków; it is $82.45 per ton of briquettes in 1994 U.S. dollars.

Polinvest calculated the price of briquettes at a Kraków fuel depot in August 1994 on the basis of an estimate of the following unit prices; manufacturing, transportation, and selling. This cost calculation was made for the following three alternative assumptions about the initial conditions:

Alternative I - assuming that these costs will be incurred to their full extent;

Alternative II - assuming that:

a) manufacturing cost will fall, either due to introducing a better process, or to improving the current process; and

b) the fuel-depot will be leased at advantageous terms;

Alternative III - assuming that:

a) manufacturing cost will fall, due either to improving the process, or awarding the manufacturer tax exemptions and deductions;

b) the manufacturer will sell at cost;

c) the fuel-depot lot will be leased on advantageous terms; and

d) the selling cost will decrease as a result of consigning the sales to a municipal utility formed for that purpose.

The following 1994 briquette prices at a fuel depot in Kraków were calculated on the basis of the estimate cost calculation from the Polinvest study:

Alternative I - **U.S. $105.17 per ton**, i.e. zł. 2,366,383 per ton, assuming that all costs will be incurred to their full extent (that is, when no measures are undertaken by the City to support the project);

Alternative II - **U.S. $95.25 per ton,** i.e., zł. 2,143,182 per ton, assuming that cost will decrease through reducing the costs of manufacturing and of leasing the fuel-depot lot; and

Alternative III - **U.S. $78.39 per ton,** i.e., zł. 1,763,743 per ton, assuming a reduction in costs of manufacturing, leasing the fuel-depot lot, selling (sales tax exemption in manufacturing and selling), and that the manufacturer and re-seller will sell at cost (without a profit margin).

Polinvest believes that the market will not accept the briquettes at prices higher than the price of coal. Neither the legislation mandating the municipal authority nor the environmental statutes make it legal for a municipality to restrict or order the use of a specific type of fuel, such as the smokeless briquettes. The City may only offer various types of assistance for the project to lower the price of briquettes to a level acceptable to the customer and, consequently, stimulate their use in Kraków. The simplest form of such assistance would be to subsidize the price of briquettes at a single re-seller, selected by bidding. The bidder, who would guarantee to sell annually the target (specified in the RFP) amount of briquettes of RFP-specified quality and whose bid for the subsidy was the lowest, would be selected as the municipal briquette reseller.

Rather than allocate funds directly to a subsidy, the City might control the rise in the demand for the briquettes through various market measures. One such measure would be to create a focused municipal utility. Such municipal utilities (organized as local government subsidiaries) enjoy statutory tax exemptions and, in justifiable cases, they may engage in non-profit business, i.e., offering goods/services for sales at cost. These input conditions were used for calculating the price of briquettes under Alternative III. Additionally, a municipal utility might avoid rent for leasing the land used for the reselling facility (lot rent is a considerable component of cost) if the fuel depot is sited on municipal land. All these factors may result in a municipal utility - should such be formed in Kraków - being able to offer lower briquette prices than other fuel resellers. Such a financing model will not in any way decrease the amount of subsidy needed to be offered by the municipality, but this type of financing may be easier to organize. Such a municipal utility organized as a subsidiary of the municipal government could be created if the bids received through an RFP process are less advantageous.

Also, it is possible for the City to indirectly affect project subsidies from the state government. It is hereby suggested that the City move that the Minister of Finance allow a temporary sales (VAT) tax exemption for briquettes. Presumably, the manufacturer also will sell some of its product for Kraków at its cost, i.e., with a null profit margin. Such a situation may actually occur if the manufacturer is granted a tax deduction or duty deductions/exemptions for its export sales through the City's efforts and/or recommendation.

U.S. Department of Energy Forecast

According to the U.S. DOE, the price of briquettes with heating value of 26.8 GJ per ton, equal to world market prices, should be U.S. $94.42 per ton in 1995, and $108.51 in 2005. These prices include the cost of delivery.

This price of briquettes corresponds to the cost level quoted in Alternative II of the estimated price, discussed above. Should one or more manufacturers selling the briquettes cheaper than the Zabrze plant appear in the Kraków area, the DOE price may prove possible. However, by August 1994 the price of briquettes will be higher than the current price of coal in Kraków. Comparing the DOE forecast for coal and briquette prices indicates that the difference between them is only 5 percent. If this difference continues in future, subsidizing briquette prices in Poland will not be necessary, particularly in view of the data discussed below.

Current and Future Operating Costs of Coal- or Briquette-Fired Ceramic Stoves

Comparison of Current Costs

Data for the calculation were taken, in part, from a study by Witold Szewczyk, D.S., *Engineering Analysis of Ceramic Space Heating Home Furnace Tests Conducted Under the American-Polish Program of Elimination of Low Emission Sources in Kraków (Analiza inżynierska wyników testowania pieców domowych, przeprowadzonego w ramach aerykańsko-polskiego programu likwidacji żródeł niskiej emisji w Krakowie),* Kraków, July 1994, and also from information obtained in August 1994 from ceramic-furnace contractors and chimney-sweep services.

The following two alternative briquette prices were assumed:

a) equal to quality coal - zł. 1,850,000 per ton;

b) calculated at the level of total cost - zł. 2,370,000 per ton.

The value of making these calculations is principally for illustration, as briquettes are not available on the market in Kraków.

Apart from the cost of briquettes, Table 6-18 also has data on operating a coal-fired ceramic stove that was derived from the study *Cost Analysis of Replacing Coal Heating with Electric Heating (Analiza kosztów zamiany orgrzewania węglowego na elektryczne).* This study was developed by Polinvest in September 1994.

The annual operating cost of a ceramic home-heating furnace by the average operator, i.e., firing coal with 55 percent efficiency, is zł. 4,356,719. The annual operating cost of a briquette-fired stove by the average operator is zł. 4,362,769 for Alternative a). These numbers are based on August 1994 prices.

Comparing the costs of coal and Alternative a) data shows that **the annual operating cost for firing briquettes is the same as for firing coal if both operators use similar operating procedures, hereinafter referred to as Procedure 55, thereby achieving a 55 percent combustion efficiency.** If briquettes are used for fuel, there is no cost for cleaning the furnace, since the smokeless briquettes create little soot during combustion. The price of briquettes is slightly higher than that of an average grade coal. The remaining components of operating cost are similar for both cases. Hence, the results of this comparison indicate that, should the sales price of briquettes be set at the level recommended by Polinvest, the briquettes will be competitive with coal. This price already contains a proposed amount of subsidy. The subsidy, calculated as the difference between the gross price of U.S. $105.33 per ton, i.e., zł. 2,370,000 per ton (Alternative I), and the price of $82.22 per ton, i.e., zł. 1,850,000 per ton, is $23.11, or zł. 520,000 at the August 1994 exchange rates, per ton. The operating cost of a briquette-fired stove without any subsidy (Alternative b) would be higher by $105.33 - $85.22 = $21, or zł. 472,000 per ton.

The tests of ceramic home-heating furnaces discussed in the study *Engineering Analysis....etc.* showed that it is possible to achieve considerably higher combustion efficiency than that achieved by the average furnace operator. Combustion efficiency can be improved simply by following the operating guidelines developed during that study. It was proven that average operating efficiency of 74 percent can be achieved both for coal and the briquettes. These improved furnace operating procedures hereinafter will be referred to as Procedure 74.

There are reasons to believe that briquette users will adapt to Procedure 74 more easily than traditional coal users, as they learn to operate their furnaces with the new fuel. The annual 1994 Procedure 74 operating cost for briquette firing is U.S. $174.75, i.e., zł. 3,391,875, for Alternative a). The use of unsubsidized fuel, i.e., Alternative b) briquettes, will increase this to U.S. $190.34, i.e., zł. 4,283,000 which is somewhat lower than the cost of Procedure 55 at subsidized prices. In other words, the subsidy would not be necessary if the furnace operator was convinced that further savings are possible. However, as this is a new product, intended to replace an existing, accepted product, it may be that a subsidy is necessary initially to introduce it on the market; this subsidy then could be gradually phased out.

The above calculations do not reflect the environmental advantages of replacing coal with smokeless briquette firing. Operators of home stoves are not liable for any additional emissions fees or fines. So far, the critical factors in using environmentally friendly types of coal is the increasing environmental awareness of individuals in the community and their resulting inclination to partake in activities expected to diminish the environmental burden.

Comparison of Forecast for Operating Costs of Ceramic Stoves

The following initial input conditions were assumed for making forecasts of the operating costs for briquette-fired ceramic stoves:

a) the calculations were made for two alternative briquette prices: one by the U.S. Department of Energy, and the other by Polinvest;

b) the project life is 20 years, assuming that this is the average term of operating a ceramic stove when firing briquettes. This is the same time as the experimentally proven useful life of a similar, coal-fired furnace. Both these fuels have similar operating costs;

Table 6-17. Input Data Assumed for Calculating Annual Operating Cost of a Briquette-Fired Ceramic Home Stove

Assumed Input Data		
Annual Consumption of Briquettes	0.908 tons/yr	
Price of Briquettes per ton: - Alternative a) - Alternative b)	1,850,000 zł. per ton 2,370,000 zł. per ton	82.22 U.S. $ per ton 105.33 U.S. $ per ton
Delivery price (per ton) for a 10 km distance	112,000 zł. per ton	4.97 U.S. $ per ton
Distance Between Fuel Depot and Operator	10 [km]	
Carrying Briquettes to Basement Storage	130,000 zł. per ton	5.77 U.S. $ per ton
Furnace Value	9,083,333 zł.	403.70 U.S. $
Depreciation	5 percent annually	
Chimney Sweeping	10,000 zł.	0.44 U.S. $
Furnace Cleaning	0 zł.	0.00 U.S. $
Maintenance	188,889 zł.	8.39 U.S. $
Accessory Materials	90,000 zł.	4.00 U.S. $
Ash Removal and Delivery of Briquettes from Basement to Upstairs Furnace	1,076,040 zł.	47.82 U.S. $
Labor for Igniting and Stoking Furnace	1,076,040 zł.	47.82 U.S. $

Table 6-18. List of Cost Components of Operating Coal- and Briquette-Fired Ceramic Home Stove

#	Type of cost	Amount Calculated (zł. annually in 1994)	
		Coal	Briquettes
1	Fuel: Alternative a) Alternative b)	1,593,750	 1,679,800 2,151,960
2	Fuel Delivery	242,000	242,000
3	Depreciation	454,166	454,166
4	Maintenance	188,889	188,889
5	Accessory Materials	90,000	90,000
6	Chimney Sweeping and Furnace Cleaning	90,000	10,000
7	Furnace Operating Labor	2,152,080	2,152,080
8	Total Cost (sum of lines 1,2,3,4,5,6, and 7) Alternative a) Alternative b)	4,356,719	 4,362,769 4,834,929

c) no additional capital cost is required to switch from coal to briquette firing;

d) it was assumed that the furnace's useful life is 20 years; however, this study pertains to a ten-year-old stove. Therefore, it must be recognized that the capital cost of constructing a new furnace will be incurred in the project's 11th year;

e) estimates of the operating costs of a ceramic, briquette-fired stove from 1995 through 2014 are based on August 1994 prices;

f) combustion efficiency is 55 percent for the average operator (Procedure 55), but is 74 percent for the improved Procedure 74;

g) The annual stove energy requirements, derived from the study *Engineering Analysis.....etc.*, is 25.1 GJ for Procedure 55, and 18.6 GJ for Procedure 74. The annual use of briquettes, per the DOE forecast, i.e. with a heating value of 26.8 GJ per ton, calculated on the above assumption, is .934 tons for Procedure 55, and .694 tons for Procedure 74. Fuel use for

Polish briquettes with a heating value of 27.6 GJ per ton (data after *Engineering Analysis...etc.*) is .908 tons for Procedure 55, and .675 tons for procedure 74;

h) delivery price for briquettes in the future will be the same as the price for delivering coal. This assumption is based on the observation the delivery of both fuels involves the same process. From a study of the costs of coal delivery from a fuel depot to an operator's home, it was assumed that this price will increase by 2 percent annually, as it has not changed in Kraków from 1993 to 1994, due to the high availability of this service. The price of briquettes from the DOE forecast includes the cost of delivery;

i) it was assumed that the remaining costs and services will rise at 5 percent annually reflecting the average cost increase index for service in Europe;

j) the cost of accessory materials was assumed to be fixed; and

k) because it was assumed that the project is not profit-oriented, the lowest average discount rate of 7 percent was used.

The future operating costs for coal- and briquette-fired furnaces were compared by calculating the cumulative discounted difference between the two over 30 years. These differences over a period of 30 years, and for Procedure 55 are the following:

a) - $15 for the U.S. Department of Energy forecast;

b) + $16 for the Polinvest forecast.

Calculations indicate that the cost of operating a furnace on briquettes may be somewhat higher than that for coal if an operator does not adhere to the correct operating procedures (DOE price - unsubsidized).

The following are the cumulative discounted differences between the expenses of operating a briquette-fired furnace using Procedure 74 and operating a coal-fired furnace using Procedure 55 for 30 years:

a) $305 for the U.S. Department of Energy forecast;

b) $247 for the Polinvest forecast.

Calculations show that stove operators using briquettes who adhere to the correct operating procedures will realize savings relative to using coal.

Distribution of Briquettes

The City could define a standard to be met by all solid fuel for home use imported to Kraków, i.e., equivalent emissions and combustion standards must be set precisely. These standards could be specified in an enclosure to the licenses for operating fuel depots in Kraków. This model is tantamount to giving all fuel resellers identical competitive positions. Possible subsidies for a manufacturer or reseller of briquettes should be awarded to the lowest tender in a bidding process.

Consultations with environmental professionals will be a pre-requisite to making any decisions about the emissions standards for fuels carried by licensed fuel resellers in Kraków. The following three emissions indices are tentatively suggested for briquettes and poorer grades of coal:

a) SO_2 emissions 5.5 g per kg of fuel

b) particulate emissions 20.0 g per kg of fuel

c) equivalent emissions 79.0 g per kg of fuel

These data pertain to combustion efficiency of 47 percent. The numbers are quoted from a study developed for Kraków Development Bureau, BRK, by PPHU Tawimex in July 1994. Advantages of having briquettes sold by a municipally funded utility created for this express purpose are that the estimated cost for this model is relatively low, and the sale of briquettes can be promoted in a situation when nobody else undertakes similar actions.

Incentives for Use of Briquettes

If briquettes are to be sold at the Polinvest proposed prices, no additional incentives are provided, except for a promotional campaign to inform the future users of the principles of using briquettes in ceramic home-heating furnaces and their advantages. However, a subsidy to the price of briquettes may be necessary.

Such a promotional campaign could include the following:

a) repetitive advertising in the local press;

b) printing and mailing two-page pamphlets to local residents promoting the use of briquettes;

c) repetitive promoting on radio and TV shows.

The estimated cost of such a promotional campaign during the two months preceding the coal-buying season is zł. 442,000,000, i.e., **U.S. $19,215** (prices at the level of August - September 1994). This could be supported by the City or conducted by the manufacturer.

Estimated Amount of Subsidies over Project's Life

The amount of subsidies for the briquettes over the entire life of the project is calculated next. However, it must be remembered that several input assumptions are estimates. Correct calculations will be possible only after appropriate market studies are conducted, and adequate marketing data obtained. Additionally, the manufacturing cost used reflects the current level of technology, described in the Kraków Development Bureau study, while it may be expected that each manufacturer will use a different process.

Several assumptions about the development of briquette sales are listed below; various combinations of assumptions may be assembled from them. Further, two combinations of assumptions are discussed, and calculations are made for the two alternative sales-development models thus created.

The following are the assumptions for calculating the amounts of subsidies to the price of briquettes over the project's entire life:

a) **briquette sales**, due to the promotional campaign, will be **1,000 tons in 1995, 10,000 tons in 1996** (or 11,000 if it is impossible to start the program in 1995), **20,000 tons in 1997,** and **30,000 tons in 1998. From 1998** on, the sales will level off at **30,000 tons**, the amount of current sales of poor grades of coal. However, such poor coal, an environmental hazardous fuel, will be eliminated from the fuel market. The price of briquettes, per ton, in the initial period of sales will be less than that for high-grade coal, a factor that may strongly impact many current users of poor grades of coal;

b) **total annual coal and briquette** sales over the entire period of project funding will be **74,400 tons annually.** Every increase of the sale of briquettes will be accompanied by a corresponding fall in the sales of coal. The assumed sales volume allowed a calculation of the cost corresponding to a ton of briquettes;

c) the fixed level of subsidies over the first three years will be U.S. $23.11 for each ton of briquettes sold in Kraków, if a subsidy is provided. The forecasted fall of briquette prices will be accompanied by a fall of the prices of materials (coal) used for their manufacture, but the current selling cost expressed in U.S. dollars will remain substantially fixed;

d) A gradual increase of the price per GJ from 1998 through 2000 will be profitable for briquette manufacturers and resellers. The subsidies will decrease from year to year during 1998 - 2000;

e) the attractive features of briquettes, supported by the education of furnace operators who soon will achieve a combustion efficiency of 74 percent, will generate a quick rise of briquette prices to a level viable both for the manufacturer and the reseller.

The cumulative discounted value of the subsidies over the entire subsidy period will be, respectively:

- **U.S. $1,360,080,** for assumptions a, b, c, d (gradual withdrawal of subsidies);
- **U.S. $600,743,** for assumptions a, b, c, e (rapid withdrawal of subsidies).

Project Feasibility from the Perspective of the City

The operator of a ceramic home-heating stove can use smokeless briquettes without having to modify the furnace. **The total cost of the project is the sum of the cost related to introducing briquettes on the market at competitive prices, and an advertizing campaign for promoting their use.** These costs may be borne either by the city interested in eliminating the sources of low emissions, by entrepreneurs and resellers in Kraków, who will undertake the risks of starting a sales operation in Kraków, or by the manufacturer who considers selling below cost an investment into the future of its market share on the fuel market. The unavailability of briquettes on the market at this time indicates that such market players are not yet interested.

From the City's point of view, the project is a fragment of a larger strategy. The project's feasibility should be evaluated from the point of view of increased revenues from tourists, and savings in health-care expenses, resulting from the decrease of emissions. However, these aspects are beyond the scope of this work, whose objective is only to determine the effectiveness of the expenditure involved. The following indices that can be used as a measure of the effectiveness of the project expenditure have been calculated:

a) current effectiveness of the capital engaged - defined as the decrease in equivalent emissions in the first year of the project, corresponding to each 1,000 dollars engaged in the project by the City. The decrease of equivalent emissions due to burning a ton of briquettes rather than a ton of coal will be 67.8 kg per ton;

b) the global effectiveness of the capital engaged - defined as the decrease in emissions over the life of the project per each 1,000 dollars expended by the City on it.

The current effectiveness of the capital engaged during the project's first year is:

- under assumptions a, b, c, d (gradual withdrawal of subsidies): **2.87** tons per each thousand dollars engaged;
- under assumptions a, b, c, e (rapid withdrawal) of subsidies): **2.87** tons per each thousand dollars engaged.

The global effectiveness of the capital engaged through the project's first 10 years is:

- under assumptions a, b, c, d (gradual withdrawal of subsidies): **10.97** tons per each thousand dollars engaged;

- under assumptions a, b, c, e (rapid withdrawal of subsidies): **24.84** tons per each thousand dollars engaged.

Comparing the effectiveness of this project with other projects (see Section 6.4.6) indicates that it will result in the City's effective use of funds to eliminate low emissions.

6.4.6 A Study of the Incentives Required for Individual Projects

Based on the economic analyses, the following shortfalls were calculated for each of the projects:

a) Connecting the MPEC district-heating network to areas where local boiler houses are eliminated (Section 6.4.1 above).

The amount is equal to the present value of the total shortfall which could be applied as subsidies necessary to enlarge the district-heating network and connect 70 boiler houses thereto; these subsidies represent the portion of the project's capital expense that is not recoverable over its 20-year life.

Amount of Incentives: U.S. $198,005

The following is the reduction of emissions expressed as equivalent emissions over the 20 years of the project (for the three areas where the project's net present value is negative):

- 12.61 tons per $1,000 in the Halicka and Szeroka Streets Area;

- 1.67 tons per $1,000 in the Zwierzyniecka and Świerczewskiego Streets Area;

- 41.56 tons per $1,000 in the Wroclawska Street Area.

The average reduction in emissions, expressed as equivalent emissions, over 20 years for the 70 boiler houses is 17.43 tons per $1,000.

b) Converting 33 local, coal/coke-fired boiler houses to gas firing (project described in Section 6.4.2).

The conversion was spread over seven years in accordance with the criterion of economic viability of the conversions. The following is the present value of **the life-cycle shortfall which could be applied as subsidies to the capital cost incurred by boiler-house owners:**

DOE alternative (100 percent subsidy) - **U.S. $1,341,593**

Polinvest alternative (subsidies of 80 or 50 percent of the capital cost - **U.S. $759,858**

The reduction of emissions, expressed as equivalent emissions, for the term of 20 years for the Polinvest alternative is 5.19 tons per $1,000, while, for the DOE alternative, it is 4.06 tons per $1,000.

c) Replacing coal firing in ceramic stoves with electric heating elements in the Łobzów Power District (project discussed in Section 6.4.4 above).

The proposed sum represents the present value of the shortfall that could be offered to the Power Company to ensure that the enlargement of the power system will not cause the Power Company to incur a loss over the 26 years of project's life.

Amount of Incentives Offered to the Power Company:

Polinvest alternative - **U.S. $975,571**

DOE alternative - **U.S. $1,070,746**

The reduction of emissions, expressed as equivalent emissions, for the term of 20 years for the Polinvest alternative is 5.04 tons per $1,000.

d) Using smokeless briquettes instead of coal in ceramic stoves (project discussed in Section 6.4.5).

The present value of the shortfall that could be offered as subsidies to the price of briquettes for the Polinvest alternative, over a 10-year period of introducing the briquettes on the market is the following:

- with gradual withdrawal of subsidies - **U.S. $1,360,000**

- with rapid withdrawal of subsidies - **U.S. $600,743**

The reduction of emissions, expressed as equivalent emissions, for the term of 20 years for the Polinvest alternative is the following:

- with gradual withdrawal of subsidies - **24.63 tons per $1,000**

- with rapid withdrawal of subsidies - **55.77 tons per $1,000**

There is no **subsidy to the price** of briquettes in the DOE alternative under the forecast assumptions that the briquettes are only 5 percent more expensive than coal.

6.5. COMPARATIVE ANALYSIS OF CURRENT AND FORECAST COST OF OPERATING HEATING EQUIPMENT WITH VARIOUS TYPES OF FUEL

6.5.1 Study Objectives and Initial Assumptions

The objective of the Polinvest study was to compare the current and forecast expenditure on heating borne by an individual resident in a selected Kraków apartment. The 87 square meter apartment selected is located at 7 Floriańska Street, and is currently heated with three coal-fired ceramic stoves[8].

The analysis compares the annual cost of operating various types of heating equipment installed in the resident's apartment, i.e.:

a) coal-fired ceramic stove;
b) briquette-fired ceramic stove operated under procedures ensuring furnace efficiency $\eta = 55\%$;
c) briquette-fired ceramic stove operated under procedures ensuring furnace efficiency $\eta = 74\%$;
d) ceramic stove equipped with an electric heating element;
e) electric storage heaters;
f) apartment-sized gas-fired hot water heating system;

and the annual expense for purchasing outside heat from a variety of sources, i.e.:

a) coal-fired building boiler house[9] with output of up to .2 MW;
b) coke-fired building boiler house with output of up to .2 MW;
c) gas-fired building boiler house with output of up to .2 MW;
d) heating oil-fired building boiler house with output of up to .2 MW;
e) culm-fired neighborhood boiler house[10] with output of up to 3.0 MW;
f) gas-fired neighborhood boiler house with output of up to 3.0 MW;
g) heating oil-fired neighborhood boiler house with output of up to 3.0 MW;
h) MPEC S.A. district heat.

It was assumed, for this comparison, that all these methods of heating can be made available in the selected apartment. Actually, to use district heat, the network would first have to be extended to the area, at a considerable capital cost. From our perspective, it is

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[8] The apartment selected is in a building representative of the Old Town area with regard to its heat-loss properties.

[9] A building boiler house is a boiler of up to .2 MW output, operated from within the building it heats.

[10] A neighborhood boiler house is a boiler house of over 1 MW output, operated from outside of the building(s) it heats.

necessary to consider such cost, as, in most cases, the critical factors in comparing the heating cost incurred while using various equipment and fuel are the building's location and the engineering problems in connecting it to the district heating network.

The current and forecast operating cost was computed under the following initial assumptions:

a) annual heating cost was calculated for the individual years from 1994 through 2015;
b) the design heat demand and total heat demand for the apartment were calculated by a Kraków Polytechnic University team in accordance with the provisions of the standard PN-83/B-03406 at 5.5 kW and 42.8 GJ, respectively;
c) calculations of current costs were based on current fuel prices in Kraków. Fuel quantities were calculated on the basis of actual heating values of the fuels, adjusted for the equipment and delivery efficiencies;
d) 1994 operating cost was calculated using the current MPEC S.A. network 1994 3rd and 4th quarter prices;
e) expense was calculated at official prices (i.e., flat, per square meter fee) for the 12 months of 1994, considering all price changes during the year;
f) operating costs forecast for 1995 through 2015 were calculated for both Polinvest's and the U.S. Department of Energy's forecasts of the prices of coal, coke, briquettes, power, gas, and heating oil;
g) operating costs for other boiler houses were taken after the MPEC S.A. data quoted in the SWECO report;
h) other cost-increase indices were assumed at the levels used in Polinvest's forecasts of the operating expense of various heating equipment[11];
i) straight-line depreciation was used at levels representative of each heating system;
j) heat fees billable to the resident for heat supplied by the building or neighborhood boiler-house were calculated using a two-tiered rate (rate for maximum output ordered was calculated as the fixed boiler-house cost divided by its rated output capacity, while the rate for heat delivered was calculated as the boiler-house variable cost divided by its total annual heat output).

The following cost categories were considered in calculating on-site (from the apartment itself) heat:

a) fuel cost including buying cost (solid-fuel buying cost, including the cost of on-site delivery and unloading into the basement, was taken as reported by Kraków fuel depots, while the cost of buying gas and power is included in the fuel price);

[11] Cost Analysis of Replacing Coal Heating with Electric Heat for the Average Ceramic Space Heating Furnace — September 1994.

b) depreciation of on-site (apartment) heating equipment and piping[12];
c) maintenance costs of heating equipment and piping;
d) labor cost.

The following cost categories were considered in calculating off-site (outside the apartment) heat:

a) annual heating fee;
b) depreciation in on-site piping and radiator;
c) maintenance of on-site piping and radiator.

The annual heating fees for the apartment were calculated using MPEC S.A. October 1994 rates and the rates forecast by Polinvest through 2015. The fees incurred by the residents for the heat delivered by the building or neighborhood boiler house were computed using a two-tiered rate calculated for average boiler house operating cost. The cost used in the calculations is similar to the actual MPEC S.A. boiler house operating cost. The data originally were quoted in the May 1994 report commissioned by MPEC S.A. to the Swedish company SWECO.

Table 6-19 shows the initial assumptions about the equipment and fuels. Effective heat prices quoted in the table and depicted on Figure 6-12 take into consideration the efficiencies of equipment and delivery.

6.5.2 Annual Heating Equipment Operating Cost

Table 6-20 shows the annual 1994 operating cost of the heating equipment for various types of fuel. Figure 6-13 compares this total 1994 heating cost for various fuels and types of equipment and the district heat at official (regulated) prices. Figure 6-14 depicts the same comparison, but omits the labor cost for the ceramic home-heating furnaces. Figure 6-15 shows the total 1994 heating cost for hot-water heat from a building and a neighborhood boiler house, and the MPEC S.A. district heat.

6.5.3 Forecast Heating Equipment and System Operating Cost

Figure 6-16 compares the operating cost of the heating equipment and systems under the Polinvest fuel and power price forecast.

Figure 6-17 depicts the comparison of the heating equipment and systems operating cost under the U.S. Department of Energy's fuel and power price forecast.

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[12] Depreciation of the heating equipment and piping is not an actual, ongoing expense. However, it is necessary to consider depreciation in calculating operating cost for the following reasons:

a) the capital expense of purchasing and installing the heating equipment is not considered;
b) the fees for district heat and the building and neighborhood boiler houses include depreciation as a part of the flat fee.

Figures 6-18 and 6-19 compare the annual costs of building and neighborhood boiler house supplied heat, under Polinvest's and the U.S. Department of Energy's price forecasts, respectively.

Table 6-21 shows the annual forecast operating cost of the various heating systems for both forecasts.

Figure 6-12

Comparison of Effective Heat Prices
of Various Fuels and Utilities

(4th Quarter 1994)

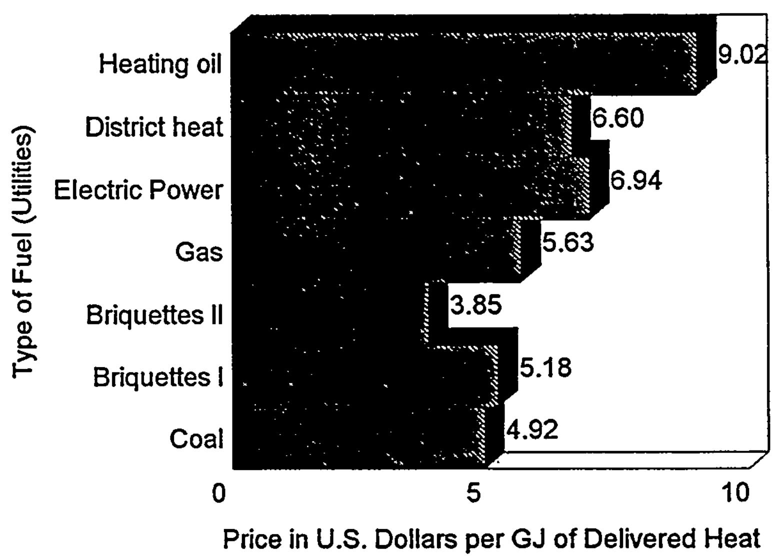


Table 6-19. Assumptions for Comparison of Home Heating Costs

Exchange rate, zl/USD = 23500

Equipment (Heating System) Type	Fuel	Units [...]	Lower Heating Value [GJ/unit]	Per Unit Price [zl/unit]	Price of Unit of Heat Contained in the Fuel [zl/GJ]	Equipment Efficiency [%]	Effective Heat Price [zl/GJ]	Effective Heat Price [USD/GJ]
Ceramic Stove	Coal	[t]	29.473	1,875,000	63,618	0.55	115,668	**4.92**
Ceramic Stove	Briquettes I	[t]	27.62	1,850,000	66,980	0.55	121,783	**5.18**
Ceramic Stove	Briquettes II	[t]	27.62	1,850,000	66,980	0.74	90,514	**3.85**
Apartment Installed Hot Water Heater	Gas	[m3]	0.0356	4,000	112,360	0.85	132,188	**5.63**
Ceramic Stove/Electric Storage Heat	Electric Power (night rate)	[kWh]	0.0036	587	163,056	1	163,056	**6.94**
District heat	Heat	[GJ]	1	139,550	139,550	0.9	155,056	**6.60**
Local Boiler House *)	Heating oil	[t]	41.5	7,100,000	171,084	0.81	211,869	**9.02**

*) System efficiency is the product of the boiler and the delivery efficiencies

Table 6-20 Listing of the Heating Equipment Operating Cost for Various Fuel Types, 7 Florianska St. Apartment

	HEATING SYSTEM TYPE						
	Coal Fired Ceramic Home Heating Furnac [t]	**Briquette I Fire Ceramic Home Heating Furnac [t]**	**Briquette II Fire Ceramic Home Heating Furnace [t]**	**Electric Heating Element Equippe Ceramic Home Heating Furnace [kWh]**	**Electric Storage Heater [kWh]**	**Gas Fired Boiler [m3]**	**MPEC S.A. District Heat [GJ]**
Fuel Amount =	2.65	2.82	2.10	13,140	11,913	1,492	47.7
Costs Type:							
Fuel	4,960,578	5,222,801	3,881,811	7,713,180	6,992,931	5,967,326	3,386,700
Fuel delivery	605,000	726,000	484,000	0	0	0	0
Fixed Fee	0	0	0	216,000	216,000	210,000	3,702,114
Cleaning	270,000	120,000	120,000	0	0	362,200	0
Deprecjation	1,457,875	1,457,875	1,457,875	1,279,725	910,000	2,325,000	1,605,000
Maintenance	566,667	566,667	566,667	750,000	750,000	500,000	400,000
Accessory Materials	270,000	270,000	270,000	0	0	0	0
Labor	3,228,120	3,228,120	2,690,100	0	0	0	0
Total Cost	**11,358,240**	**11,591,463**	**9,470,453**	**9,958,905**	**8,868,931**	**9,364,526**	**9,093,814**
Total Cost in zl. per GJ	**265,379**	**270,829**	**221,272**	**232,685**	**207,218**	**218,797**	**212,472**
Total Cost Minus Labor in zl. per GJ	**189,956**	**195,405**	**158,419**	**232,685**	**207,218**	**218,797**	**212,472**
Local Boiler House Hot Water Heat:							
Output Capacity and Fuel Type	**O.2 MW coke**	**O.2 MW coal**	**3 MW culm**	**O.2 MW gas**	**3 MW gas**	**O.2 MW heating oil**	**3 MW heating oil**
Total Cost in zl.thousand annual	**14,177**	**13,321**	**5,838**	**12,393**	**9,092**	**17,568**	**15,697**
Total Cost in zl. per GJ	**331,243**	**311,231**	**136,392**	**289,555**	**212,425**	**410,477**	**366,752**

Figure 6-13
Total 1994 Heating Cost
for Various Systems
for the 7 Florianska St. Apartment

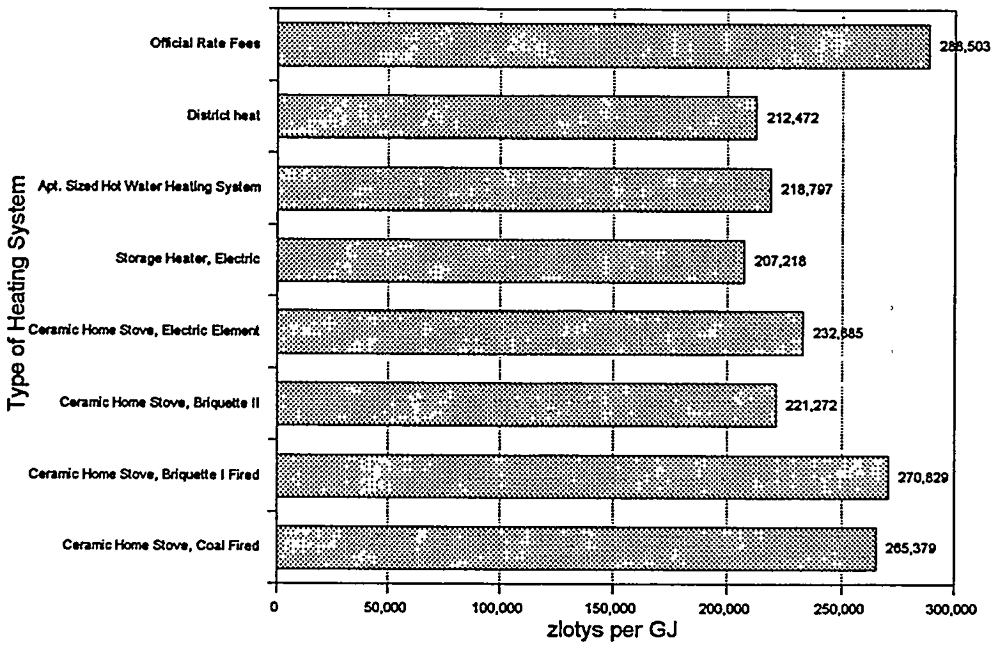


Figure 6-14
Total 1994 Heating Cost
for Various Systems
for the 7 Florianska St. Apartment, without Labor Cost

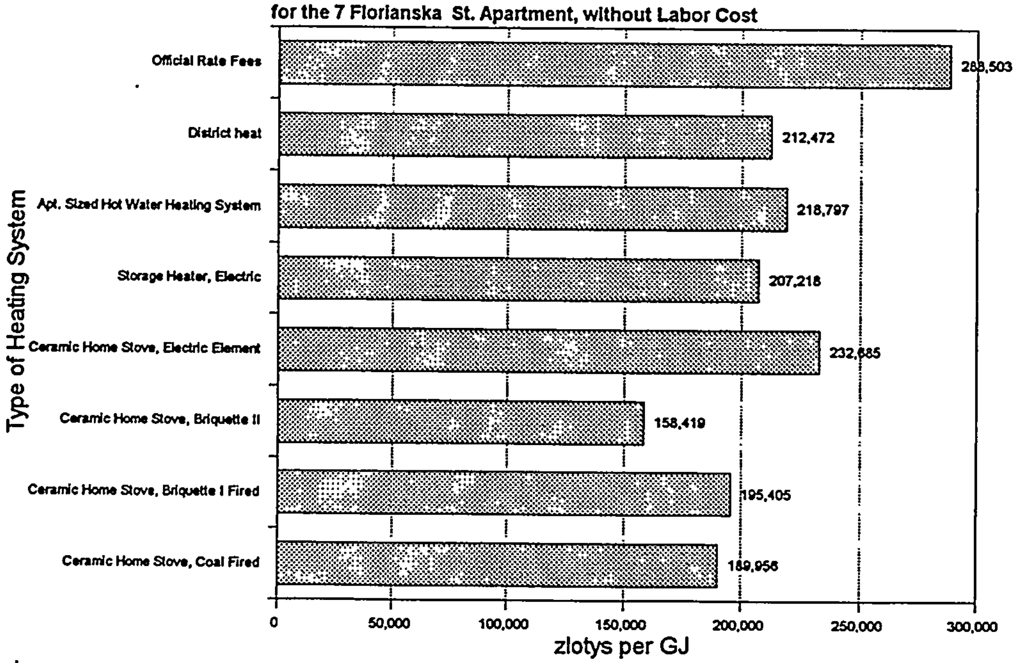


Figure 6-15

Total 1994 Local Boiler House and MPEC

District Heating Cost (in zl. per GJ)

for the Florianska St. Apartment, Using 47.7 GJ of Heat Annually, with Max. Heat Output Demand Ordered at 5.5 kW

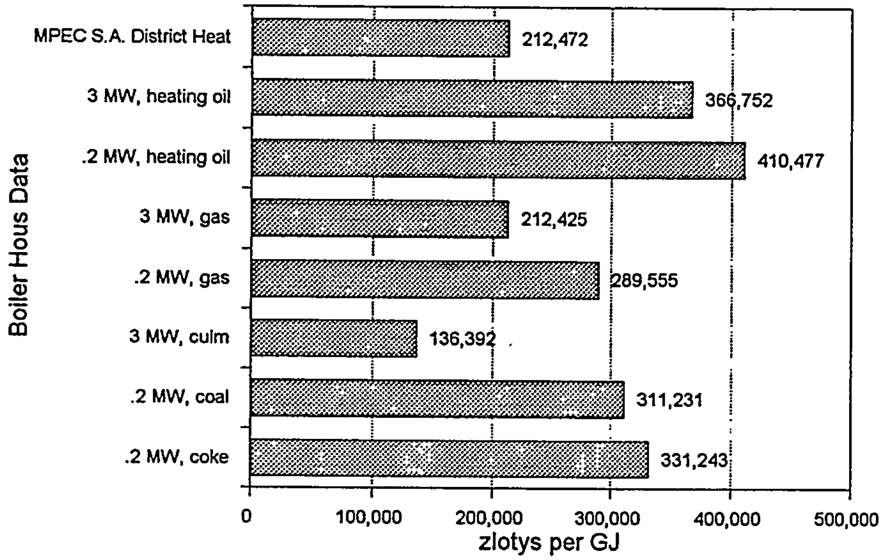


Figure 6-16

Heating Equipment Operating Costs

POLINVEST Energy Price Forecast

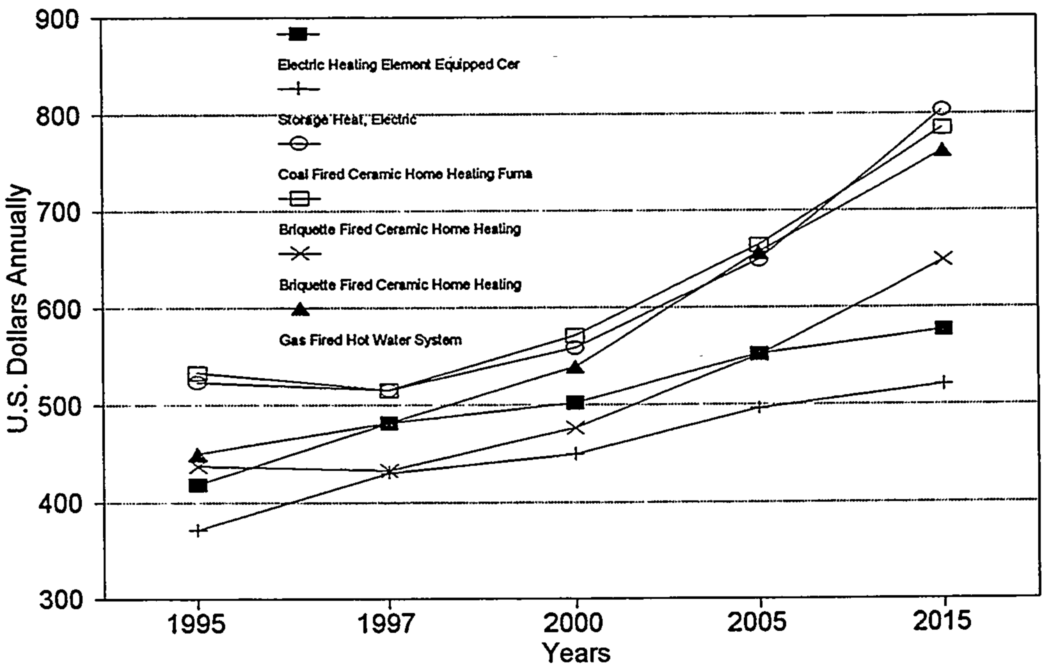


Figure 6-17

Heating Equipment Operating Costs

U. S. Department of Energy Price Forecast

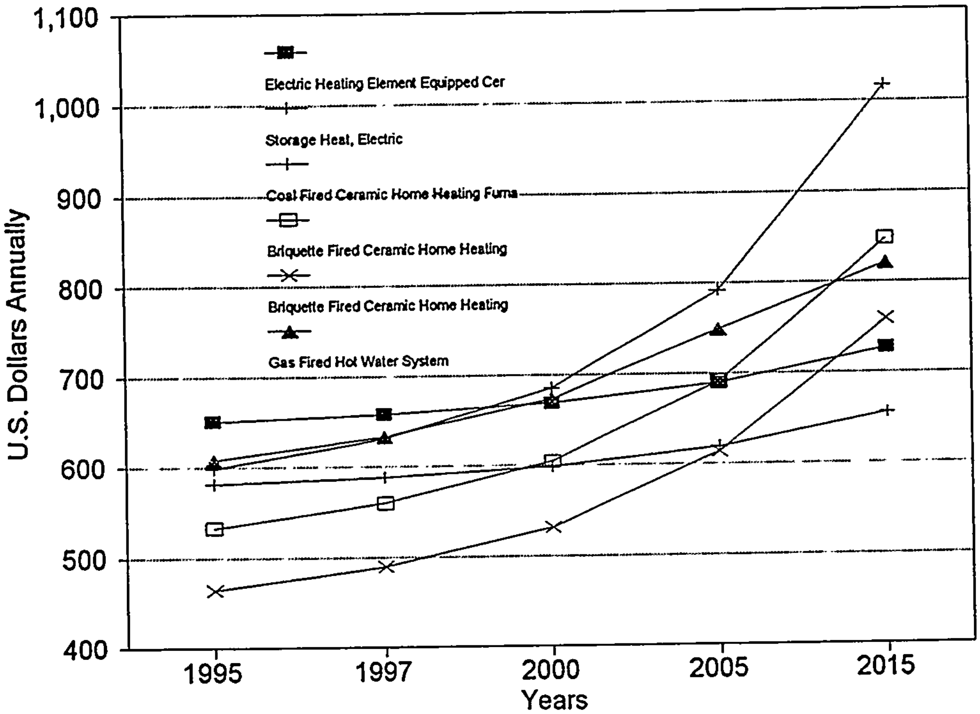


Figure 6-18

Annual Hot Water System Heating Cost

Heat Delivered from Boiler Houses

Under the Conditions of the POLINVEST Fuel and Power Price Forecast

for the 7 Floriańska St. Apartment, Using 47.7 GJ of Heat Annually, with Max, Heat Output Demand at 5.5 kW

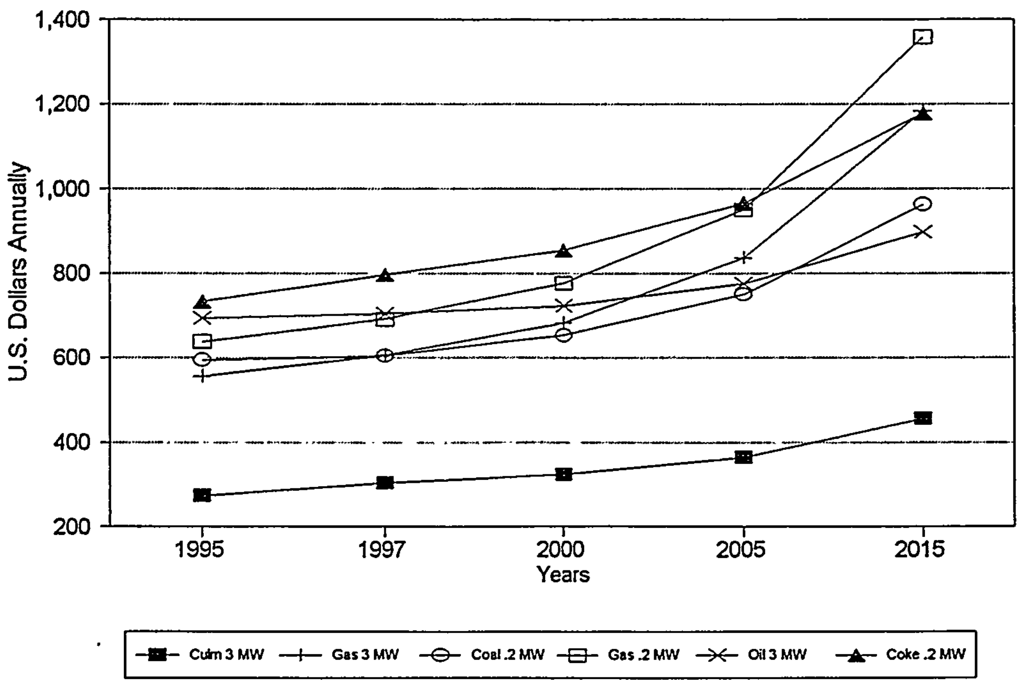


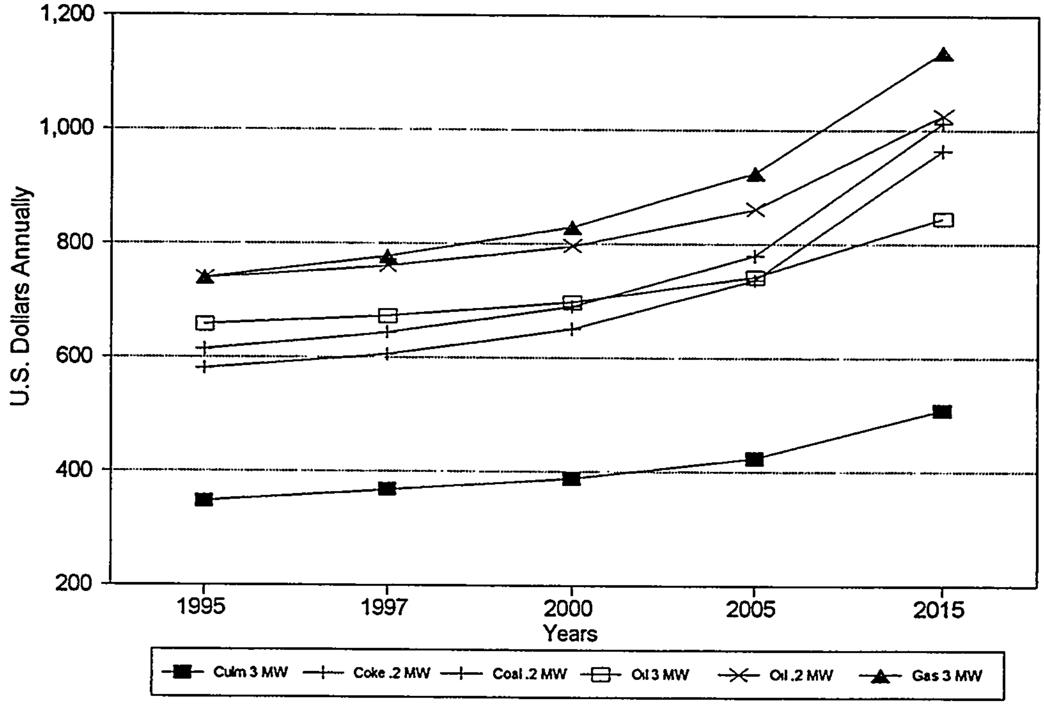
Figure 6-19

Annual Hot Water System Heating Cost

Heat Delivered from Boiler Houses

Under the Conditions of the U.S. D.O.E. Fuel and Power Price Forecast

for the 7 Floriańska St. Apartment, Using 47.7 GJ of Heat Annually, with Max. Heat Output Demand at 5.5 kW



6.6 RECOMMENDATION OF POSSSIBLE ACTIONS TO BE UNDERTAKEN BY THE CITY HALL IN ORDER TO CARRY OUT THE PROGRAM

6.6.1 Recommendations on Deductions, Exemptions, and Other Possible Measures to be Undertaken by the City

Property Tax Deduction

According to the Local Tax and Fee Act of 12 January 1991 (*Congressional Reports* or *Dziennik Urzędowy* #9, item 31 with subsequent amendments, *Congr. Reports* 1991 #101, item 44, and *Congr. Reports* 1992 #21, item 86) property tax is a local tax. In Kraków, the City Council sets and mandates any exemptions thereto, by resolution. Property tax revenues go to the City's budget. After considering changes in the consumer price index during the first three quarters of the year when taxes are to be raised relative to the preceding year, the Minister of Finance, by executive order, sets the property tax caps for each fiscal year. The Kraków Municipality's expected 1994 individual and corporate property tax revenue is zł. 550 billion, while the proposed 1995 budget includes an expected property tax revenue of zł. 690 billion.

Table 6-21 Listing of the Annual Forecast Operating Cost
of Various Heating Equipment and Systems Using Various Fuels,
Under the Conditions of the POLINVEST and the U.S. Department of Energy Forecasts

Annual Forecast Operating Cost Under the Conditions of the POLINVEST Forecast

	U.S. Dollars Annually				
Type of Heating system	1995	1997	2000	2005	2015
Electric Heating Element Equipped Home Stove	418	482	502	553	577
Storage Heat, Electric	372	430	450	496	521
Coal-Fired Ceramic Home Stove	523	515	559	649	804
Briquette-Fired Home Stove, Efficiency 55 %	533	515	571	664	785
Briquette-Fired Home Stove, Efficiency 74 %	438	433	476	551	649
Gas-Fired Hot Water System	450	482	539	657	762

Annual Forecast Operating Cost Under the Conditions of the U.S. Department of Energy Forecast

	U.S. Dollars Annually				
Type of Heating system	1995	1997	2000	2005	2015
Electric Heating Element Equipped Home Stove	651	657	669	690	727
Storage Heat, Electric	581	588	599	619	655
Coal-Fired Ceramic Home Stove	599	631	685	792	1,016
Briquette-Fired Home Stove, Efficiency 55 %	533	560	605	692	848
Briquette-Fired Home Stove, Efficiency 74 %	465	490	532	614	759
Gas-Fired Hot Water System	608	633	674	749	820

Heat Delivered from Neighbourhood (3 MW) and Building (.2 MW) Boiler Houses

Annual Forecast Operating Cost Under the Conditions of the POLINVEST Forecast

	U.S. Dollars Annually				
Type of Fuel and Output Capacity	1995	1997	2000	2005	2015
Culm 3 MW	274	303	324	365	456
Gas 3 MW	556	607	683	836	1,184
Coal .2 MW	594	604	653	749	963
Gas .2 MW	638	692	778	950	1,359
Oil 3 MW	694	703	724	775	897
Coke .2 MW	733	797	855	966	1,178

Annual Forecast Operating Cost Under the Conditions of the U.S. Department of Energy Forecast

	U.S. Dollars Annually				
Type of Fuel and Output Capacity	1995	1997	2000	2005	2015
Culm 3 MW	347	368	387	424	508
Coke .2 MW	580	605	650	736	964
Coal .2 MW	614	643	690	779	1,012
Oil 3 MW	658	673	697	742	845
Oil .2 MW	739	761	795	861	1,026
Gas 3 MW	740	778	829	924	1,137

Pursuant to the above mentioned Local Tax and Fee Act, the following individuals, corporations, and non-corporate entities are liable for property tax:

a) fee simple and *de facto* owners of real property and appurtenances thereto;
b) tenants and administrators of state and municipal real property and appurtenances thereto, if the subject possession is contractual or the administration granted by the rightful owner;
c) occupants of state and municipal real property and appurtenances thereto whose possession is not mandated by a legal title; and
d) real property perpetual users.

The statutes of Article 5.1 of the Local Tax and Fee Act mandate that the municipal councils set property tax rates; therefore, on December 17, 1993 the Kraków City Council set the following 1994 property tax rates per square meter of usable property footage:

a) residential buildings and parts thereof — zł. 1,300 per square meter;
b) buildings and parts thereof used for commercial purposes other than farming and forestry and parts of residential buildings used for business — zł. 50,200; and from buildings or parts thereof located underground, per square meter of usable footage — zł. 40,800;
c) from other buildings and parts thereof — zł. 4,800.

The statutes of Article 7.10 of the Local Tax and Fee Act mandate that land and buildings entered in the National Register of Historical Landmarks be exempt from property tax whenever these buildings and land are maintained and restored in adherence to historical landmark preservation statutes; the exemption does not, however, apply to the parts of the above-described buildings used for commercial purposes.

The statutes of Article 7.2 of the Local Tax and Fee Act mandate that the municipal councils shall have the authority to set other than the statutory local tax and fee exemptions. In accordance with these provisions, on December 1, 1993, the Kraków City Council exempted from property tax the following types of property:

a) rent controlled apartments (until rent controls are lifted), except commercial space;
b) buildings, parts thereof, and land used by City financed dramatic theaters, libraries, clubs, community centers, infant daycare centers, welfare centers and facilities, and alcohol-abuse holding facilities;
c) buildings and parts thereof used for charity.

The statutes of Article 7.2 of the Local Tax and Fee Act mandate that the **municipal councils shall have the authority to set other than the statutory local tax and fee exemptions** i.e., the **Kraków City Council may exempt from property taxes those rental property owners who install environmentally friendly, non-polluting heating systems.** This exemption may be restricted to the amount of capital expense the property owners incur for converting the heating system, but there are no legal impediments to setting this exemption higher, even at twice the level of the capital expense, thereby providing a stronger incentive to modernize.

The property tax exemption for property owners who expend capital on converting their heating systems to systems that are environmentally more friendly may apply to all parts of Kraków, but it would provide a particularly strong incentive in the Old Town area.

Municipal Environmental Protection Fund Subsidies

All projects listed in section 6.4, *Results of Capital Project Studies*, may receive subsidies from the Municipal Environmental Protection Fund. Pursuant to the April 3, 1993, amendment of the Environmental Protection and Management Act and the Water Statutes Act, the following funds were created:

a) National Environmental Protection and Water Management Fund;
b) County Environmental Protection and Water Management Fund;
b) Municipal Environmental Protection and Water Management Funds.

Revenues of the National Environmental Protection and Water Management Fund, County, and Municipal Funds are derived specifically from fees and fines collected for the business use of the natural environment, receipts from projects organized to benefit environmental protection and water management, donations from businesses, donations and bequests from individuals and corporations, and monetary and in-kind payments from non-profit foundations.

Fifty percent of the fees for storing and disposing of waste within the municipality, all of the fees and fines removing trees and bushes, and 10 percent of the receipts from fees and penalties for other business use of the natural environment, for changing the environment and for the specific use of water, waterways, and waterway equipment constitute the revenues of the Municipal Funds. The remainder of these sums, after the above amounts are allocated to the Municipal Funds, are divided between the National Fund (40 percent) and the County Fund (60 percent).

The monies of the Municipal Funds are allocated for the following purposes:

a) environmental education and campaigns for environmentally beneficial projects;
b) assistance for environmental monitoring systems;
c) **implementation of modernization and capital construction projects to benefit environmental protection and water management;**
d) landscaping and maintenance of greenery, wooded and bush-covered areas, and rural parks;
e) **implementation of waste recycling, storage, and disposal projects;**
f) **other environmentally beneficial projects, as resolved by the municipal council.**

The August 25, 1994, Kraków City Council Resolution approved the regulations for managing the funds of the Municipal Environmental Protection and Water Management Fund in Kraków. In accordance with these regulations, the **Municipal Fund's monies are first allocated to subsidize the Kraków Municipality's statutory business in the sector of environmental** protection and water management, primarily as defined by the March 8, 1990, Local Government Act (with subsequent amendments) and the January 31, 1980, Environmental Protection and Management Act (with subsequent Amendments).

Municipal agencies and other corporations **performing municipal statutory business have the priority in requesting subsidies from the Municipal Fund.** All projects requesting subsidies from the Municipal Fund must be accompanied by appropriate engineering and financial documentation, and all capital construction projects must have been issued valid building permits. The cap on the subsidies is set at 50 percent of the capital cost, except in specially justified cases, when it is set at 70 percent of the project capital cost. **A priority in allocating subsidies is given to those projects that can validate the expenditure of the applicants' own monies or assets. In exceptional cases, environmental projects carried out by the municipality may be fully subsidized.**

Applications for subsidies for environmental projects must be submitted not later than the last day of September of the year immediately preceding the year when the monies are expected to be disbursed. The County Environmental Protection Department pre-selects the applications and a Task Force appointed by the Mayor of Kraków finally evaluates the applications. The Task Force submits the project evaluation criteria to the Mayor's Office for acceptance and lists all projects to be subsidized from the Municipal Fund during the given year at a time adequate for them to be considered in the municipal budget negotiations. The Mayor's Office passes an appropriate resolution, developed by the City's Environmental Protection Department.

On April 8, 1994, the City Council passed a resolution regarding the Municipal Environmental Fund's revenues and disbursements for the Fiscal Year 1994. The 1994 disbursements are planned in the resolution at zl. 23,681,201 thousand; this includes zl. 12.6 billion in subsidies allocated for new environmental protection and water management projects and modernization.

Recommendations on Supporting Grass Roots Initiatives

Because of the high cost of the Program, individual owners often are unable to unilaterally finance environmentally friendly projects. Grass roots movements can help such projects by organizing volunteer committees.

Such committees may play a substantial role in replacing coal-fired ceramic home stoves with electric heat, since including the owners of the residential rental property where the project is to be carried out will substantially decrease the costs of the project and will make it possible for the Municipality to subsidize it from its own budget.

If volunteer committees are not organized, the project can be run through a Foundation, organized with the participation of the Municipality, whose principal business is carrying out environmental projects, including air-quality protection.

Local initiatives for environmental protection may be carried out in accordance with the following blueprint:

a) a volunteer committee shall be organized and joined by the future users of the environmentally friendly equipment;
b) the committee shall be informed of the engineering requirements for the project by the appropriate authorities;
c) the committee shall obtain the support of the Borough Council for the project;
d) the committee shall be registered with the Municipal Utility District (*Zakład Gospodarki Komunalnej* or *ZGK*) appropriate for the project's location.

After the committee is registered it must prepare the project, obtain a building permit, and prove that the committee shall provide not less than 50 percent of the project's capital cost. Further actions are carried out jointly by the Municipal Utility District and the committee, or by the Municipal Utility District on behalf of the committee. The Municipal Utility District applies to the City for project funding. The Municipality funds up to 50 percent of project's capital cost. Next, the Municipal Utility District names a bid review board whose work is joined by the volunteer committee. Bids for project work are solicited and awarded in accordance with a Bidding Program adopted by the City Council and the Public Purchasing Act.

The decisions about approval of subsidies are made by the Mayor's Office, and any possible funds awarded from the monies allocated in the municipal budget to support for grass roots initiatives. The criteria for ranking the importance of the proposed initiatives are organized around solving the City's most critical problems. Incentives could be applied in the organization and the functioning of the committees, so that all residents whose heating system will be modernized with the use of the project monies join the appropriate committee. One of these incentives is to convince residents that the more people in a given area who convert their heating system to a more environmentally friendly one, the cheaper such a project will prove per apartment (building).

In passing the 1994 budget, the Kraków City Council stated that it is necessary that the Municipality support arising grass movement initiatives. Therefore, the 1994 budget contains a zł. 54 billion provision for financing projects recommended by the Borough Councils.

Organizing a Municipal Budgetary Agency

The provisions of article 7.1.1. of the Local Government Act state that protecting the environment is a statutory municipal task. To carry out its statutory tasks, a municipality has the authority to found organizations, including commercial ventures, and enter into contracts with other entities.

Therefore, in carrying out its statutory task of environmental protection, namely, air quality protection, the Municipality may organize Budgetary Agencies, whose principal business shall be to carry out the Program. Municipal business is carried out by Municipal Budgetary Agencies, i.e., organizations with defined autonomy whose receipts from the sale of goods and services are passed on to the municipal budget. The municipal budget, in turn, funds the operations of the Budgetary Agencies and subsidizes the difference between an Agency's operating cost and its receipts from the sale of goods and services.

A Budgetary Agency's business could be to implement the Program. Budgetary Agencies may be subsidized; the subsidies can come from the municipal budget or from the Environmental Protection Fund. There is a provision in the regulations of administering the monies of the Municipal Environmental Protection Fund stating that: *the monies of the Municipal Environmental Protection Fund are primarily to be allocated to subsidizing the Kraków Municipality's statutory business with regard to the protection of the natural environment and water management, as defined by the Environmental Protection and Water Management Act* (unified text dated April 15, 1994).

Articles 25 and 26 of the Environmental Protection and Water Management Act provide the following: *the protection of the air against pollution is based on preventing concentrations of pollutants in the air in excess of the statutory limits and restricting or eliminating the emission into the air of these pollutants by the manufacturing and service industry facilities, motor vehicles, spoil banks, landfills, and other pollution sources. The emission into the air of solids, liquids, and gases in the amounts that may have a negative effect on human health, the climate, flora and fauna, soil and water, or create other damage to the natural environment constitutes polluting the air.*

It follows, from the above, that the monies of the Municipal Environmental Protection Fund may be allocated to subsidizing Municipal Budgetary Agencies.

A Budgetary Agency may play a significant role by purchasing wholesale smokeless briquettes at the manufacturer and retailing them to the residents of Kraków. The Agency's task could be to retail the briquettes at the highest possible price accepted by the customers (the market). As long as this price is below the manufacturer's wholesale price, the Agency shall require a subsidy. This subsidy may come from the municipal budget or from the Municipal Environmental Protection Fund.

Recommendations on Using Administrative Orders by the Municipal Authorities in Order to Carry Out the Program

Administrative Prohibition of the Sale of Low Quality Coal by the Fuel Depots

The City Council may pass a resolution (pursuant to article 40.4 of the Local Government Act of March 8, 1990, and article 82 of the Environmental Protection and Water Management Act of January 31, 1980) to introduce a local ordinance mandating licensing of fuel depots. The license shall contain a provision making it illegal for depots to purchase low quality coal.

Failure to observe the provisions of the licensing agreement shall be punishable by a fine at the maximum statutory amount allowed to be levied by the municipalities.

Issuance of Building Permits for Remodelling National Historical Landmark Register Multi-Family Buildings and Other Rental Multi-Family Buildings

Pursuant to article 20 of the Protection of Goods of Culture and Museums Act of February 15, 1962, the *voivods* (county governors), acting on a motion by the county historical landmark curator and in consultation with the curator, shall have the authority to determine the building codes applicable throughout the construction industry in their jurisdiction, or order the removal, updating, or reconstruction of individual buildings, or issue other orders with the intent to protect historical urban arrangements and buildings listed in the National Historical Landmark Register.

Pursuant to article 27.1 of the above referred Act, it is illegal to change, remodel, reconstruct, restore, build over, rebuild, decorate, add onto, trench through, and make any other changes to national historical landmarks without the express permit having been issued by the appropriate county historical landmark curator. These statutes apply also to those goods of culture that have not yet been listed in the National Register of Historical Landmarks, if there are grounds for such. However, if such a building is not listed in the National Register of Historical Landmarks within three months, the county historical landmark curators have the authority to issue a stop work order for up to three months.

All work on historical landmarks may be conducted only if a permit has been issued by the appropriate county curator for national historical landmarks.

A county's national historical landmark curator has the authority to order a change of a building's heating system and, if the owner does not agree to carry out such an order, a building permit for remodelling the building shall not be issued. The curator's decision may indicate the preferential treatment and financial assistance that the owner or operator shall receive in exchange for adhering to the curator's decision. A curator's decision may be appealed in accordance with the Administrative Procedure Code.

Therefore, the above mentioned statutes authorize the local government to prohibit the erection of new, polluting heating-equipment located in historical landmark buildings and areas listed in the National Register of Historical Landmarks.

Issuance of Administrative Orders to Limit the Environmental Burden of Plants and Equipment

Pursuant to article 76 of the Environmental Protection and Management Act of January 31, 1980, (*Congr. Reports* #3, item 6, with subsequent amendments) a municipal agency has the authority to order an operator of a plant and/or machinery (such as e.g. coal-fired heating systems and heat delivery systems) to perform specific tasks to minimize the burden on the natural environment. In case of failure to meet the provisions of such an order, the municipal agency has the authority to order the closure of such plant and/or equipment. The above quoted statute is applicable to all entities whose actions create environmental hazards (pursuant to article 64 of the above quoted Act).

Pursuant to article 5.16.s. of the May 17, 1990 Act Regarding the Division of Tasks and Authority, as Set Forth in Specific Legislation, Between Municipal and State Government Agencies and Amending Other Acts, local agencies of the state government have the authority to issue orders to bring a building to an appropriate use, nonhazardous to the natural environment (article 50 of the Construction Statutes Act of July 7, 1994, *Congr. Reports* #89, item 414).

Therefore, the above mentioned statutes authorize the local authority to set forth pollution standards to be met by the boiler houses and, in cases of failure to meet the standards, the offending boiler houses may be ordered closed.

Mandatory Use of Environmentally Friendly Heating Systems in the Old Town Retrofit Buildings Erected on Post-Demolition Lots

The Environmental Protection and Management Act mandates that the owner (developer), the architect/engineer, and the builder perform the following:

a) consider environmental issues in the construction project;
b) ensure the use, particularly in residential and public construction, of building materials and elements effectively protecting the users of such facilities against noise and vibrations, and other health hazards.

The developer and the architect of all commercial construction projects are required to use processes that are the least hazardous to the environment and to effectively resolve the issues of waste management, and particularly, the issue of waste recycling. A newly constructed or remodelled building or a group of buildings shall not be issued an occupancy permit unless the statutory and/or specifically mandated plant and equipment have been erected. Therefore, in constructing new residential and/or public buildings, the authority issuing building permits, particularly for Old Town construction projects, may make such issuance contingent on resolving the issue of heating the facility or building in an environmentally friendly fashion.

Subsidies for Heating System Conversions in Buildings Owned by Individuals

On December 13, 1993, the Mayor's Office, pursuant to the Local Government Act of March 8, 1990 and the Executive Order of the Council of Ministers of November 9, 1887, resolved to subsidize remodeling of buildings owned by individuals.

Pursuant to this resolution the owners (managers) of buildings occupied by rent-control tenants are eligible for **subsidies of up to zł. 10 million in three year periods for repairing heating**

equipment, but no more than zł. 30 thousand per square meter of usable building footage occupied by rent control tenants. The awarded monies are disbursed as refunds of actual expenses, as documented by actual invoices or post-construction cost specifications.

Campaigns Promoting Heating System Conversions

Any campaigns promoting conversions of heating systems should concentrate on exposing the negative effects of the continued use of coal in ceramic stoves for the City and the health of its residents, and on demonstrating the benefits of using environmentally friendly heating systems. Such a comparison may be shown on pictures and diagrams in a flyer promoting their use. The objective is to eliminate the use of coal in home stoves, and to replace it with briquettes, or to install entirely different, environmentally friendly heating systems. This objective may be achieved through using mandatory measures (discussed herein) and through a promotional campaign.

The promotional campaign may consist of the following:

- a series of advertisements in the local papers;
- double-sided flyers promoting the use of briquettes and mailing this to the public;
- a series of radio shows;
- a series of TV shows.

The estimated cost of such a campaign during the two months preceding the heating season (i.e., in September and October) is zł. 500 million.

Organizing a Non-Profit Organization *Foundation EKO-INWEST Kraków*

The following could be the founding members of a non-profit organization *Foundation EKO-INWEST Kraków:*

- owners of Kraków multi-family residential buildings;
- City of Kraków Municipality;
- Kraków Gas Company;
- Environmental Protection Bank;
- Power Company;
- other companies involved in the program.

The foundation may receive continued sponsorship from the following:

- County Environmental Protection Fund;
- banks with branches in Kraków;
- Kraków restaurants and hotels;
- Kraków manufacturing and service industry businesses;
- other active sponsors.

The Foundation's objective should be to organize and financially support actions leading to the elimination of low emission sources in Kraków. The Foundation could assist in replacing coal-fired heating systems (eliminating coal-fired boiler houses) with gas-fired systems in the boiler houses responsible for highest emissions, and in eliminating coal-fired stoves.

The elimination of low emission sources would start with the coal/coke-fired boiler houses that are environmentally the most hazardous.

The Foundation's funds for implementing the program could come from the following sources:

a) owners of buildings equipped with coal-fired boiler houses who will commit to convert to gas-firing may be exempted by the City Council, e.g. for five years, from property tax, provided that the amount of property tax due will be transferred to the Foundation's accounts;
b) foreign funds;
c) donations made by Kraków's businesses and residents.

The Foundation would manage all organizational matters related to developing a project to eliminate coal-fired boiler houses, organizing bidding for implementing the project, executing credit agreements with boiler house owners for purchasing boiler houses and equipment related to the installation of new boiler houses, or organizing and co-financing new connections to the district heating network.

6.6.2 Statutory Tax Deductions and Exemptions

Individual Income Tax Deduction

Pursuant to article 26, paragraph 5 of the Individual Income Tax Act of July 26, 1991, with subsequent amendments, an income tax deduction is allowed for individuals for capital expense related to remodelling and/or refurbishing of residential property.

Maintaining, refurbishing and replacing existing heating equipment and systems and installating new equipment and systems are considered allowed capital expense related to remodelling and/or refurbishing of residential property.

In November 1994, the Congress amended the Individual Income Tax Act. It adopted legislation setting a cap on the deduction for remodelling and/or refurbishing of residential property at zł. 18.6 million. This deduction is allowed if the taxpayer can prove the actual expense with an invoice from an organization not exempt from the VAT sales tax.

Corporate Income Tax Deduction

Pursuant to article 18.1 of the Corporate Income Tax and Amendment of Select Taxation Regulations Act of February 15, 1992, (with subsequent amendments) donations related to research, environmental protection, and health protection, in the amount not to exceed 10 percent of total income, are exempted from corporate income tax.

After the VAT sales tax was instituted in 1993, the Corporate Tax Act was amended by the Amendment of Some Taxation Principles and Other Selected Acts Act of March 6, 1993, (*Congr. Reports* #28, item 127). Article 18.1 was amended by adding article 18.1.a, reading: *If the donation consists of goods and/or services taxable under the VAT tax, the value of the donation shall be construed to amount to the value of the subject goods and/or services after the VAT tax had been assessed and added.*

Since converting heating systems to more environmentally friendly systems qualifies as *environmental protection*, every corporation making a donation, either monetary or in kind (e.g. equipment), for implementing the program may subtract the amount of the donation from its gross profit, up to the statutory limit (10 %).

The October 9, 1992 Executive Order of the Minister of Finance *Changing the Order Regarding Execution of Some of the Statutes of the Corporate Income Tax Act* (*Congr. Reports* #78 item 396) exempts from corporate income tax any income attributed to the donation of fixed assets classified as the following plant, facilities, and networks: power generation (electrical and gas), water and sewage, heating, and telecommunications plant.

Exemption and Abatements from VAT and Import Sales Tax for Program Implementation

Pursuant to the statutes of the VAT and Betterment Tax Act of January 8, 1993, (*Congr. Reports* #11, item 50), importing goods exempt from the customs tax under the provisions of the Customs Statutes Act of December 28, 1989, (*Congr. Reports* 1989 #75 item 445, with subsequent amendments) is also exempted from the VAT tax.

Article 14.1 of the Customs Statutes Act lists a number of exemptions from customs tax for import of foreign goods. Some of these are applicable to the import of the following goods:

a) goods imported as foreign aid provided by foreign governments and alliances of foreign governments;
b) goods received by non-profit organizations for statutory objectives other than for-profit business;
c) goods received free of charge by state agencies to be used for their ordinary business.

Therefore, if the program of elimination of low emission sources is assisted by foreign governments and if equipment is imported as part of this aid program, then pursuant to the regulations listed in item a) above, this equipment will be exempt from customs and VAT taxes. However, this exemption will only apply with regard to equipment received from government agencies listed by the Superior Bureau of Customs or if the subject goods are imported for state agencies and organizations and/or for non-profit organizations.

If an environmental non-profit organization is founded in order to implement the program of elimination of low emission sources, then pursuant to regulations listed in item b) above, the equipment imported for the purpose of program implementation will also be exempt from customs and VAT taxes. A number of organizations involved in the implementation of the program of elimination of low emission sources are state agencies and these, pursuant to regulation listed in item c) above, will be exempt from customs and VAT taxes for equipment received free of charge.

The above listed exemptions do not apply to goods not exempted from customs under the customs statutes. The VAT tax liability arises simultaneously with the customs tax liability. Sales tax exemptions and abatements, and general tax exemptions granted under other statutes do not apply to the VAT and betterment taxes (Article 8). The April 6, 1992 Executive Order of the Minister of Finance *Regarding Sales Tax for Goods Imported or Sent from Abroad and Exemptions from this Tax* (*Congr. Reports* #32, item 140 with subsequent amendments) lists goods exempted from this tax. Materials used for production (including cooperative efforts of more than one manufacturer) and for capital projects imported by taxpayers with legal situs or residence in the Republic of Poland are exempt from any sales tax in excess of the amount calculated as six percent of the assessed value of these goods. These regulations apply also to individuals and organizations with legal situs or residence outside of the Republic of Poland, provided these persons or organizations are licensed in accordance with other statutes to engage in business in the Republic of Poland, or are performing contractual obligations with respect to contracts with Polish businesses for construction, erection, or maintenance work.

The following goods are exempted from sales tax payable at the border:

- goods imported by state organizations and agencies, including their for profit departments, provided these goods are not for resale;
- goods exempted from customs tax, i.e. goods listed in items a through c, above.

If boilers imported for the elimination of low emission sources are not exempted from tax under the above statutes, then customs tax will be assessed at 15 percent, and sales tax at six percent. In such case, the taxpayer will also be liable for a seven or 22 percent VAT tax, depending on the classification of the subject equipment and/or service.

6.6.3 Environmental Protection Fund Subsidies and Loans, Preferential Loans

Environmental Protection Fund Subsidies and Loans

Pursuant to the April 3, 1993 amendment of the Environmental Protection and Management Act and the Water Statutes Act, the following funds were created:

a) National Environmental Protection and Water Management Fund (National Fund);
b) County Environmental Protection and Water Management Fund (County Fund);
c) Municipal Environmental Protection and Water Management Funds (Municipal Funds).

The National Fund and the County Funds are corporations exempt from income tax. The National Fund's and the County Funds' objectives are foremost to assist Municipal Fund sponsored projects and other statutory objectives.

The National Fund's and the County Funds' monies may be allocated specifically for the following purposes:

a) granting of interest bearing loans (these loans may be forgiven, wholly or in part, when projects are completed on time and achieve design objectives);
b) **granting subsidies, particularly for large projects affecting two or more counties;**
c) organization of partnerships and corporations both locally and abroad, and purchase of shares in existing corporations and partnerships;
d) issuing of bonds and purchase of bonds and stock.
e) purchase of currencies;
f) compensation and awards for actions benefitting the cause of environmental protection and water management, other than services performed in the line of duty by state and local government employees.

The procedures of granting and forgiving loans and granting subsidies from the Kraków County Environmental Protection and Water Management Fund is spelled out in an appendix to the Resolution 12A/94 of the Fund's Board of Directors, dated February 21, 1994.

Loans and subsidies from the Fund may only be given for projects in the following areas:

a) environmental education and campaigns for environmentally beneficial projects;
b) assistance to environmental monitoring systems;
c) modernization and capital construction projects to benefit environmental protection and water management;
d) landscaping and maintenance of greenery, wooded and brush covered areas, and rural parks;
e) waste recycling, storage, and disposal projects;
f) actions for the protection of nature, and particularly forests;
g) actions for the prevention and elimination of extraordinary environmental hazards;
h) research and popularization of the results thereof and of new technologies in the fields of environmental protection and water management;
i) development and implementation of new techniques and technologies, particularly relating to sewage, fuel and exhaust, recycling, noise and radiation abatement, and water use;

j) preventative health measures for children in special environmental protection zones, where pollution standards are exceeded;
k) other environmental and water management projects, as set in the County Fund's program.

Subsidies from the Fund may only be given to the following entities:

a) state organizations and agencies, such as schools, centers and dormitories for the homeless and the needy, hospitals, national parks, etc.;
b) local government organizations and agencies in cases of elimination of extreme environmental hazards and environmental disaster cleanup;
c) research institutions working on environmental protection projects;
d) volunteer environmental protection organizations.

Loans from the Fund may only be given to the following entities:

a) local government organizations and agencies, public utilities owned by the local government, and water and water/sewage utility corporations;
b) manufacturing industry companies engaging in the business of environmental protection;
c) developers and builders carrying out environmentally beneficial measures.

County Fund loans and subsidies are not grantable for and to the following:

a) carrying out environmental protection measures as part of new construction projects;
b) individuals;
c) political parties;
d) construction of gas and water pipelines, district heating mains, sewers, and sewer hook-ups.

Loans and subsidies may be disbursed in one or more installments.

County Fund subsidies for capital projects are given up to the amount of the owner or developer's own project capital expense or other sources of project funding, however, the Fund may waive this cap on an individual basis. Fund loans bear preferential interest, usually within the range of .2 to .8 times the National Bank of Poland discount rate.

Preferential Loans

Water, air, and soil protection projects are eligible for preferential loans. This is possible due to the National Fund's (and County Funds') subsidies of interest rates of loans granted by financial institutions for environmental protection projects. In 1993, the Environmental Protection Bank's environmental loans made up 62 percent of all loans granted by the bank.

The following conditions must be met in order to obtain a loan from the Environmental Protection Bank:

- total loan amount may not exceed 50 percent of total project capital expense;
- the principal developer/builder's equity share in the project must equal or exceed 20 percent of total project capital cost;
- the developer/builder must provide adequate security for the loan.

Funds are disbursed in one or more installments against project invoices, at the following terms:

- variable interest rate of 7 to 35 percent (contingent on the National Bank of Poland discount rate — 35 percent in 1994; Environmental Protection Bank's loan interest rates range, depending on project type, from .2 to 1.0 of the discount rate);
- four year terms;
- principal payments begin 18 months after loan disbursement.

Preferential loan interest depends also on the type of borrower:

- interest rate for the manufacturers of environmental protection equipment varies from 14 to 28 percent;
- interest rate for local government, water utility corporations, and pilot programs varies from 7 to 21 percent.

If the project fails to carry out the design environmental effect, the loan loses its preferential status.

6.6.4 Municipal Strategy and Mechanisms Requisite for the Elimination of Low Emissions

Introduction

The City's task is to create a long term strategy making the reduction and eventual elimination of low emissions in Kraków possible. The results of the Polinvest studies indicate that the projects necessary for the reduction of low emissions may require financial incentives in order to be undertaken and carried out. Considering the funds currently allocated from the municipal budget, the process may take upwards of a dozen years. The success of elimination of low emissions requires that the following entities join the program:

a) local government;
b) developers;
c) owners and operators of low emission sources;
d) residents whom the individual projects affect.

Under commission from the Kraków Development Bureau, Polinvest has conducted **feasibility studies of projects** of converting the existing heating systems and equipment to non-emitting heating systems and equipment or those using environmentally "clean" fuels. Project studies were performed on actual existing facilities (e.g., boiler houses) and were based on project specific data (e.g., operating cost, capital expense required for connection to the MPEC S.A. district heating network).[13]

Based on the Polinvest studies, the following conclusions and recommendations with regard to the strategy for the implementation of the program may be posed for Kraków's municipal authorities:

a) **the Municipality's responsibility is to initiate the process of low emissions elimination, through appropriate incentive and stimuli resolutions;**
b) **the Municipality's strategy should be based on the assumption that the evaluation of project profitability is the responsibility of the owners and developers. The City's responsibility is to support individual projects and organize conditions conducive to carrying the project out;**
c) **the Municipality will impact project profitability and project terms through the creation of appropriate legal conditions and project co-financing, acting in its own best interest, as the Municipality's support for the owners and developers will protect it against future expenditure.**

The City's Responsibilities

Polinvest suggests that the City undertake the following actions in order to create favorable conditions for the operation of owners and developers in the process of low emissions reduction:

a) passing of a local incentive and stimuli ordinance;
b) allocation of municipal and Municipal Environmental Protection Fund funds for support of owners and developers (participation in the funding assembly process of individual projects);
c) organization of project construction and supply bidding competitions for municipally supported low emissions elimination projects;
d) financial and logistical support for grass roots initiatives in the field of elimination of low emission sources through such actions as the organization of a Program Promotion and Servicing Agency.

Polinvest suggests that specific amounts be allocated in the municipal budget for subsidizing specific low emissions elimination projects.

[13] Some project data were not independently verified by Polinvest, but rather used as quoted by the Kraków Development Bureau.

Funding Assembly

The **assembly of funding** will be the principal tool required to carry out the subject projects. Each of the projects studied requires more than one source of funding. For example, project funds may be obtained from the following variety of sources:

a) owners/developers;
b) the Municipality;
c) Environmental Protection Fund;
d) environmental protection geared loans;
e) equity investment by the owners, operators, and customers of the low emissions sources.

The City's responsibility shall be to attract to the low emissions elimination project the following businesses:

- heat manufacturers and distributors;
- fuel and power distributors;
- various heating service industry companies, such as wholesalers and/or retailers, contractors, maintenance contractors, and operators.

Under the current statutes, the Municipality may subsidize low emissions elimination projects out of monies allocated to grass roots initiative support. The success of these initiatives will depend on the amount of funds allocated and on the level of public involvement.

6.6.5 Incentives and Stimuli Appropriate for the Low Emissions Reduction Program's Individual Subprojects

Subproject #1 — connection of the existing boiler houses to the MPEC S.A. district heating network.

The following incentives and stimuli are appropriate for Subproject #1:

a) issuing administrative prohibition orders against the continuing operation of coal/coke-fired boiler houses;
b) funding by the Municipal Environmental Protection Fund;
c) funding by EKO-INWEST, a non-profit corporation.

Subproject #2 — conversion of coal/coke-fired boiler houses in the very center of town to gas-firing.

The following incentives and stimuli are appropriate for Subproject #2:

a) issuing administrative prohibition orders against the continuing operation of coal/coke-fired boiler houses;

b) granting property tax exemptions;
c) making the issuing of residential investment property major remodel building permits contingent on the replacement of the current heating systems;
d) funding by the Municipal Environmental Protection Fund;
e) funding by EKO-INWEST, a non-profit corporation.

Subproject #3 — equipping coal-fired ceramic stoves with electric heating elements.

The following incentives and stimuli are appropriate for Subproject #3:

a) creating and supporting grass roots committees for the construction and enlargement of power supply equipment;
b) granting property tax exemptions;
c) making the issuing of residential investment property major remodel building permits contingent on the replacement of the current heating systems;
d) funding by the Municipal Environmental Protection Fund;
e) funding by EKO-INWEST, a non-profit corporation.

Subproject #4 — modernization of boiler houses not scheduled for conversion to gas-firing or for connection to the MPEC S.A, district heating network.

The following incentives and stimuli are appropriate for Subproject #4:

a) issuing administrative orders to reduce emissions from the currently operated coal/coke-fired boiler houses;
b) funding by the Municipal Environmental Protection Fund;
c) funding by EKO-INWEST, a non-profit corporation.

Subproject #5 — replacing coal, the fuel currently used for heating with home stoves, with a less environmentally damaging fuel.

The following incentives and stimuli are appropriate for Subproject #5:

a) issuing administrative orders prohibiting the sale of poor quality coal;
b) supporting the manufacturing and sale of cleaned (washed) coal in Kraków;
c) supporting the manufacture and sale of smokeless briquettes in Kraków.

7.0 ENERGY CONSERVATION DEMONSTRATION

7.1 BACKGROUND AND OBJECTIVES

The Kraków building stock, typical of most of Poland, includes about 1,000 buildings made of prefabricated concrete panels, with little or no insulation. These buildings are usually heated by the municipal (pressurized hot water) district heat system or by local coal- or coke-fired boilers. Conservation is a potential pollution reduction plan, according to the following scenarios:

- Less fuel can be burned by the coal- or coke-fired heating systems.
- By reducing building heat requirements, it is less costly for the residents to burn alternate fuels, which are less polluting, but more expensive, than coal. This encourages conversion to non-coal fuels.
- Reducing the heating requirements for district heat-supplied buildings will enable the existing district heat system both to serve additional customers without constructing new heat sources and to eliminate local boiler houses on the district heat system.

In all cases, effective use of energy can improve the economics of the pollution reduction options evaluated in the Kraków Clean Fossil Fuels and Energy Efficiency Project.

The objectives of the conservation demonstration were to:

- Identify affordable, cost-effective residential energy efficiency measures.
- Evaluate the costs and energy reductions due to selected measures.
- Identify institutional and infrastructure impediments to the adoption of economically attractive energy efficiency measures and means to overcome those obstacles.

7.2 KRAKÓW BUILDING STOCK AND ENERGY PRICING

The demonstration focussed on retrofits to existing concrete element buildings. The concrete elements are usually pre-fabricated at a factory and shipped to the building site for assembly. The walls of the older buildings are uninsulated concrete with a heat transfer coefficient not much better than double-glazed windows. (Newer buildings have some insulation, but it is not very effective.) The apartments have double-glazed, wood-framed casement windows. The air space between panes is approximately 3 cm, and the outside pane is set in its own wooden frame, separable for cleaning. There is usually a small transom window above the main windows that is opened for ventilation. Most apartments have balconies, with a wood-framed glazed door. There is significant infiltration around the window and door frames. The window frames warp, resulting in air gaps as large as 2 cm. Also, the concrete slabs often settle unevenly after construction, leading to distortion of the frames and, frequently, cracks in the concrete. As a result, many of the windows and doors have large visible air gaps and/or cannot be closed tightly.

Ventilation in the apartments is by natural convection, using internal ventilation chimneys. This works poorly in mild weather and not at all in warm weather. However, the windows are also opened for ventilation. Most cooking stoves are gas-fired, and hot water is supplied by gas-fired instantaneous water heaters mounted on the wall above the faucets and in the bathroom. Some kitchens have exhaust fans, but these are not very effective. Additional ventilation is often needed because many of the residents smoke, and the small transom windows are used for this purpose. Pre-demonstration inspections showed a number of apartments had high levels of carbon dioxide (CO_2) and carbon monoxide (CO), especially during cooking.

Many of the apartments have moisture problems. The uninsulated walls are cold, and water vapor condenses on the interior surface. In some apartments (on the first two floors), the walls have been so cold that the condensation froze, resulting in ice on the inside surface of the exterior walls.

Radiators in the rooms are located under the windows, usually with a stone or concrete shelf over the radiator. Furniture is often placed in front of the radiator, and most apartments have floor-to-ceiling curtains that cover the radiator. The result is that the heat from the radiator is often impeded from warming the room; instead, the radiator warms the exterior concrete wall.

Heat is supplied to the building by pressurized hot water from the municipal district heat utility. Hot water at 150°C is provided to the building through a hydroelevator. The hydroelevator is designed to mix the district heat supply water with the water already circulating in the building, so water entering the building piping system will be at approximately 90°C on design cold days, and water returned to the network will be about 70°C.

Most buildings have no controls. Instead, the utility regulates the temperature it sends out from the heat source, varying the temperature of water in the network from 150°C to about 75°C. The water temperature in the buildings' radiators will vary in proportion. The radiators are often warmer than necessary on mild days.

Most radiators do not have thermostatic valves. There are on/off valves, but if these are used, they leak; consequently, almost everyone sets them fully open and leaves them alone. When the room becomes too warm, the residents open windows to cool off.

Residents pay a nationally-set price for district heat, which is defined in złotych per square meter of heated floor space in the apartment. This amount is due every month of the year, and does not reflect actual energy use or demand for heat.

The district heat utility charges the building owner for calculated energy used or, where a heat meter has been installed in the building, for actual energy usage. The district heat utility also charges a fixed "capacity fee" based on the diameter of the pipe with which district heat water is supplied to the building, or the calculated maximum (i.e., peak) heat usage of the building.

The difference between what a building owner receives from the tenants (fixed price for heat) and what it is charged by the district heat utility (calculated cost of energy) is paid by the building owner. Most buildings are owned by the Polish state government or by the municipality (approximately 20% of Kraków's multifamily residential buildings are city-owned.)

Until recently the fixed price was much less than the bill presented by the district utility. The payments, by the City or the federal government (the Voivodeship) to make up the difference were subsidizing the price of district heat. The Polish government has been raising the fixed price, faster than inflation levels, in order to eliminate this subsidy. In 1990, when the project was first proposed, the subsidy was on average about 80% of the cost of district heat. By the end of 1994, rising fixed prices for heat had all but eliminated the subsidy in most buildings.

Poland passed a law stating that all buildings had to meter heat energy use. Heat meters are installed in new buildings, but only about 5% or less of existing buildings have had them installed, as the cost of the meter is too high for the district heat utility (MPEC) to purchase and install them in all buildings immediately. As a result, MPEC continues to calculate design maximum demand for district heat (at -20°C design temperature) and apply a factor based on the actual monthly temperature profile in order to estimate energy used. The calculated energy use is derived from the design parameters of the building; it does not take into account building condition (e.g., increased infiltration due to building deterioration) or some building efficiency improvements (e.g., thermostatic valves, weatherization, etc.) As a result, owners of the most efficient buildings have begun to buy their own heat meters, to convert from calculated energy bills to (usually lower) bills based on measured energy use. The least efficient buildings, with, presumably, higher actual than calculated energy use, remain without heat meters.

MPEC's tariffs consist of both a fixed (i.e., capacity) and variable (i.e., energy) component. The fixed component is based on the calculated maximum demand for heat and the diameter of the pipe delivering MPEC heat to the building. This remains a calculated number even when building heat use is metered, since there are no inexpensive heat demand meters. Where a building's energy efficiency has been improved, the owner may "negotiate" a lower capacity price with MPEC, and an appropriate flow restrictor, reducing the diameter/orifice of the heat supply pipe, will be installed.

At the beginning of the project, fixed costs averaged about 75% of the revenue for district heat utilities nationwide. Tariff reform, especially in Kraków, has modified tariff structures, so fixed charges account for less than 40% of the heat bills in Kraków now. However, this still means that when a building owner reduces his use of district heat, even when a meter has been installed, he reduces only the 60% component of his bill tied to energy. He must still negotiate the reduction of the non-metered 40% of his bill.

The subsidized price of district heat and the inability to tie heat bills to actual energy use have been substantial disincentives to implementation of energy efficiency measures.

7.3 DESIGN OF THE CONSERVATION DEMONSTRATION

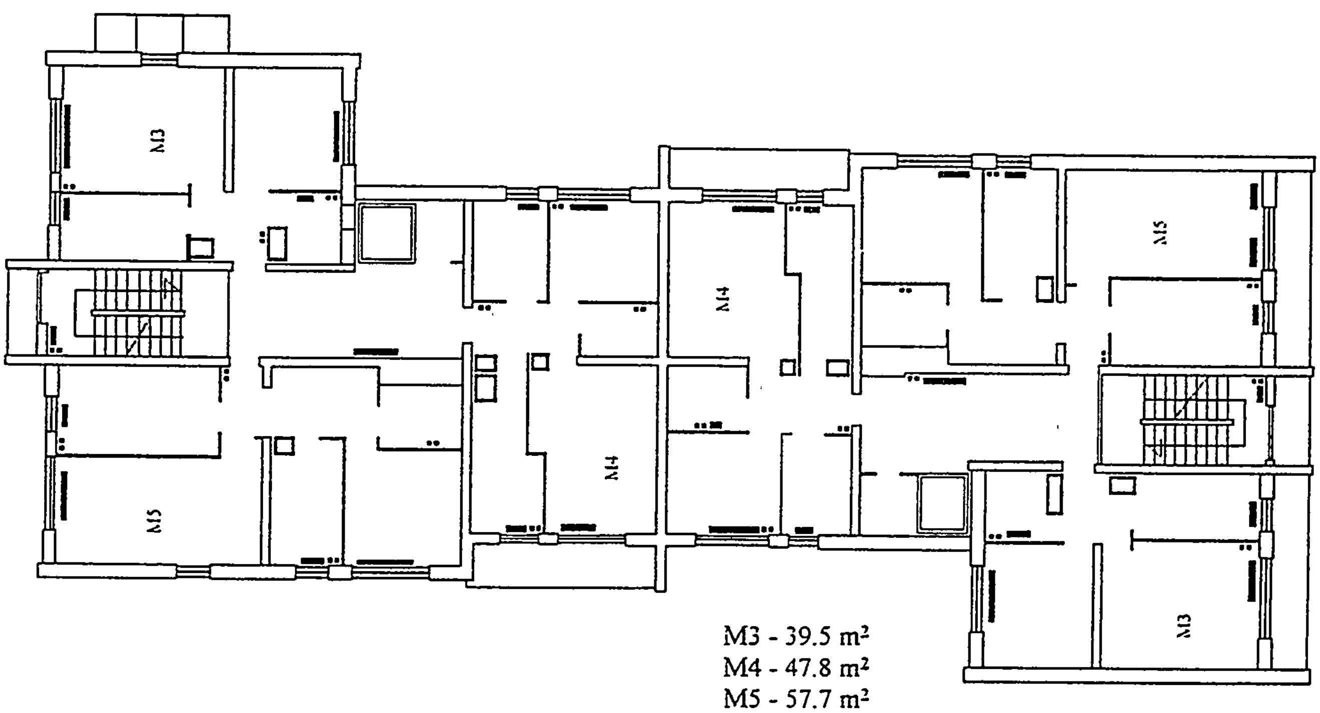
7.3.1 Experiment Structure

Weatherization measures may reduce the amount of heat needed in a building, but without accompanying controls, MPEC will deliver the same amount of heat; residents will just overheat and have to open their windows more often; no energy will be saved. Better controls will reduce energy used on mild days, but without weatherization, the capacity requirements for heat will not change, and the buildings may still be uncomfortable on cold days. In addition to technological "fixes," any efficiency program must include the economic incentives to motivate its implementation. Therefore, the Kraków conservation experiment has three major aspects:

- Building envelope improvements, to reduce the requirement for heat and improve comfort.
- Building-level control, to reduce the amount of heat delivered to the building during mild weather.
- Thermostatic controls of individual radiators, and incentives for the residents to use them.

Four adjacent "identical" buildings were selected for the project. The buildings are eleven stories high, with six apartments per floor, and have a basement storage area. The buildings have the same orientations and are located at numbers 4, 6, 8, and 10 Wolasa Street in the housing cooperative Spółdzielnia Mieszkaniowa "Krowodrza." Figure 7-1 shows the building

Figure 7-1. Floor Plan of Wolasa Street Buildings



floor plan. All floors in each building are identical. The building heating system consists of hot water radiators, generally piped vertically, with added heating supplied by pipe loops in bathrooms and foyers. Radiator sizing is adjusted for the calculated heat loss of each room, giving consideration to orientation, roof or floor heat loss, etc. The building heating energy source is the Kraków municipal district heat utility (MPEC). Before the project improvements, each of the four buildings used about 15 GJ of energy per day. (The four buildings' baseline energy use was within 5% of each other.)

A heat meter and data collection system were installed in each building to monitor conditions during the 1992-93 and 1993-94 heating seasons. The primary quantities measured were:

- building heat energy use
- building electricity use
- water flows, temperatures, and pressures (supply and return)
- outdoor air temperature
- indoor air temperatures at selected locations.

While the total building's heat energy use was metered, it was not possible to meter each apartment's energy use with one meter because the heating system uses vertical risers, with each riser supplying hot water to 11 different apartments. Each apartment is supplied by four to five risers. Instead, energy use by each radiator was estimated by using a "cost allocator" device with a digital readout. These devices measure the temperature difference between the radiator and the indoor air and, based upon radiator size and shape, estimate the energy transfer from the radiator. FEWE-Kraków staff read and recorded these values monthly (for rebate.)

The two heating seasons were each divided into two parts:

Period I:	October - December, 1992
Period II:	January - April, 1993
Period III:	October - December, 1993
Period IV:	January - April, 1994

Different sets of efficiency measures were demonstrated in each building in each period. The building's energy use and sample indoor temperatures were monitored.

7.3.2 Conservation Measures Demonstrated

This section describes the energy efficiency measures demonstrated. They are summarized in Table 7-1.

Base Case – Hydroelevator with No Control

All four buildings originally used a hydroelevator with no temperature reset control. Baseline monitoring was done for Wolasa 4, 6, 8, and 10 during Period I and for Wolasa 4 and 6 during alternate 2-week intervals of Period III (denoted as Period IIIA). We also alternated weatherized (Wolasa 4 and 6) and insulated (Wolasa 8 and 10) buildings for two weeks with the hydroelevator and two weeks with the regulated heat exchanger during Periods III and IV (denoted as periods IIIA and IVA–hydroelevator and as IIIB and IVB–heat exchanger).

Hydroelevator with Temperature-Reset Control

An outside temperature-based controller was installed on the hydroelevator in Wolasa 4. The controller regulated the amount of heat extracted from the MPEC supply, based upon outside air temperature. The objective was to reduce overheating the apartments on mild days. This

TABLE 7-1. CONSERVATION MEASURES DEMONSTRATED

PERIOD	Wolasa 4				Wolasa 6				Wolasa 8				Wolasa 10			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
CONSERVATION MEASURES																
Base Case-Hydroelevator	X		X[1]	X[1]	X		X[1]	X[1]	X		X[1]		X		X[1]	
Regulated Hydroelevator		X	X[1]	X[1]												
Regulated Heat Exchanger						X	X[1]	X[1]		X	X[1]	X		X	X[1]	X
Weatherization and Attic Insulation				X				X			X	X		X	X	X
Thermostatic Valves										X	X[4]	X		X	X[5]	X
Conservation Incentives										X				X		
Pipe Cleaning							X	X	X	X	X	X	X	X	X	X
External Insulation											X[2]	X[2]			X[3]	X[3]

[1] Alternating 2-week period between base case hydroelevator and temperature-controlled heat exchanger (Wolasa 6, 8, and 10) or controlled hydroelevator (Wolasa 4)
[2] External insulation on windowless walls only
[3] Full external insulation
[4] Residents reinstalled 36% of the thermostat heads during this period.
[5] Residents reinstalled 48% of the thermostat heads during this period.

Period I: October-December 1992
Period II: January-April 1993
Period III: October-December 1993
Period IV: January-April 1994

controller was activated in January 1993 for Period II. It was also activated and deactivated for alternating 2-week periods for Period III. (In this way, Period III gave us two weeks of baseline data alternated with two weeks of regulated hydroelevator data for Wolasa 4.)

Heat Exchanger with Temperature-Reset Control

Flat-plate heat exchangers with outside air temperature-based controls were installed in Wolasa 6, 8, and 10 in parallel with the existing hydroelevators. The piping and valves were configured so that the building could be switched between hydroelevator and heat exchanger operation. The temperature-based regulation system was designed to vary the heat input to the building water loop, based upon outside air temperature, thus reducing overheating on mild days. Use of the heat exchanger and an in-building pump gave better control of water flows and temperatures, and also isolated the building water from the MPEC supply water. Since some of MPEC's water losses appear to be the result of diversion, this is a feature that MPEC finds particularly attractive. The heat exchangers were activated in Wolasa 6, 8, and 10 at the start of Period II. The heat exchanger in Wolasa 6 was switched every two weeks (alternating heat exchanger and hydroelevator) for Periods III and IV. The heat exchanger and hydroelevator were also switched every two weeks during Period III in Wolasa buildings 8 and 10.

Weatherization Measures

All four buildings were weatherized, as follows:

- Caulking of window and door frames, and cracks in walls.
- Weatherstripping of windows and doors.
- Door sweeps and thresholds installed on entry and balcony doors.
- Insulated reflective barriers installed between each radiator and the wall, and also on the bottom of the window shelf above the radiator.
- Approximately 20 cm of fiberglass insulation was blown into the space between the top apartment's ceiling and the building's roof.
- Fiberglass insulation was blown into air channels in the basement ceiling, for the entire basement of Wolasa 8 and 10 and the basement perimeter of Wolasa 6.
- Infiltration bypasses caused by pipe and electrical conduit openings in the basement ceiling were sealed.

The basement sealing was done to reduce the significant stack effect observed. No internal insulation (beyond the use of the radiator shields) was tried because of the buildings' moisture problems. CO and CO_2 levels in each apartment were measured before and after weatherization.

When doing apartment weatherization work, FEWE-Kraków staff also described to the residents the need to keep the air flow over the radiator unobstructed (i.e., don't block radiator with curtains or furniture). The weatherization of each building was done as follows: Wolasa 10–January 1993; Wolasa 8–August 1993; Wolasa 4 and 6–January 1994.

Thermostatic Valves

Thermostatic valves were installed on each radiator (except those in common area staircases and hallways) in Wolasa 8 and 10 in August-September of 1992. These were set "full open" and the heads removed (i.e., they were disabled) during Periods I and III. The heating system pipes of Wolasa 8 and 10 were chemically cleaned with an acid solution in August 1992. This was done to prevent the thermostats from becoming fouled by scale deposits from the district heat system water. An alternative chemical cleaning method using a nonacidic process, which can be done while the heating system is operating, was demonstrated on Wolasa 6 during the summer of 1993.

External Insulation

External plastic foam insulation has traditionally been the means of insulating buildings in Poland. This was done for Wolasa 10 (all exterior walls) and Wolasa 8 (only those wall surfaces without windows or loggias) during the summer of 1993.

7.3.3 Energy Efficiency Incentives

Because Polish experience with regulation valves on radiators is so negative — the valves leak if used — the project team was concerned that the thermostatic valves, when installed, would simply be turned to their fully opened positions (i.e., not used). To create an incentive to use the thermostatic valves, a rebate program was instituted for the second half of the first heating season (Period II).

The rebates were payments to be given to residents of buildings 8 and 10 if their energy use was below a certain pre-calculated target. Two rebate components were designed:

- Building-level rebates (the so-called "Solidarity Rebate" because everyone in the building received it) if monthly building energy use was below a target number. The more the building's metered heat energy was below this target, the greater the rebate.
- Apartment-level rebates — each apartment's target energy use was calculated based upon design heat loss, expected weather, and number and size of radiators in the apartment. Cost allocator meters were installed on each radiator in buildings 8 and 10. The sum of the "cost allocator" meters on each apartment's radiators was compared to the apartment's monthly energy use target. (The cost allocators were read at the end of each month.) As with the building level rebate, the size of the payment increased the more the resident's energy use was below the target. Residents who exceeded the target energy use did not receive an apartment-level rebate for that month; however, they still received their building-level ("Solidarity") rebate.

Using demonstration project funds, a total of approximately 54 million złotych was paid to the residents in rebates under Period II. Additionally, at the end of the heating season the district heat utility, MPEC, gave the housing cooperative a 72 million zł refund for the same period, as the actual heat energy consumption of the test buildings was less than MPEC calculated it would be, and MPEC had initially billed the cooperative based upon the old system of energy use calculations. The rebates to residents averaged about $30 per apartment (from a low of $15 to a high of about $65). This is equivalent to about one month's heating bill. It was high enough to be significant, but not so high that people forced themselves to be cold in order to "earn" the rebate.

The rebate program was successful, in that it motivated the residents to use their thermostats, and learn for themselves what improved comfort the thermostatic valves could provide.

During Period III, we attempted to disable all thermostatic valves temporarily (for three months) by removing the adjustment heads after setting them to the fully open position. We wished, in this way, to evaluate additional combinations of energy efficiency measures without thermostats. However, the residents had grown so used to the thermostatic valves that 1/3 to 1/2 requested we not remove their valves or they reinstalled the heads themselves.

7.4 EVALUATION OF ENERGY SAVINGS

The analytical methodology used is to extrapolate the measured building energy use to a typical Kraków winter, using linear regression. During the baseline, no control was exercised other than by MPEC's varying the district heat supply temperature. The energy use in any building is thus a function only of the temperature of the district heat water and weather conditions. In essence, the entire building can be viewed as a radiator providing a resistance to heat flow from the district heat system to outdoors.

For Periods II, III, and IV, the energy use is dependent on both the district heat supply temperature and outdoor temperature. This is as expected, since local control in the buildings allowed a better match of energy use with energy needs (i.e., current weather conditions). (Tests of power fits were also made, since radiators in heated rooms transfer energy in proportion to T^K where K ranges from 1.1 to about 1.5. However, these regressions gave no significant improvement over the linear model.)

The base case data analysis showed the Wolasa buildings used about 15.23 GJ/per average winter day (annually, about 3046 GJ/building or 46 GJ/apartment). Each building's energy use during the baseline period was within 5% of the other buildings'. Physical problems during the experiment resulted in shorter periods of valid data than desired for some conservation measure combinations, but enough valid days were measured that statistically significant estimates can be made of the savings due to each "package" of conservation measures. (One such problem was a break in a pipe in the basement of Wolasa 8, that shut down its heating system for three days during very cold weather. Another problem was a malfunction of the heat source, at Łęg, during cold days, that interrupted heat to the entire city for many hours.) During Periods III and IV, when the building regulation systems were being switched on and off every two weeks, we also had to discard data for the day the system was switched, to give the building heat system time to reach equilibrium under the other control/regulation scheme.

The interaction of the different conservation measures is very important. Neither the weatherization/attic insulation nor the external insulation will save any energy without controls. However, it is possible the MPEC system control of water temperature would be sufficient if the (unregulated) hydroelevators were downsized to match the lowered heat loss. The building-level controls will also show no savings without reducing the heat loss, if the hydroelevator is initially set correctly, and if MPEC correctly manages the system. Indeed, since MPEC considers cloud cover, building thermal lag, and forecasted weather, their adjustments at the Leg combined heat and power plant may be more accurate than an outside air temperature reset at the building. (Hopkowicz, M., 1988.)

Base Case. We have voluminous base period data over six cases: 4-I (i.e., building 4, during Period I), 6-I, 8-I, 10-I, 4-IIIA, and 6-IIIA. The average of these is daily energy use measurements of 15.23 GJ, with a standard error of 0.67 GJ/day. All of the cases are within one standard error of the mean. With the exception of building 6, all of the cases are within ±22 percent of the standard error.

Weatherization Without Control. We expect that weatherization (without added control) will save no energy, since the MPEC system will put the same amount of heat into the building regardless of heat loss. In fact the two weatherized cases without control (4-IVA and 6-IVA) use the same energy as the base case, 15.19 ±0.89 GJ/day. (The difference is insignificant, 0.045 ±1.11 GJ/day.) Since both theory and test show no difference, we combine 4-IVA and 6-IVA into the base case data set to improve the accuracy, resulting in 15.22±0.54 GJ/day.

Building Level Control. We expect no savings from building level control if MPEC system level control is as good or better than building-level control and if the hydroelevators are set properly. MPEC did check and install correctly sized orifices at the test sites just before Period I. The analysis shows that the regulated hydroelevator tests, 4-II and 4-IIIB, used 14.8 GJ/day. The standard error of the difference to the base case is, however, greater than the difference of 0.45 GJ/day. We have, therefore, not demonstrated any savings for the regulated hydroelevator versus the unregulated hydroelevator. The two regulated heat exchanger cases, 6-II and 6-IIIB show average use of 14.6 GJ/day. However, the standard error of the difference again exceeds the value of the difference from the base case. There is no statistically significant difference (at the one standard error level) between the results for the two types of building level controls. Considering all periods of building level control (to reduce the experimental error) gives an average use of 14.7 GJ/day. The difference of 0.54 GJ/day is still not significant. We do not include these cases in the base analysis since a theoretical difference due to control is possible.

Where the heat loss is reduced, building level control will save energy versus the case of an incorrectly sized, unregulated hydroelevator. The savings will depend on the amount the system is oversized. The fact that the controls can work in this circumstance is clearly shown in buildings 8 and 10, during periods III and IV and is discussed below.

District Heat Node Controls. MPEC suggested that a more cost-effective means of effecting building-level control would be to install a heat exchanger and control system in the district heat network nodes, each of which serves 5 to 20 buildings. The cost would not be much more for a node serving five buildings than for the building-level controller used in the Wolasa Street demonstration. (The node heat exchanger and controls would be supplemented with simple temperature sensors and small auxiliary pumps and controls at each building.) MPEC felt the energy efficiency would be comparable to that of the in-building heat exchanger and controls, but at a cost of $50-80 per apartment, compared to $250/apartment for the control system tested in Wolasa Street. (MPEC does have experience with such district heat node controls.) Accordingly, costs for this option, as an alternative to the controls actually demonstrated, are given in Table 7-4.

Weatherization plus Building Level Control. Cases 4-IV and 6-IV show essentially identical results of 13.9 GJ/day. The incremental effect of the weatherization cannot be separated from the controls with any significance. However, the combination of weatherization and controls shows a savings of 1.33 GJ/day or 8.8%, which is greater than the standard error. It should be noted that the attic of building 4 was not insulated until near the end of Period IV, and in neither building 4 nor building 6 were the basement air gaps sealed as specified. The expected savings from a completed weatherization package with controls would likely be somewhat slightly higher.

Thermostatic Valves. We have no cases with thermostatic valves alone. For case 8-II, thermostatic valves on radiators used in conjunction with a building level regulated heat exchanger (and price incentives), the energy use is 13.13 GJ/day. The savings of 2.09 GJ/day (13.7%) is significant. The amount of that believed attributable to pricing and rebates alone is small. (Wisnewski, 1994.) In addition, building 8 was cold in Period II, leading to the belief that the 13.7% is higher than would be seen under normal conditions. Comparisons with periods III and IV seems to indicate that the pricing/rebates by themselves have little effect.

Thermostats with Weatherization. Again, there are no cases without building level control. Case 10-II, with room thermostats, regulated heat exchanger and weatherization, used 12.0 GJ/day. The savings to the base case is 3.20 GJ/day (21.0%) and is significant. The difference to the case without weatherization is 8.5% (of case 8-II) and is also significant. Remembering that building 8 was cold in Period II, this is consistent with our estimate of weatherization (with controls) savings of somewhat over 9%.

Exterior Insulation. Exterior insulation with controls saves significant energy. For the case with regulated heat exchanger, room thermostats and partial exterior insulation (8-IVA), savings are 4.01 GJ/day (26.3% of base use). Adding full exterior insulation (10-IVA) raises the savings to 5.27 GJ/day (34.6% of base). The cases without thermostats (8- and 10-IIIA and-IVB) were not conclusive. Many occupants refused to give up the thermostats, and the results show evidence of use. Building 8, for example, shows no difference between the periods (8-IIIB to 8-IVA). The comparisons of conditions A and B within periods III and IV clearly show that

Table 7-2. Summary of Energy Savings

Technique	Incremental Demonstrated Savings per building			Total Savings	Comments
	%	GJ/year	%	GJ/year	
Building Level Controls	None		None		May be needed to allow savings from other techniques, correct for errors in node sizing.
Low cost weatherization and attic insulation	8.8%	268	8.8%	268	May be slightly higher
Radiator thermostatic valves	13.7%	418	21.0%	640	May be somewhat lower
Price incentives/rebates	None	-0-	21.0%	640	Served "awareness" function
Add partial exterior insulation	5.3%	162	26.3%	802	
Add full exterior insulation	13.6%	414	34/6%	1054	

building level control has an effect. The savings will depend on the oversizing in the unregulated hydroelevator.

Table 7-2 summarizes the observed savings. Note that since the exterior insulation cases were never evaluated for non-weatherized, non-thermostatic-controlled buildings, the values for external insulation are only for the incremental savings after weatherization, etc.

7.5 COST OF MEASURES AND SAVINGS

In order to evaluate the effectiveness of the energy conservation measures, the costs of the measures must be compared to the price of energy saved. Table 7-3 gives the costs of delivered energy for space heating in April 1994 from various sources:

Table 7-3. April 1994, Cost of Delivered Energy in Poland

District Heat (includes the capacity charge)	$5.00/GJ
Coal-fired home stove	$5.00/GJ
Coal-fired hand-stoked boiler	$4.75/GJ
Coke-fired hand-stoked boiler	$6.15/GJ
Coal-fired mechanical stoker boiler	$5.50/GJ
Gas-fired boiler	$5.10/GJ
Electric resistance heat	$0.046/kWh

The costs of the conservation measures are given in Table 7-4. Table 7-5 compares the per-apartment energy savings and required investment costs.

The weatherization and attic insulation show a simple payback of four years at a price of heat of $5/GJ. This heat price is already higher, and is expected to go to about $8.5/GJ within the next year (without a corresponding increase in the installed cost of the weatherization). This would lead to a simple payback of 2.4 years.

TABLE 7-4. Costs of Conservation Measures Taken in Kraków

Measure	Unit Cost	Installed Cost per Apartment	Installed Cost per Building
Weatherization		$ 45	$ 3,000
Attic Insulation*	$7/M²	$ 37	$ 2,500
Thermostatic Valves and Pipe Cleaning	$25/valve $5000/bldg	$ 110 $ 76	$ 7,500 $ 5,000
Exterior Insulation (flat walls only) (all surfaces)	 $20-25/M² $20-25/M²	 $ 850 $1,400	 $56,000 $90,000
Building level controls	$16,500	$ 250	$16,500
DH Node controls	$25,000	$ 80	$ 5,000

* Attic insulation will be less per M² for long, low buildings with more roof area. Total cost per building (and per apartment in that building) will increase, but so will energy savings.

TABLE 7-5. Savings vs Costs for Selected Efficiency Measures

Measure	Annual Savings/ Apartment/Year	Installed Cost	Simple Payback (years)
Building Controls Building-level Node-level	$ 0.00	$ 250 $ 80	none
Weatherization and Attic Insulation	$20.30	$ 82	4.0
Thermostatic Valves and Pipe Cleaning	$31.60	$ 186	5.9
Exterior Insulation Partial Full	 $12.30 $31.40	 $ 850 $1,400	 69 45

Controls are needed to realize the savings. Control at the building can be exercised by a heat exchanger and controller at each building, as was done in this demonstration (cost $250/apartment), or by a controller and heat exchanger, for similar total cost, installed at the district heat network node serving 5 to 20 buildings (cost is conservatively $80/apartment). Thermostatic radiator valves may perform this same function. (The valves cost $110/apartment, giving a simple payback of 3.5 years at current prices, 2 years at forecast prices. However, the pipe cleaning — chemical or acid — needed to prevent the thermostats from fouling costs about $5,000 per building, or $76 per apartment, leading to a simple payback of about six years.) Other, lower cost possibilities are to re-calibrate and/or downsize the existing hydroelevator and rebalance the building heat system, for minimal cost ($3,000-$4,000 per building, or $50/apartment).

7.6 DISCUSSION

Wolasa 4, with the addition of the regulated hydroelevator, allowing outdoor air reset, showed no savings. The Wolasa buildings are near the end of the MPEC supply lines, and thus may have less overheating than in average buildings. More significantly, the control on the regulated hydroelevator was set too high in 1993, continuing the previous levels of overheating.

Wolasa 8 was retrofit with a heat exchanger and outdoor temperature air reset controls, thermostats on almost all radiators, and cost allocators. In addition, as an incentive to use the thermostats, rebates were paid to the occupants of the building based on their apartment's energy use and on the building's total energy use. This building did not always maintain comfort conditions throughout the post retrofit period. Thus, a direct comparison is not possible. The 13.7% savings estimated from thermostatic valves may in reality be 9-10% — the difference between the reductions at Wolasa 8 and Wolasa 6. Temperature data collected show clear evidence of occupant thermostat use, and of thermostat control of flow and energy use. However, some time periods show full open thermostats operation with cold interior temperatures. It can be speculated that not all of the apparent savings are due to thermostatic control. Some could be the result of low (uncomfortable) indoor temperatures. This would increase the amount of savings attributable to weatherization.

Wolasa 10 was treated the same as Wolasa 8 in the first heating season. In addition, the building was weatherized following methods found successful in the United States and adapted to Polish construction and materials. The treatment included infiltration reduction methods, improvement of glazing, and attic insulation. The 21% savings are apparently real and due to the project. Based on comparison with the other buildings, we can conclude the weatherization saved a minimum of 9%. The actual value is probably higher than that for two reasons. First, Wolasa 8 had much lower indoor temperatures during several time periods (below the comfort level), so the pricing-thermostat savings are less. Second, the weatherization and insulation were not all completed before the beginning of the post period (Period II). In fact, the analysis includes a significant number of days where the building was partially unweatherized. Note that weatherization has no effect if occupants open windows due to overheating in mild periods, so some control is necessary to achieve maximum savings.

For district heat-served customers, the building-level heat exchanger and controller are expensive on a per-apartment basis (about $250 per apartment). MPEC feels that substation-level heat exchangers and controls (a single installation would serve 5 to 20 buildings), with simple auxiliary controls in each building, could achieve almost the same benefits at a cost of about $80 per apartment.

7.7 CONCLUSIONS

The weatherization and control measures implemented in Wolasa 10 showed it is possible to save over 20% of a building's space heat energy. These are *demonstrated*, not theoretical savings. Actual savings will almost always be less than engineering calculations, as people open windows for ventilation; building settling means that some windows can't be weatherstripped, or they won't close; some people will opt for higher indoor temperatures—comfort—instead of using less energy; etc.

Again, it must be recognized that controls and weatherization are *both* necessary to save significant energy. Weatherization can reduce the amount of heat a building *needs*. Controls are needed to reduce the amount of heat a building *takes*. In buildings heated by district heat or individual boilers, a conservation program *must* include installation of appropriate controls. Where there is already a thermostat-controlled heat source (e.g., electric heat or thermostat-controlled gas furnaces), then the controls are already in place. For hand-stoked boilers or coal stoves, the operator must be trained to reduce the amount of fuel used.

These data suggest which energy efficiency measures are cost-effective for the large concrete buildings:

- Caulking, weatherstripping, and radiator shields
- Attic/roof insulation
- Control of energy supply at the radiator or substation level.

Individual radiator thermostatic valves afford a comfort control that is a major "selling point" for an energy efficiency program.

Kraków's plans to eliminate 633 local solid-fuel boilers and connect their buildings to the district heat system will increase the demand for the MPEC network to about 2060 MW (Bieda, et. al., 1995), compared to an existing central heat and power plant capacity of 1730 MW. Obviously, a comprehensive conservation program that can reduce district heat demand by 20% will eliminate, or defer significantly, the need for construction of new central heating sources. Thus, conservation must be a key element to the City's strategy for eliminating local boilers.

While the analysis shown relates to the large multi-family buildings, smaller scale demonstrations in the Old Town during this project have shown comparable energy savings in gas-heated apartments in smaller, 400- to 500-year-old masonry and brick structures.

In summary, the project team has identified and demonstrated affordable and effective conservation technologies that can be applied to Kraków's existing concrete-element residential housing. The results suggest that conservation strategies will be key to many alternatives in the City of Kraków's plan to eliminate low-emissions sources:

- Connecting more customers to the MPEC network and eliminating local boilers without requiring construction of new combined heat and power plants.
- Reducing heat costs for customers converting from solid fuel heat sources to less polluting sources.
- Reducing heat demand so more customers can be served by existing gas and electric distribution systems.

To fully encourage energy efficiency and exploit the demonstrated savings, the existing system of tariffs, subsidies and payments must be revised so the people who use heat 1) can control their usage, and 2) have an economic incentive to reduce their usage. The project has shown that this is indeed possible without putting a heavy financial burden on the residents. The national and city governments are actively designing and evaluating programs to implement such incentives.

8.0 COMPARISON OF OPTIONS

8.1 COMPARISON METHODOLOGY

There are many different ways in which options for reducing pollution problems caused by the low emission sources can be compared. The approach used in this program is based on a spreadsheet program written under sponsorship of the U.S. Department of energy for making simple comparisons between such options (Hershey and Barta, 1994).

The spreadsheet program for comparing options was written as a screening tool, providing a rapid method of analyzing of many options primarily to aid policy decisions on a city-wide scale. Two important simplifying assumptions are used in the model: 1) constant fuel and electric energy prices over the project's life, and 2) averaged capital costs for conversions between options and other costs averaged for large categories of emission sources. This spreadsheet is not intended for project investment analysis, which must be done on a case-specific basis with energy-price escalation scenarios based on the actual expected project start dates. This second point is especially important in Poland and other Central European countries where energy prices have been changing rapidly. Even with these limitations, the spreadsheet program is a very effective, efficient tool for rapid comparison of options.

In the spreadsheet, all of the low emission sources in the city are placed into categories based on physical characteristics and type of fuel used. This spreadsheet has been developed as a general tool and has been applied to several Central European cities. In the application to Kraków , the low emission sources have been divided into 25 categories. For example, one defined category is hand-fired boilers which burn coke and do not have cyclone particulate collectors. For each such category, information is entered on total current (baseline) fuel use, efficiency, fuel type and cost, air pollutant emission factors, operating costs, and maintenance costs. In Kraków , this information for these categories was derived from surveys made of the boiler and stove populations and also from the engineering cost studies and the source testing program conducted as part of this work.

Some of the categories defined in the spreadsheet are only possible, future options and, in these cases, baseline fuel use is zero. Using the spreadsheet, heating options available to the city can be compared by varying the fuel use assigned to each defined category and tallying the resultant costs and emissions. In this way, future options can be factored into the city's heating mix and compared to current heating methods. For example, one category consists of coal-fired tile stoves with a very substantial current fuel use, and another category consists of the same stoves firing smokeless briquettes which are not yet available in Kraków . Using the spreadsheet, the impacts of using such a candidate alternative fuel in some or all of the home stoves can be evaluated by moving capacity from the coal-fired stove category into the briquette-fired stove category.

In evaluating options using the spreadsheet there are several choices:

1) heating capacity can be changed from one category to another (for example, from hand-fired boilers to gas-fired boilers);

2) the efficiency of boilers or stoves in a category can be increased (by adding economizers to boilers, for example);

3) heat demand and fuel use in a specific category can be reduced through building energy-conservation measures;

4) pollution controls can be added or upgraded in a specific source category.

For each of these choices, the capital costs of the modifications must be input as well as the operating, fuel, and maintenance costs.

Output from a spreadsheet run includes the total emissions for each pollutant and total annual "user" costs (TAUC) before and after the option is implemented. The latter include energy, operating, and maintenance costs.

Capital costs (CC) include direct costs which the end users must pay for implementing the project but generally do not include all infrastructure costs, such as upgrading electrical or gas distribution networks to meet increased demand following conversions. It is assumed that such costs will be met by the utilities and reflect current energy prices. Details on the costs included in this capital conversion cost for specific options are discussed in Section 8.4.

The spreadsheet program provides details of costs and emissions of specific pollutants before and after conversion in tabular and graphical form. It is useful, also, to have a single number which indicates the cost effectiveness of each case being evaluated. To do this, emissions of specific pollutants are first combined into a single "Equivalent Emission" (EE, defined in section 2.2). Conversion or upgrade capital costs then are annualized with the capital recovery factor for a project life of 30 years and an interest rate of 15%. This annualized capital cost then is added to the annual user cost and the result is termed the "user combined cost" (UCC). Finally, for any specific option implemented, the change in user combined cost is calculated per-ton of reduction of equivalent emissions:

$UCC/\Delta EE = -((0.1523*CC + \Delta TAUC)/\Delta EE)$, where Δ means difference of results after and before conversion.

This user combined cost-per-ton of EE reduction is taken as a primary basis for comparing options. In addition to this relative measure of cost effectiveness, it also is necessary to consider the impact of options on total emissions. Options which are highly cost-effective but which do not have substantial impacts on total emissions should not be pursued.

As discussed in Chapter 6 of this report, two different sets of energy price projections have been used in economic analyses in this program. These projections, detailed in Section 6.2, are termed the U.S. DOE forecast and the Polinvest forecast. In the later forecast, current (1992) prices in Poland were taken as a starting point and these were then projected to increase over time. The U.S. DOE forecast takes instead typical, current Western European prices as a starting point as a method of determining price relations which would prevail if all energy price subsidies were removed. The Polinvest projections are most important from the perspective of an individual considering investment in the current climate. The U.S. DOE forecast has the objective of coming closer to free market price relations, which are expected to exist in the future. The U.S. DOE forecast would be more useful in evaluating long term public policy. Results of option comparisons with both sets of price projections are included in the following sections.

8.2 CATEGORIES OF LOW EMISSION SOURCES CONSIDERED IN THE COMPARISON OF OPTIONS FOR KRAKÓW

As already mentioned in Section 8.1, for the spreadsheet model to be adapted for the Kraków conditions, the heating facilities which are sources of low emissions have to be grouped; Table 8-1 lists these categories.

8.3 INPUT ASSUMPTIONS FOR SOURCE CATEGORIES

For each of the heating facilities, the spreadsheet required the following data to be entered:

1) The number of heating facilities, total design output, kind of fuel used, fuel consumption, and the annual operating time. These data were taken from the above-mentioned data bases. The consumption of fuel by home heating facilities was estimated based on the space heated; this information was taken from the home heating systems data base.

2) The average efficiency of the heating facilities, average emission factors for SO_2, CO, CH_4, NO_x, the efficiency of the particulates control systems all were taken from the results of the test program accomplished in Phase I, i.e. the boiler testing (see Sections 2.4 and 2.5 of this report) and the home stove testing (Section 2.1). The only exception is the SO_2 emission factor for boilers fired with coal, coke or a mixture of these fuels; in this case the emission factor was calculated from the formula:

$$SO_2 \text{ [kg/kg of fuel]} = 19.5 \bullet \text{(percent of total sulfur in fuel)}/1000$$

The capital costs of heating facilities were based on the engineering analysis; operating and maintenance costs were based on the Polinvest economic analysis. In preparing this analysis Polinvest used the information obtained from MPEC (Municipal District Heating Utility) and the results of questionnaire-type survey conducted among boiler users.

3) The prices of fuel are based on the fuel price projections developed by Polinvest and DOE with 1996 as a reference year (see Section 6.2 of this report).

Table 8-1. Categorization of Low Emission Sources in Kraków

Item	Source category	Total designed capacity [MW]	Number of units
1	Stoker Coal Boilers >=3 MW with PCE's	224.328	38
2	Stoker Coal Boilers < 3 MW with PCE's	229.798	147
3	Stoker Coal Boilers < 3 MW w/o PCE's	56.519	44
4	Hand-Fired Coal & Coal Blend Boilers with PCE's	17.129	42
5	Hand-Fired Coal & Coal Boilers w/o PCE's	153.683	643
7	Hand-Fired Coal Boilers with PCE's	34.439	42
8	Hand-Fired Coal Boilers w/o PCE's	30.871	188
9	Hand-Fired Coke Boilers with PCE's	3.671	10
10	Hand -Fired Coke Boilers w/o PCE's	214.227	1108
11	Fuel Oil Boilers	5.564	7
12	Diesel Oil Boilers	3.333	7
13	Natural Gas Boilers	76.844	644
14	Home Coal Stoves	199.972	99,986
15	Home stoves with electric inserts	50.934	25,467
16	Natural Gas Home Boilers	277.440	16,320
17	Home Coal Boilers	34.512	4,314
18	Home stoves/ briquettes	0.0	0
19	Stokers >=3 MW / Improved Coal	0.0	0
20	Stokers < 3 MW with PCE's / Improved Coal	0.0	0
21	Stokers < 3 MW w/o PCE's / Improved Coal	0.0	0
22	Hand-Fired Coal Boilers with PCE's / Briquettes	0.0	0
23	Hand- Fired Coal Boilers w/o PCE's / Briquettes	0.0	0
24	Connection to District Heating System	0.0	0
25	Modernized Stokers	0.0	0

Stoker boilers with a design capacity of 3 MW or over, with particulates control equipment.

Based on the above sources of data, it was assumed that boilers of this category are fired with fine coal with a lower heating value of 19.014 MJ/kg, 1.50% total sulfur, and 22.91% ash. The average efficiency of this class of boilers was assumed to be 63% and average emission factors (kg per kg of fuel) are as follows: particulates - 0.0249 (before cyclone), CO - 0.00494, NO_x - - 0.00278, volatile hydrocarbons (CH_4) - 0.000; the calculated SO_2 emission factor is 0.02925 kg/kg of fuel. The efficiency of cyclones was assumed to be 75%. The annual operating time of the facilities is 6756 hours. The price of this kind of fuel, according to the Polinvest projection, was assumed to be US$ 30.9 per metric ton of fuel; according to the DOE projection, the price was 66.88 US$/ton. The capital costs of this kind of boilers were assumed to be 21,887 US$/MW, the operating and maintenance costs were assumed to be 20.8% and 17.6% of the capital costs, respectively.

Stoker boilers with a design capacity below 3 MW, with particulates control equipment.

Based on the same data sources as in the previous category, it was assumed that boilers of this category are fired with the same fuel as stoker boilers with a design capacity of 3 MW and over. The average efficiency of this class of boilers was assumed to be 53% and the average emission factors are as follows: particulates - 0.008420 (before cyclone), CO - 0.020250, NO_x - 0.003536, volatile hydrocarbons (CH_4) - 0.000; the calculated SO_2 emission factor is 0.02925 kg/kg of fuel. The average efficiency of cyclones in this category of boilers was assumed to be 75%. The annual operating time of the facilities is 5633 hours. The capital costs of this kind of boilers were assumed to be 34,676 US$/MW, and the operating and maintenance costs were assumed to be 20.19% and 17.04% of the capital costs, respectively.

Stoker boilers with a design capacity below 3 MW, without particulates control equipment.

Fuel properties, efficiency of boilers, emission coefficients, and operating time are the same as in the previous category. The capital costs of this kind of boiler were assumed to be 31,240 US$/MW, and the operating and maintenance costs were assumed to be 22.4% and 18.9% of the capital costs, respectively.

Hand-fired coal & coke blend boilers, with particulates control equipment.

Based on the above-mentioned data sources, it was assumed that boilers of this category are fired with a mixture of 50% coal and 50% coke. This fuel has a heating value of 25.224 MJ/kg, 1.02% total sulfur, and 8.42% ash. The average efficiency of this category of boilers was assumed to be 65%, and the average emission factors (kg/kg of fuel) are as follows: particulates - 0.00539, CO - 0.074411, NO_x - 0.00116, volatile hydrocarbons (CH_4) - 0.00626; the calculated SO_2 emission factor is 0.01989 kg/kg of fuel. The average efficiency of particulates collecting devices for this category of boilers was assumed to be 70%. The annual operating time of the facilities is 5400 hours. The price of this kind of fuel mixture, according to the Polinvest projection, was assumed to be US$ 70.72 per ton; according to the DOE projection

- the price is 74.71 US$/ton. The capital costs of this kind of boiler were assumed to be 17,691 US$/MW; and the operating and maintenance costs were assumed to be 156.73% and 33.4% of the capital costs, respectively.

Hand-fired coal & coke blend boilers without particulates control equipmnent.

All the data, except those pertaining to costs, are the same as for hand-fired boilers burning the coal/coke mixture, equipped with particulates control systems. The capital costs of this kind of boiler were assumed to be 15,108 US$/MW, and the operating and maintenance costs were assumed to be 183.5% and 39.1% of the capital costs, respectively.

Hand-fired coal boilers, with particulates control equipment.

Based on the above data sources, it was assumed that boilers of this category are fired with coal with a heating value of 28.993 MJ/kg, 0.93% total sulfur, and 9.2% ash. The average efficiency of this category of boilers is 60%, and the average emission factors (kg/kg of fuel) are as follows: particulates - 0.01884, CO - 0.05230, NO_x - 0.0022, volatile hydrocarbons (CH_4) - 0.00409; the calculated SO_2 emission factor is 0.01813 kg/kg of fuel. The average efficiency of particulates collecting devices for this category of boilers was assumed to be 70%. The annual operating time of these boilers is 5448 hours. The price of this kind of fuel mixture, according to the Polinvest projection, was assumed to be US$ 77.62 per ton; according to the DOE projection - the price is 76.60 US$/ton. The capital costs of this kind of boilers were assumed to be 20.883 US$/MW; the operating and maintenance costs were assumed to be 133.1% and 28.36% of the capital costs, respectively.

Hand-fired coal boilers, without particulates control equipment.

Fuel properties, efficiency of boilers, emission coefficients, and operating time are the same as in the previous category. The capital costs of this kind of boiler were assumed to be 18,939 US$/MW; the operating and maintenance costs were assumed to be 146.4% and 31.2% of the capital costs, respectively.

Hand-fired coke boilers, with particulates control equipment.

It was assumed that boilers of this category are fired with coal which has a heating value of 27.49 MJ/kg, 0.91% total sulfur, and 11.1% ash. The average efficiency of this category of boilers is 72%, and the average emission factors (kg/kg of fuel) are as follows: particulates - 0.001512, CO - 0.06999, NO_x - 0.00143, volatile hydrocarbons (CH_4) - 0.00055; the calculated SO_2 emission factor is 0.01774 kg/kg of fuel. The average efficiency of particulates collecting devices for this category of boilers was assumed to be 70%. The annual operating time of the facilities is 5400 hours. The price of this kind of fuel, according to the Polinvest projection, was assumed to be US$ 63.82 per ton; according to the DOE projection, the price is 72.82 US$/ton. The capital costs of this kind of boilers were assumed to be 17,691 US$/MW; the operating and maintenance costs were assumed to be 156.7% and 33.4% of the capital costs, respectively.

Hand-fired coke boilers, without particulates control equipment.

The data pertaining to the fuel, efficiencies of the facilities, and operating time are the same as in the previous category of boilers. The capital costs for this kind of boiler were assumed to be 15,108 US$/MW, and the operating and maintenance costs were assumed to be 183.5% and 39.1% of the capital costs, respectively.

Fuel oil-fired boilers.

Based on the information obtained from the distributor, the oil has a heating value of 41.3 MJ/kg, 1% total sulfur, and 0.01% ash. The average efficiency of this category of boilers is 85%, and the annual operating time is 7396 hours. The average emission factors (kg/kg of fuel) are as follows: particulates - 0.0016, CO - 0.0005, NO_x - 0.0, volatile hydrocarbons (CH_4) - 0.0, SO_2 - 0.0427 kg/kg of fuel. The price of heating oil, according to the Polinvest projection, was assumed to be US$ 337.5 per ton; according to the DOE projection, the price is 327.8 US$/ton. The capital costs of this kind of boilers were assumed to be 52,085 US$/MW; the operating and maintenance costs were assumed to be 32.3% and 6.1% of the capital costs, respectively.

Diesel oil-fired boilers.

Based on a proximate analysis the following characteristics of the light diesel oil were assumed: a heating value of 41.84 MJ/kg, 0.6% total sulfur, and 0.01% ash. The average efficiency of this category of boilers was assumed to be 85%, and the annual operating time is 7200 hours. The average emission factors (kg/kg of fuel) are as follows: particulates - 0.0009, CO - 0.0003, NO_x - 0.0, volatile hydrocarbons (CH_4) - 0.0, SO_2 - 0.0245 kg/kg of fuel. The price of oil, according to the Polinvest projection, was assumed to be US$ 337.5 per ton; according to the DOE projection, the price is 327.8 US$/ton. The capital, maintenance, and operating costs of this kind of boiler were assumed to be the same as for boilers fired with heating oil.

Natural gas boilers.

Boilers of this category are fired with natural gas with a heating value of 35.6 MJ/Nm^3. The average efficiency of this category of boilers was assumed to be 85%, and the annual operating time is 5808 hours. The average emission factors (in kg/Nm^3) are as follows: particulates - 0.0003, CO - 0.003, NO_x - 0.00281, volatile hydrocarbons (CH_4) - 0.0, SO_2 - 0.0. The price of gas, according to the Polinvest projection, was assumed to be US$ 0.216 per Nm^3; according to the DOE projection, the price is 0.327 US$/$Nm^3$. The capital costs of this kind of boilers were assumed to be 52,085 US$/MW; the operating and maintenance costs were assumed to be 32.29% and 6.1% of the capital costs, respectively.

Coal home stoves.

It was assumed that heating facilities of this category are fired with coal which has a heating value of 29.473 MJ/kg, 0.96% total sulfur, and 5.55% ash. The stoves were assumed to burn the fuel with an average efficiency of 55%, and to operate for 5328 hours annually. The average emission factors (kg/kg of fuel) are as follows: particulates - 0.018, CO - 0.0259, NO_x - 0.0055, volatile hydrocarbons (CH_4) - 0.0026, SO_2 - 0.0092. The price of this kind of fuel, according to the Polinvest projection, was assumed to be US$ 77.62 per ton; according to the DOE projection, the price is 76.6 US$/ton. The capital costs for tile stoves were assumed to be 206,727 US$/M; and the operating and maintenance costs are 16.88% and 3.08% of the capital costs, respectively.

Home stoves with electric inserts.

The stoves use electric energy producing 3600 MJ/MWh. A 100% efficiency was assumed and an annual operating time of 5328 hours. They generate no low emission pollutants. The electricity price, according to the Polinvest projection, was assumed to be in 1996 US$ 26.14 US$/MWh; according to the DOE projection, the price will be 42.6 US$/MWh. The capital costs of stoves with electric inserts were assumed to be 324,719 US$/MW. The operating costs were assumed to be zero, and the maintenance costs to be 1.76% of the capital costs.

Natural gas home boilers.

The boilers were assumed to operate with an efficiency of 85%, 5328 hours per year, and to have the same emission factors as gas boilers. The capital costs for home gas-fired boilers were assumed to be 308,295 US$/MW. The operating costs were assumed to be zero and the maintenance costs to be 2.12% of the capital costs.

Home coal boilers.

It was assumed that these boilers are fired with the same coal which is used in tile stoves. The boilers were assumed to burn the fuel with an average efficiency of 60%, and to operate for 5328 hours annually, and to have the same emission factors as in the case of home stoves. The capital costs for coal-fired home boilers were assumed to be 299,818 US$/MW, the operating and maintenance costs 8.13% and 1.52% of the capital costs, respectively.

Home stoves fired with briquettes.

It was assumed that this category of future heating facilities will be fired with briquettes which have a heating value of 27.611 MJ/kg, 0.60% total sulfur, and 11.3% ash. The stoves were assumed to burn the fuel with an average efficiency of 1) 74% and 2) 55%, and to operate for 5328 hours annually. The average emission factors (kg/kg of fuel) are as follows: particulates - 0.00119, CO - 0.0208, NO_x - 0.00179, volatile hydrocarbons (CH_4) - 0.00137, SO_2 - 0.00411. The price of home stove briquettes, according to the Polinvest projection, was assumed to be

US$ 76.38 per ton; according to the DOE projection, the price is 95.75 US$/ton. The capital and maintenance costs were assumed to be the same as for coal-fired home stoves. The operating costs were assumed to be 12.88% of the capital costs.

Stoker boilers, burning improved coal, with a design capacity of 3 MW or over, with particulates control equipment.

The fuel selected for this future category of heating facilities is improved (washed) coal with a heating value of 26.217 MJ/kg, 0.59% total sulfur, and 9.32% ash. The average efficiency of this class of boilers was assumed to be 73% and average emission factors (in kg per kg of fuel) are as follows: particulates - 0.01122 (before cyclone), CO - 0.00139, NO_x - 0.00419, volatile hydrocarbons (CH_4) - 0.0; the calculated SO_2 emission factor is 0.01151 kg/kg of fuel. The efficiency of cyclones in this category of boilers was assumed to be 75%. The annual operating time of the facilities is 6756 hours. The price of this kind of fuel, according to the Polinvest projection, was assumed to be US$ 43.8 per ton of fuel; according to the DOE projection, the price was 94.8 US$/ton. The capital, operating and maintenance costs were assumed to be the same as for stoker boilers with a design capacity of 3 MW or over, with particulates control systems.

Stoker boilers, firing improved coal, with a design capacity below 3 MW, with particulates control equipment.

The fuel selected for this future category of heating facilities is improved (washed and screened) coal with a heating value of 26.840 MJ/kg, 0.72% total sulfur, and 6.05% ash. Boilers of this category were assumed to operate with an average efficiency of 73% for 5633 hours annually. The average emission factors (in kg/kg of fuel) are as follows: particulates - 0.001586, CO - 0.017867, NO_x - 0.00348, volatile hydrocarbons (CH_4) - 0.0; the calculated SO_2 emission factor is 0.01404 kg/kg of fuel. The average efficiency of cyclones for this category of boilers was assumed to be 75%. The price of this kind of fuel, according to the Polinvest projection, was assumed to be US$ 43.8 per ton of fuel; according to the DOE projection, the price was 94.8 US$/ton. The capital, operating, and maintenance costs were assumed to be the same as for stoker boilers with a design capacity below 3 MW, with particulates control systems.

Stoker boilers fired with improved coal, with a design capacity below 3 MW, without particulates control equipment.

All data, except the costs, are the same as in the previous category. The capital, operating and maintenance costs are the same as for stoker boilers with a design capacity below 3 MW, without particulates control systems.

Hand-fired boilers burning briquettes, with particulates control equipment.

These boilers are fired with briquettes with a heating value of 26.787 MJ/kg, 0.62% total sulfur, and 13.1% ash. The average emission factors (kg/kg of fuel) are as follows: particulates -

0.00185, CO - 0.0416, volatile hydrocarbons (CH_4) - 0.0019, NO_x - 0.00099, SO_2 - 0.0025. The same prices of briquettes (according to both projections) were assumed as for briquettes to be used in tile stoves. The boilers, were assumed to operate with an average efficiency of 71% for 5448 hours annually. The average efficiency of cyclones was assumed to be 70%. The capital, operating and maintenance costs are the same as for hand-fired boilers burning coal, equipped with particulates control systems.

Hand-fired boilers burning briquettes, without particulates control equipment.

All the data, except those pertaining to costs, are the same as for boilers of the previous category. The capital, operating, and maintenance costs are the same as for hand-fired boilers burning coal, without particulates control systems.

Connection to the district heating system.

This category replaces a portion of the solid-fuel-fired boiler category. The "fuel" for this category is heat supplied by the municipal district heating network. The heat-price projection for 1996 is 0.00632 US$/MJ according to Polinvest, and 0.01368 US$/MJ according to DOE. It was assumed that heat will be supplied by the municipal district heating network for 5633 hours, without causing pollution classified as low emissions. The capital costs of connecting the boiler houses to the municipal district heating network were estimated to be 88,412 US$/MW and operating and maintenance costs were assumed to be zero (included in the price of heat).

Modernized stokers.

This is a future category of stoker boilers. They were assumed to be modernized according to the RPF option for the Krzesławice boiler house (fluidized bed boilers, Polish equipment see Section 3.5). It was assumed that the boilers will be fired with the same kind of fuel as in other categories of stoker boilers. The boilers were assumed to operate with an average efficiency of 80% for 5633 hours annually. The following average emission factors (in kg/kg of fuel) were assumed: particulates -0.001714, CO - 0.00025, NO_x 0.00323, volatile hydrocarbons (CH_4) - 0.0, SO_2 - 0.0038. The average efficiency of particulates collecting devices was assumed to be 75%. The capital costs for this category of boilers were assumed to be 86,090 US$/MW; the operating, and maintenance costs are 35.43% and 17.72% of the capital costs, respectively.

8.4 COMPARISON OF RESULTS OF OPTIONS

Table 8-4 presents the results calculated using the spreadsheet model for various options of the heating systems conversion. To compare the options in terms of environmental effects (per cent of the equivalent emissions eliminated) and in terms of environmental/cost benefits (user combined cost per ton of equivalent emission reduced) such options were compared in which 100% of the group's capacity was converted (boilers with and without particulates control systems were considered as belonging to the same category). Only such options were considered

Table 8-2. Assumptions Regarding Capital Costs of Various Options of Conversion

Type of conversion	Region of Kraków	Cost, US$/MW
Conversion of home stoves to electric heating	Łobzów	227,000
	Old Town	138,000
	Average cost for the whole city	151,000
Conversion of home stoves to natural gas home boilers	Old Town	308,400
	Area within II ring	320,600
	Average cost for the whole city	320,600
Conversion of home coal boilers to natural gas home boilers	Average cost for the whole city	118,500
Conversion of hand-fired boilers (all categories) to natural gas boilers	Old Town	125,000
	Area within II ring	132,000
	Average cost for the whole city	125,500
Connection to the district heating system	Average cost for the whole city	88,400
Modernization of stoker boilers	Average cost for the whole city	244,000

The annual atmospheric emissions of pollutants from the existing sources of low emissions (so-called baseline option) are presented in the Table 8-3, below:

Table 8-3. Emissions of Pollutants - Baseline Option

SO_2 ton/year	particulates ton/year	CO ton/year	Volatile hydrocarbons (CH_4) ton/year	NO_x ton/year	Equivalent emissions ton/year
10508	3541	14868	741	1635	32952

which, based on the analyses in Phase I of the American-Polish Program, proved applicable for Kraków and could clearly result in a reduction of low emissions.

The following options were considered in calculations, using Polinvest and DOE fuel price projections:

1 - conversion of coal-fired home stoves to stoves with electric inserts
2 - conversion of coal-fired home stoves to home gas boilers
3 - conversion of coal-fired home stoves to briquette-fired home stoves with 74% efficiency of combustion
4 - conversion of coal-fired home stoves to briquette-fired home stoves with 55% efficiency of combustion
5 - conversion of coal-fired home boilers to gas-fired home boilers
6 - conversion of hand-fired coal boilers to natural gas boilers
7 - conversion of hand-fired coke boilers to natural gas boilers
8 - conversion of hand-fired coal & coke blend boilers to natural gas boilers
9 - connection of hand-fired coal boilers to the Municipal District Heating System
10 - connection of hand-fired boilers burning coke to the Municipal District Heating System
11 - connection of hand-fired boilers burning coal and coke blend to the Municipal District Heating System
12 - connection of stoker boilers with a capacity of 3 MW or over to the Municipal District Heating System
13 - connection of stoker boilers with a capacity below 3 MW to the Municipal District Heating System
14 - modernization of stoker boilers with a capacity of 3 MW or over
15 - modernization of stoker boilers with a capacity below 3 MW
16 - using improved fuel in stoker boilers with a capacity of 3 MW or over
17 - using improved fuel in stoker boilers with a capacity below 3 MW
18 - using briquettes in hand-fired boilers burning coal
19 - using coke in hand-fired boilers burning coal & coke blend

Table 8-4 summarizes the results of these 19 conversion options. Figures 8-1 and 8-2 rank the options (beginning from the best one, in terms of "user combined cost" per ton reduction in reduction in emissions). The graphs show clearly that for both price projections the most cost effective options are converting to fuel of higher quality, as this solution does not involve any capital costs. Also, conversion of coal-fired home stoves to electric heating is a very economical option.

Table 8-4. Results of Option Comparison for Polinvest's and DOE's Fuel Price Forecast

Option	User Combined Cost per ton of annual reduction in equivalent emissions [$/t/year]		Reduction in annual emissions in tons and % of total											
	Polin-vest's prices	DOE's prices	S02		Particu-lates		CO		Volatile Hydro-carbons		NOx		Equivalent emission	
			t	%	t	%	t	%	t	%	t	%	t	%
1.Conversion of home stoves to electric heating	98	930	782	7.44	1530	43.21	2201	14.81	221	29.83	467	28.56	7674	23.29
2. Conversion of home stoves to natural gas home boilers	961	1721	782	7.44	1516	42.81	2188	14.72	221	29.8	340	20.79	7258	22.02
3. Conversion of home stoves to briquettes - 74% efficiency	-507	-279	505	4.80	1450	40.95	802	5.39	129	17.36	346	21.16	6114	18.55
4. Conversion of home stoves to briquettes - 55% efficiency	-237	94	409	3.89	1422	40.16	318	2.14	97	13.05	305	18.65	5576	16.92

Table 8-4. Results of Option Comparison for Polinvest's and DOE's Fuel Price Forecast (con't.)

Option	User Combined Cost per ton of annual reduction in equivalent emissions [$/t/year]		Reduction in annual emissions in tons and % of total											
	Polin-vest's prices	DOE's prices	S02		Particu-lates		CO		Volatile Hydro-carbons		NOx		Equivalent emission	
			t	%	t	%	t	%	t	%	t	%	t	%
Conversion of home coal boilers to natural gas home boilers	630	1407	122	1.16	236	6.66	341	2.29	34	4.65	51	3.12	1125	3.41
Conversion of hand-fired coal boilers to natural gas boilers	958	1842	586	5.58	333	9.40	1683	11.32	132	17.81	19	1.16	2448	7.43
Conversion of hand-fired coke boilers to natural gas boilers	1402	2637	918	8.74	67	1.89	3612	24.29	28	3.84	-21	-1.28	2857	8.67

Table 8-4. Results of Option Comparison for Polinvest's and DOE's Fuel Price Forecast (con't.)

Option	User Combined Cost per ton of annual reduction in equivalent emissions [$/t/year]		Reduction in annual emissions in tons and % of total											
	Polin-vest's prices	DOE's prices	S02		Particu-lates		CO		Volatile Hydro-carbons		NOx		Equivalent emission	
			t	%	t	%	t	%	t	%	t	%	t	%
Conversion of hand-fired coke & coal blend boilers to natural gas boilers	708	1565	1033	9.83	247	6.97	3857	25.94	325	43.86	-19	-1.16	3623	10.99
Connection of hand-fired coal boilers to DHS	-105	1487	586	5.58	338	9.55	1688	11.35	132	17.81	71	4.34	2616	7.94
Connection of hand-fired coke boilers to DHS	-387	1848	919	8.75	77	2.17	3622	24.36	28	3.84	73	4.46	3165	9.60
Connection of hand-fired coke & coal blend boilers to DHS	-447	1115	1034	9.84	255	7.20	3866	26	325	43.87	60	3.67	3880	11.78

Table 8-4. Results of Option Comparison for Polinvest's and DOE's Fuel Price Forecast (con't.)

Option	User Combined Cost per ton of annual reduction in equivalent emissions [$/t/year]		Reduction in annual emissions in tons and % of total											
	Polin-vest's prices	DOE's prices	S02		Particu-lates		CO		Volatile Hydro-carbons		NOx		Equivalent emission	
			t	%	t	%	t	%	t	%	t	%	t	%
Connection of stokers >=3MW to DHS	953	1855	3212	30.57	685	19.34	543	3.65	-	-	305	18.65	6354	19.28
Connection of stokers <3MW to DHS	586	1244	3740	35.59	398	11.24	2589	-	-	-	452	27.65	7499	22.76
Moderniza-tion of stokers >=3MW MW	3138	2973	2884	27.45	648	18.3	521	3.51	-	-	25	1.53	5096	15.47
Moderniza-tion of stokers <3MW	2897	2652	3416	32.51	362	10.22	2568	17.27	-	-	177	10.83	6263	19.01
Improved fuel in stokers >=3MW	-93	-201	2422	23.05	492	13.89	447	3.01	-	-	16	0.98	4119	12.50

Table 8-4. Results of Option Comparison for Polinvest's and DOE's Fuel Price Forecast (con't.)

Option	User Combined Cost per ton of annual reduction in equivalent emissions [$/t/year]		Reduction in annual emissions in tons and % of total											
	Polin-vest's prices	DOE's prices	S02		Particu-lates		CO		Volatile Hydro-carbons		NOx		Equivalent emission	
			t	%	t	%	t	%	t	%	t	%	t	%
Improved fuel in stokers <3MW	-288	-624	2812	26.76	372	10.51	1407	9.47	-	-	230	14.07	5262	15.97
Briquettes in hand-fired coal boilers	-1488	-1469	511	4.86	284	8.02	460	3.09	76	10.24	41	2.51	1684	5.11
Coke in hand-fired coke & coal blend boilers	-626	-483	270	2.57	196	5.54	854	5.74	301	40.68	-2	-0.12	1259	3.82

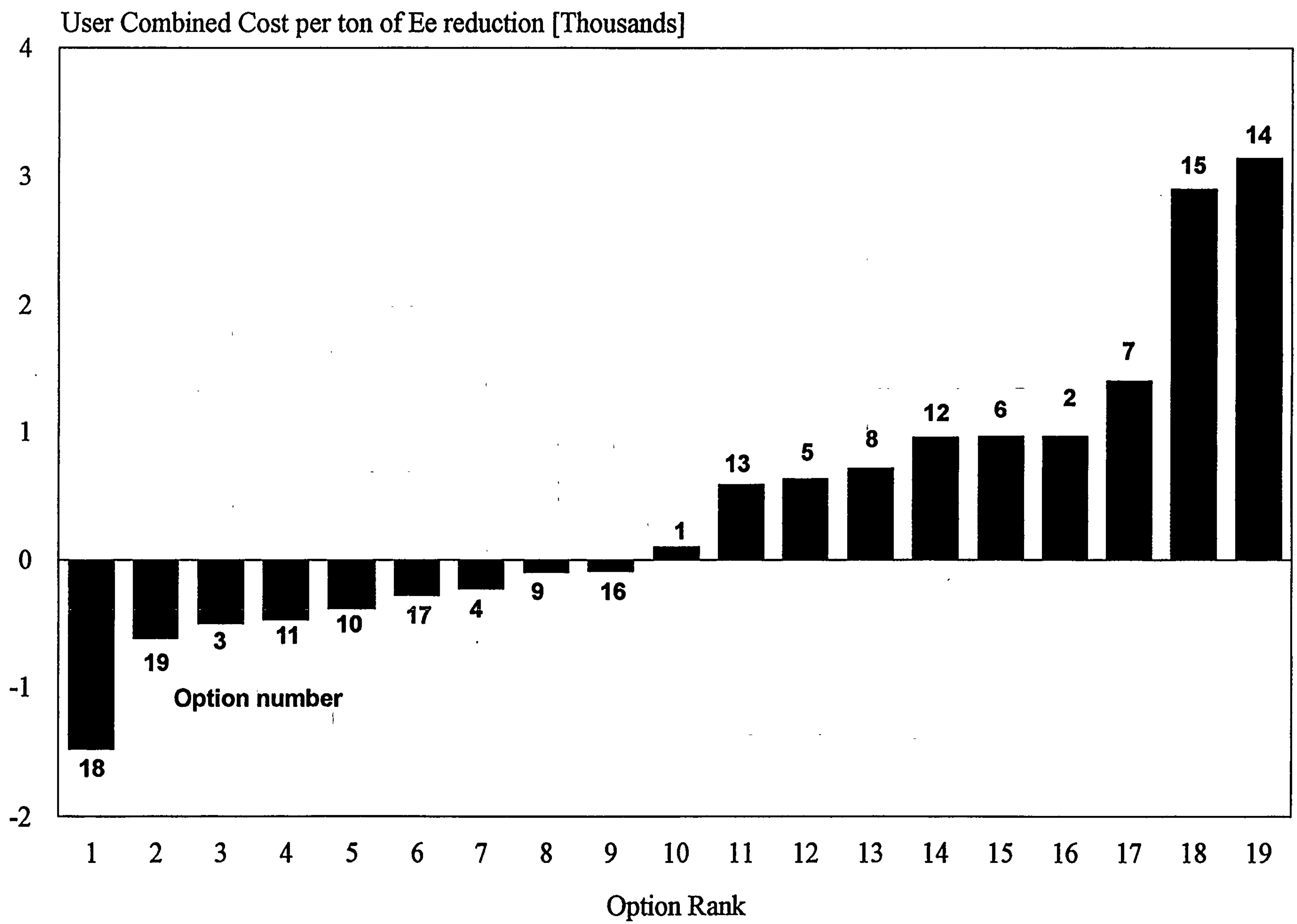


Figure 8-1. Comparison of options using energy price forecast prepared by Polinvest

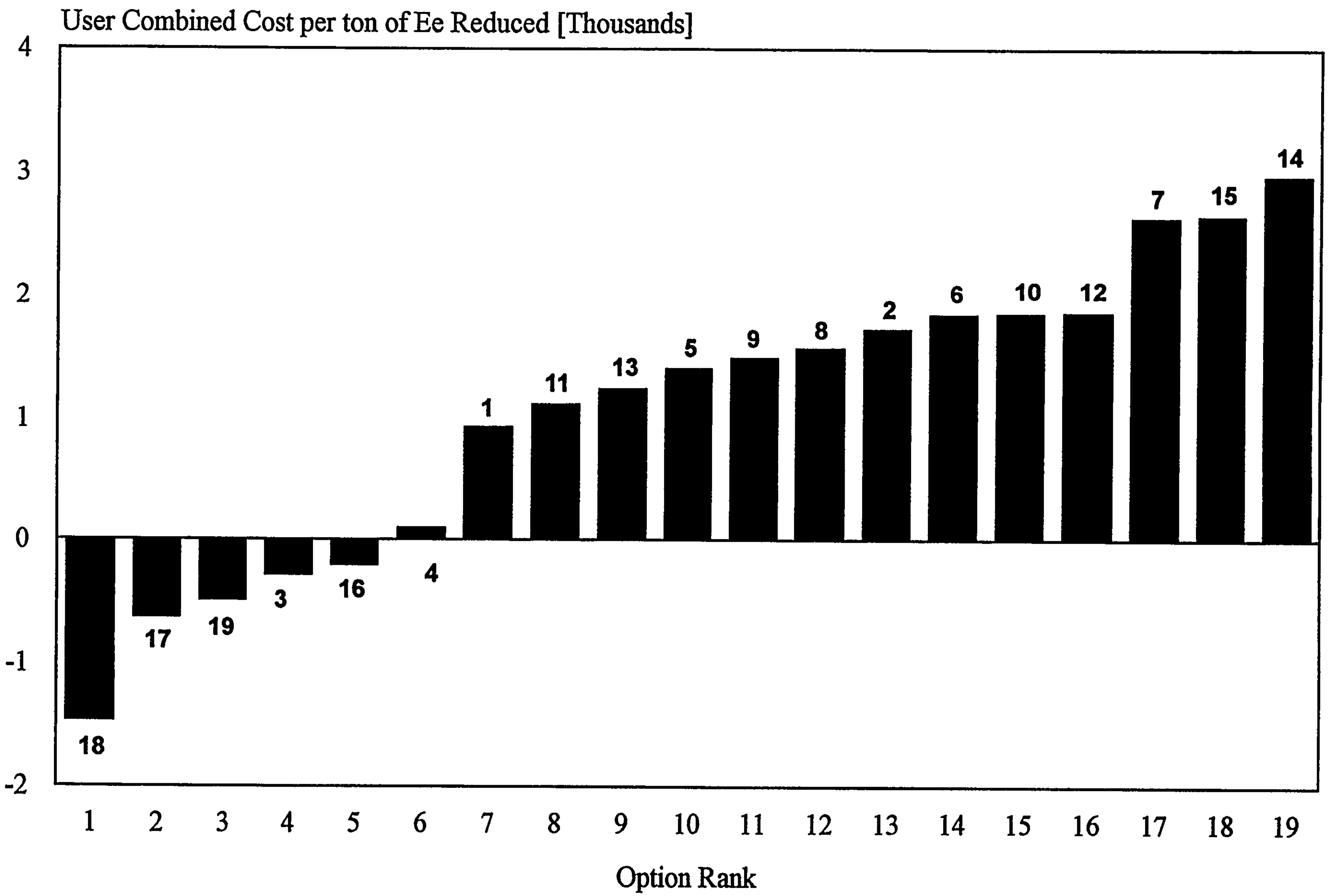


Figure 8-2. Comparison of options using energy price forecast prepared by DOE

8.5 ILLUSTRATION OF THE USE OF THE SPREADSHEET TO COMPARE COMPLETE SCENARIOS FOR THE CITY

The spreadsheet model can also be used to calculate complete scenarios or combinations of options for fully eliminating low emissions in Kraków. The first scenario (Scenario I) consists of the following conversions:

1. Elimination of home coal-fired heating facilities.

   This option consists in converting 45.72% of the home stoves to electric heating; the remaining portion (44.78%) would be converted to gas heating (the percentages reflect the numbers of stoves located in the areas planned for conversion to gas and electric heating). All coal-fired home boilers would be converted to gas-fired boilers.

2. A portion of solid-fuel hand-fired boilers (113.74 MW) would be converted to gas boilers.

   Conversion to gas would cover 25.29% of hand-fired coal & coke blend boilers (with a combined capacity of 43.2 MW), 24.34% of hand-fired coal boilers (with a combined capacity of 15.9 MW), and 25.1 % of hand-fired coke boilers (with a combined capacity of 54.64 MW).

3. Connecting a portion of the solid-fuel-fired boiler houses (466.44 MW) to the municipal district heating system.

   This project consists of several sub-options:

   Connecting to the municipal district heating system: 9.64% of stoker boilers with a capacity of 3 MW or over (with a combined capacity of 21.63 MW), 38.43% of stokers with a capacity below 3 MW (with a combined capacity of 110.04 MW), 74.71% of hand-fired coal & coke blend boilers (with a combined capacity of 127.61 MW); and 67.22% of hand-fired coal boilers (with a combined capacity of 163.26 MW).

   As in the previous cases, all the data were calculated using the design capacities of the boiler selected for connection to the municipal district heating system.

4. Modernization of a portion of solid-fuel-fired boiler houses (with a combined capacity of 324.46 MW).

   These categories of boilers would be modernized as follows: 84.65% of stoker boilers with a capacity of 3 MW or over (with a combined capacity of 189.91 MW), and 46.99% of stokers with a capacity below 3 MW (with a combined capacity of 134.55 MW)

5. The remaining portion of solid-fuel-fired stoker boilers would use improved coal, and hand-fired coal boilers will use briquettes.

The results of calculating these conversion options are presented in Table 8-5.

The approach described above (Scenario I), represents a full elimination of the low emission sources. Under this scenario, all home stoves would be converted to either gas or electric heating, hand-fired boilers would be converted to gas or connected to the district heating system, and some of the larger, stoker-fired boiler houses would be modernized (new boilers and pollution controls).

In the second example of combined options, Scenario II, all of the home stoves would use briquettes, some of the hand-fired boilers would be connected to the district heating system, the remainder of the hand-fired boilers would use briquettes or coke, and the stoker-fired boiler houses would use improved fuels and operations.

Scenario III represents an example that involves no user capital costs. Home stoves would use briquettes, and boilers would use improved fuels, briquettes or coke.

The point of this comparison is to show how the spreadsheet can be useful in comparing total-city scenarios. Table 8-6 compares results from these three examples. Total elimination of the low sources, Scenario I, which was an approach considered very attractive to the city at the beginning of this program, involves very high capital costs. Scenarios II and III suggest that large emission reductions can be achieved with fuel- and operations-related intermediate measures. Many of the Phase 3 projects, involving U.S./Polish commercial joint ventures now in progress, target these lower cost opportunities. See Section 1.4 for a discussion of the program phases.

Table 8-5. Calculations of One Scenario for Eliminating Low Emission in Kraków

Option	Capital cost $	Reduction in annual emission in tons and % of total											
		SO2		Particulates		CO		Volatile hydrocarbons		NOx		Equivalent emission	
		t	%	t	%	t	%	t	%	t	%	t	%
Elimination of home coal heating systems	52,695,995	903	8.59	1759	49.67	2535	17.05	255	34.41	449	27.46	8574	26.02
Conversion of solid fuel boilers natural gas boilers	14,285,415	634	6.03	160	4.52	2292	15.41	121	16.39	-6	-0.37	2226	6.76
Connecting solid fuel boilers to DHS	41,233,061	3600	34.26	695	19.63	7783	52.35	353	47.62	351	21.47	10525	31.94
Modernization of stokers	79,161,899	4046	38.5	718	20.28	1648	11.08	-	-	105	6.42	7257	22.02
Change of fuel	-	592	5.63	108	3.05	270	1.81	6	0.86	38	2.32	1150	3.49
All above conversions (Scenario I total)	187,385,454	9775	93.02	3441	97.18	14527	97.71	736	99.33	938	57.37	29732	90.23

Table 8-6. Spreadsheet Example Results

Scenario	Capital Cost ($)	Increase in Annual User Costs ($)	Emission Reductions (%)					Capital cost per ton of Equivalent Emission Reduced ($)	User Combined cost per ton of Equivalent Emission Reduced ($)
			SO2	Particulates	CO	NOx	Equivalent Emissions		
I	187,000,000	21,000,000	93	97	98	57	90	6302	1667
II	41,000,000	3,000,000	79	84	69	53	74	1683	388
III	0	-9,000,000	62	80	27	39	56	0	-481

9.0 CONCLUSIONS AND RECOMMENDATIONS

1. The permissible annual average air-pollution concentrations often are exceeded in Kraków, especially in the central area of the city. According to available monitoring data, the annual average concentrations of suspended particulates and sulfur dioxide in the Kraków Center in recent years were as follows:

YEAR	PARTICULATES, $\mu g/m^3$ (Permissible Concentration 50 $\mu g/m^3$)	SO_2, $\mu g/m^3$ (Permissible Concentration 32 $\mu g/m^3$)
1987	110	119
1988	81	91
1989	74	84
1990	64	75
1991	57	85
1992	52	75
1993	45	57
1994	41	42

As these data indicate, air quality in Kraków has improved considerably in recent years. Most of this improvement comes from the economic recession and the closing of parts of Kraków's steelworks.

The calculations done as part of the program demonstrated that low emission sources contribute only 35 - 40% of the total pollution. The remaining part is due to :

- vehicular traffic (cars, buses)
- emissions from high sources (stacks)
- inflow from other regions

Eliminating of low emission sources will considerably, though not completely, improve air quality in Kraków.

2. Considering the amount of fuel used and the results of these emissions studies, the most harmful sources of low emissions are home stoves which are responsible for a high contribution to particulate emissions (they account for over 40% of the total particulates emissions). The harmful effect of the tile stoves recently has increased by burning cheaper, lower quality coals (with higher content of sulfur, ash, and volatiles). In addition, various plastic, rubber, and other wastes are burned in the stoves.

3. It is technically possible to totally eliminate stove heating in houses by:

   a) Connecting the buildings to the municipal district heating network, which would require fitting internal heating installations in the buildings, in addition to laying the heating network and installing heat exchangers.

   b) Using low (night-time) tariffs for electric heating, either by retrofitting tile stoves with electric inserts or by installing new electric thermal-storage heaters.

   c) Using gas-heating systems, most often in individual apartments, which would involve installing a gas boiler and the heating installations in the apartments.

   Stove-heated buildings are very rarely connected to the municipal district heating network throughout the entire area of the city due to the high capital costs involved.

   The use of gas heating in individual apartments is a more common solution. Converting from stove heating to gas heating is done in some 500 apartments annually. The basic obstacle to accelerating this course of action is the cost. The fuel cost for gas is higher than coal, and it is expected to rise further as subsidies on natural gas are phased out. The capital cost of conversion can be as high as $4,000 per apartment, based on the results of engineering studies conducted as part of this program.

   The most common conversion for stoves is electric heating (retrofitting the existing stoves with electric coils); the costs are up to US$ 1,000, and some 1,500 apartments are converted to electric heating annually. Eliminating stove heating by conversion to electric heating is hindered by the insufficiency of the city's electric infrastructure. In some areas of Kraków, applicants for electric heating are not granted the so-called "electric power allocation". To eliminate 100% of the stoves by converting them to electric heating, the Electricity Distribution Utility would have to invest about US$ 10 million to modernize its system.

4. Due to the high conversion and heating costs, some form of incentive would be required if the City chose to promote the replacement of tile stoves with gas or electric heating. Current regulations make direct financial assistance impossible and they could be modified. Kraków municipal authorities already have undertaken actions to change the relevant regulations; also, there is an opportunity to obtain funds from the Gmina's (local) Environmental Protection Fund. A questionnaire-type survey demonstrated that

many tile stove users are willing to replace them with electric or gas heating, if the cost is not excessive.

5. It does not appear possible to eliminate coal stove heating in Kraków in the near-term. Temporary solutions should be adopted which would significantly reduce the emissions from the still-existing coal-fired stoves:

   - Removing the worst stove coals from the market by imposing a ban on the sale such coals; for example, by licensing the sale of solid fuels. Only coals with sulfur, ash and volatiles contents below predetermined limits would be acceptable for sale. These limits will need to be determined, based on the standard combustion tests developed as part of the program.

   - Popularizing the most economical procedures for firing. Multi-option tests of burning various kinds of fuel demonstrated that stove combustion can be improved, mainly by controlling the access of air to the combustion chamber; this increases the efficiency of an average stove by 15% - 20%, with lower coal consumption and the resultant decrease in emissions of pollutants. The optimum firing procedure could be introduced by having the licensed coal sellers inform their customers, for instance.

   - Making available for sale various kinds of environmentally friendly fuels, including smokeless briquettes. Tests conducted under the program demonstrated that using smokeless briquettes or coke with a low volatile content decreases emissions of particulates 12 - 15 times, compared to the emissions from firing best quality coals. Also, SO_2 emissions from firing the briquettes is about 50% lower than from firing good coal. The adoption of the new firing procedure and replacing coal with briquettes is the optimum method of reducing emissions as this does not involve any capital costs for conversion.

6. Quantitatively, the greatest amount of pollutants is generated by burning solid fuels in boilers. The survey conducted in Kraków in 1990 - 1991 revealed that there are 1,133 boiler houses fired with solid fuel (duf, coal, coke, coal/coke mixture) with a combined capacity of 996 MW. The boiler houses used 375,000 tons of fuel per year, consisting of:

   - 230,000 tons of duf,
   - 57,000 tons of coal, and
   - 88,000 tons of coke.

   Two groups of boilers can be separated with regard to their effects on protecting the atmosphere:

- Hand-fired boilers made of steel (designed to be fired with coal) or made of cast-iron (designed to be fired with coke); these boilers have virtually no equipment for protecting the atmosphere. They are installed in boiler rooms, most often providing heat to one building and less often to several buildings. In the central area of the city, all boilers are of the hand-fired kind.

- Stoker boilers, designed to fire pea-size graded coal; for the most part, these are equipped with particulates-collecting devices (cyclones, multicyclones). Unfortunately, these boilers are usually fired with "raw", ungraded duf. Boiler houses with stoker-fired boilers are situated outside the central area of the city and supply heat to larger groups of buildings. These boiler houses operate as suppliers of space heat, space heat and process steam, or process steam.

Solid fuel-fired boiler houses in the central area of Kraków should be eliminated. However, a portion of solid fuel-fired boiler houses will operate for many years; thus, it is necessary to find ways of reducing their environmental nuisance.

7. Cast-iron boilers which are designed to fire coke should be fired only with coke. They should not be fired with a coal/coke mixture as then the equivalent emissions increase by about 36% relative to coke.

8. Hand-fired steel boilers which are designed to be fired with coal are characterized by high emissions of pollutants (the equivalent emission is higher by 60% than for cast-iron boilers fired with coke). The emissions from this group of boilers can be reduced by replacing coal with smokeless briquettes - the equivalent emissions drop by 63% and the emissions of particulates drop from 650 g/GJ to 69 g/GJ.

9. The stoker-fired boilers tested operated with much lower efficiencies (about 50% - 60%) than are technically attainable. As these tests showed, their efficiency can be improved to 75%, and their equivalent emissions reduced from 2,000 g/GJ to 1,000 g/GJ, that is by 50%, by improving the operating procedure and using washed and graded coal. Additional ways to improve their efficiency and reduce emissions can be effected by controlling and optimizing the combustion process.

10. Energy can be conserved in all parts of the heating system as well as at end users. The biggest and most quantifiable energy savings can be achieved at the heat consumers by insulating the buildings, installing measurement and temperature-control devices in the spaces heated, and charging the individual for the heating used. The energy conservation program demonstrated that such savings can be higher than 30%; this would amount to savings of 400 - 500 MW in the municipal district heating system supplied from the heat and power plant.

11. Surplus heat capacity in the central heat sources would permit more than half of the existing boiler houses to be eliminated by connecting them to the municipal district heating network; 635 boiler houses with a combined capacity of 450 MW could be eliminated throughout the whole city.

12. The gas supply system in the Old Town has sufficient capacity to allow replacing coal- and coke-fired boiler houses with gas-fired boiler houses. To supply gas to such boiler houses located in the remaining parts of the central area of Kraków between 1st and 2nd ring, the gas infrastructure needs modernizing; however, the capital cost required are within the financial capacity of the Gas Utility in Kraków. The necessary modernization can be accomplished within several years.

13. To eliminate or significantly reduce low emissions in Kraków various actions can be undertaken:

- Employ improved operating procedures for stoves and boilers.
- Use fuel of higher quality in stoves and boilers.
- Connect coal- and coke-fired boiler houses to the municipal district heating network.
- Replace coal- and coke-fired boilers with gas boilers.
- Modernize boiler houses, especially hand-fired boiler houses, and use all technically possible methods to increase their efficiency and reduce their emissions.
- Eliminate coal-fired tile stoves, replacing them by electric or gas heating.

The attractiveness of these options strongly depends upon the location within the city. While general comparisons can be made, site-specific studies must be done to support local decisions.

14. The following are the unit capital costs (per 1 kW capacity) required to implement various options of low emissions sources conversion, averaged for the area of the whole city:

• Connect boiler-houses to the municipal district heating network	US$ 90 kW
• Convert coal-fired home stoves to gas boilers	US$ 120 kW
• Convert coal- and coke-fired DH boilers to gas-fired boilers	US$ 125 kW
• Convert coal-fired stoves to electric heating	US$ 150 kW
• Modernize stoker-fired boiler houses fully	US$ 245 kW
• Convert coal-fired home stoves to gas heating	US$ 320 kW

15. As part of the program, a spreadsheet-based model was developed as a tool to quickly analyze the economic and environmental efficiency of many possible options. Despite

simplifying assumptions made in preparing data for the model and in constructing the model, the results of the analyses can be useful in contributing to decisions about energy policy at the city level.

The model includes a quantity, "user combined cost", - which is defined as the annualized capital cost of a given conversion option over the project's lifetime, including the interest rate of the investment credit and the user's annual costs after and before (baseline costs) conversion (the difference in fuel, operating, and maintenance costs). User combined cost is normalized to a unit (1 ton) decrease in the equivalent emissions due to that conversion option. This is an attempt to use a criterion that takes into account the total capital costs necessary to implement the option, the pre- and post-conversion differences in operating and maintenance costs borne by the user, and the environmental effectiveness of the measures undertaken. Using such a criterion, calculated with the spreadsheet model, the following list ranking the measures aimed at eliminating or reducing low emissions was established (starting from the most effective one):

- Using improved fuel.
- Connecting to the municipal district heating network.
- Converting of coal-fired tile stoves to electric heating.
- Converting of solid fuel-fired tile stoves to gas heating.
- Converting of coal-fired tile stoves to gas heating.
- Completely modernizing stoker-fired boilers.

16. Using the spreadsheet-based model, a general long-term concept was studied of activities that could be undertaken to greatly reduce low emissions in Kraków:

- Replacing heating by coal stoves with electric or gas heating.
- Replacing small solid fuel-fired boilers in individual apartments (or single family houses) with gas-fired boilers.
- Replacing all solid fuel-fired boilers in the Old Town area with gas-fired boilers, consequently leaving no solid fuel-fired heating facilities there.
- Replacing solid fuel-fired boilers in the remaining part of Kraków's central area (between 1st and 2nd ring) in part with gas-fired boilers or eliminating them by connecting them to the municipal district heating network, consequently, leaving no solid fuel-fired boilers in this part of Kraków.
- Connecting gas boiler houses and the heating part of heat and process heat/steam boiler houses to the municipal district heating network in the area outside the city center that is covered by the network. Boiler houses which supply process steam will continue to burn solid fuel but will be modernized.
- Using improved fuels in boiler houses situated at the city outskirts beyond the extent of the municipal district heating network; these are considered to be a lesser nuisance for the environment and their emissions can be reduced in this way.

It will take many years and a large capital investment to reach these goals. In the near term, options should be selected which involve no capital costs, that is firing stoves and hand-fired steel boilers with smokeless briquettes, firing hand-fired cast iron boilers with coke, and firing stoker-fired boilers with washed and graded coal.

17. One example concept of totally eliminating low emissions was analyzed with the spreadsheet-based model. The following are the most important results of the calculations:

- The investment costs required to implement the options in the concept amount to US$ 190 M.
- The equivalent emissions will be reduced by about 90%, particulates by 97% and SO_2 by 93%.
- Eliminating stoves and coal-fired boilers for heating apartments will reduce the equivalent emissions by about 26% and particulates emissions by about 50%.

Other low-cost concepts were also evaluated using the spreadsheet and were shown to be very attractive. These examples showed that with low or no capital investment, emissions can be significantly reduced. Simply by using better fuels, for example, SO_2 emissions could be reduced by 62% and particulate emissions by 80%.

18. Experiences gained in the recent several months may have some effect on small modifications to the general concept of elimination of low emissions sources.

- An important factor is a decision by the Municipal District Heating Utility (MPEC) to operate the DH network round the year, beginning from the 1995 - 1996 heating season, instead of restricting the operation to the heating season as has been the practice. This decision could mean eliminating those boiler houses which produce domestic hot water by connecting them to the municipal network.

- The part of the central area of the city that is accessible to the DH network is increasing. The use of "bare" DH network (without tunnels) is gaining popularity; it permits penetration of the city's central areas with dense housing and the underground infrastructure.

- The natural gas supply that is easily available outside the city center could result in converting some boiler houses to gas, instead of modernizing them.

- A costly complete modernization of big, coal-fired boiler houses could be replaced with the effective technologies offered by American companies operating in Kraków. Instead of installing fluidized-bed boilers, these companies offer complete control and automation of combustion, recovery of flue-gas heat, and efficient air protection equipment, which can give similar results at lower capital costs. A detailed concept will be developed in the master plan for low emissions elimination, undertaken by the Kraków Development Office.

19. With current price trends of energy carriers and the operating and capital costs, conversion of heating systems imposes high cost burdens on users. The City will need to implement some type of incentives program for almost all those who change their heating system. This could involve direct financial assistance. The regional authorities, municipal authorities, and distributors of fuel energy are in a position to provide such assistance. It will be necessary to change some legal regulations so that such assistance can be given to individuals. Currently, prices of gas and electric heat are considered low in Poland. If conversions are delayed and future prices come in line with Western European prices, the subsidy levels required will increase significantly.

20. A further decrease in low emissions in Kraków is feasible. In ten to twenty years, the issue of low emissions from energy-generating sources should no longer be one of the most serious environmental problems facing the city.

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APPENDIX 1. LIST OF REPORTS

This appendix lists all the reports that have been prepared during Phase I of the Krakow Clean Fossil Fuels and Energy Efficiency Program. The reports are listed by Subproject and task number. English-language versions of most reports are available from Brookhaven National Laboratory.

Task

Subproject 1 - District Heat

1.1.1 Conception for Elimination of Solid Fuel Fired Boiler Houses by Connecting Them to Municipal Heating Network, Volume I, BRK, June 1992.
Volume II, December 1992.
Volume III, December 1992.

1.1.6 Evaluation of Air Quality Improvement in Local and Regional Scale Expected as a Result of Switching the Local Boiler Houses Existing at Present to the central Heating Network, EKOPOL, June 1993.

1.1.6 App. 1 Calculation of sulphur dioxide concentration caused by the group of boiler houses provided for liquidation; App. 2 Evaluated increase in sulphur dioxide concentration related to the increase inpower demand in the centralized district heating sources, EKOPOL, nd.

1.2.1 Analysis and Prognosis of Possibly Increase in District Heat Prices, and Possible Timing of These Increments
1.2.2 Analysis of Legal Possibilities of Introducing by MPEC Local Prices for District Heat, Together with Prognosis Concerned
1.2.4 Cost Analysis of Heating from District Heating Network Versus Existing Boiler-Houses Heating
1.2.5 Cost-Effective Analysis of Heat Distribution in EC Leg Concerning Production Costs of Electric Energy in Cogeneration, Polinvest, August 1992.

1.2.3 Fee and Penalty Analysis for the User of a Local Boiler House Firing Solid Fuel of Various Types Charge on the Base of the Existing Law Regarding Permissible Air Pollution Emissions, EKOPOL, October 1991.

1.2.7 Incentive Analysis and Recommended Actions to be Taken by Municipal Authorities to Facilitate the Elimination of the Existing Boiler Houses and to Connect Them to the District Central Heating System, Polinvest, June 1993.

1.2.9 Initial Feasibility Investigation of Replacement of 28 Local Boiler Houses in the Region of Halicka and Szeroka Streets with District Heating Network, Polinvest, August 1993.

Subproject 2 - Gas Conversion

2.1.6 Testing of Type ECA-IV Boilers in the ul. Rydla 28 Boiler House, Energoekspert, 1993.
Testing of Steel Heating Boilers in the ul. Ułanow Boiler House, Energoekspert, 1993.

2.2.1 Conception for Replacing Solid Fuel Fired Boiler Houses with Gas Ones, and
2.2.2 Investment Costs Estimate, BRK, April 1992. (Design Study)

2.2.3 Analysis of Reasons of Leakage Creation in the Town Gas Distribution Network and Estimation of Possible Measures Aimed at Improving Its Condition, BRK, December 1993.

2.2.4 Analysis of Feasibilities of Coal to Natural Gas Boiler House and Stove Heatings Conversion Within the Area of II Ring Road, BRK, May 1993.

Discussion of the Possible Adaptation of Gas Distribution in Cracow From the Point of View of Increasing Consumption of Gas for Heating Purposes. Part 1 Synthesis, BRK, December 1994.

2.2.6 Estimation of the Improvement of Air Quality, in Local and Regional Scale, to be Reached After Implementation of Gas-Fired Boiler Houses in the Old City Area, EKOPOL, June 1992, revised December 1992.

2.3.1 Forecast of Gas Price Trajectories for Individual Consumers and Anticipated Timetable of Price Rises
2.3.2 Survey of Legal Framework and Forecast of Introducing Local Rate System for Natural Gas by The Krakow Gas Utility Company, Polinvest, March 1992.

2.- "Gas Price Forecast for Boilers. Cash Flow for Building and Operation of Gas Boilers." Annex to Polinvest's Analysis of March 1993 Incentives Analysis and Recommendation of Activities by the City Authorities for Encouraging the End-User of Coal Burning Boilers to Convert to Gas Boilers, Polinvest, April 1993.

2.3.3 "Elaboration of Calculations of Fees and Penalties to be Paid by the User of Solid Fuel Boiler House Because of the Emission of Atmosphere Pollutions Basing on the Rule in Force," EKOPOL, June 1992. (An assessment of effectiveness of current regulations; an expansion of a study nominally done under Subproject 1)

2.3.4 Comparative Analysis of Current and Future Costs of Operating Heating Installations Burning Different Types of Fuels for Two Different Apartment Types in Cracow, Polinvest, November 1992 (applies to all subprojects)

Comparative Analysis of Present and Future Costs of Operating Heating Devices Using Various Kinds of Fuel, for an Apartment at Floriańska Street in Cracow, update of above, Polinvest, November 1994.

2.3.5 Incentives Analysis and Recommendation of Possible Actions by the City to Interest Coal Fired Boiler House Owners to Convert to Gas Firing," Part I. Economic Analysis, Polinvest, December 1993.

2.3.5 Incentives Analysis and Recommendation of Possible Actions by the City to Interest Coal Fired Boiler House Owners to Convert to Gas Firing," Part II. Incentive Analysis, Polinvest, December 1993.

Subproject 3 - Electric Heating

3.2.1 A Conceptual Study of GPZ "Lobzow" Electric Energy

3.2.2 Distribution System for Replacing Stove Heating with Electric Heating, Together with Cost Estimate, Volumes I and II, BRK, July 1992.

3.2.3 Estimation of the Average Investment Cost Which Has to be Covered by a Resident Who Changes Coal-Fired Stove Heating for Electric Heating, BRK, May 1993.

3.2.5 Using Electricity for Heating in Cracow's Old Town, Volume III - Synthesis, Elpromont, February 1993.

A Feasibility Study on Using Electric Energy for Heating Residential Flats within the Area of the City of Krakow, Electric Equipment Design, Manufacturing and Installment Enterprise (ELPROMONT), 1994.

3.2.6 Estimation of Local and Regional Improvement of Air Quality to be Reached Due to the Planned Change of Heating Method in the Discussed Area Taking into Account both the Decrease in Pollutant Emission After Elimination of Coal-Fired Stoves and Increase in Pollutant Emission Due to Electric Energy Production, EKOPOL, September 1992, revised December 1992.

3.3.1 Forecast of Electricity Price Trajectories for Individual Consumers and Anticipated Timetable of Price Rises

3.3.2 Survey of Legal Framework and Forecast of Introducing Local Rate System for Electricity by the Krakow Power Supply Company, Polinvest, March 1992.

3.3.3 Discussion of the cost of switch over from coal fuel to electric heating for a typical tile stove, POLINVEST, September 1994.

3.3.4 Rates Making the Extension of the Łobzow Energy System Profitable, POLINVEST, September 1994.

3.3.5 Recommendation of the possible actions of town authorities in order to encourage and stimulate the inhabitants to switch their heating systems from coal-fired stoves to electric energy, POLINVEST, September 1994.

Subproject 4 - Boilerhouse Modernization

Calculation of Fees and Penalties (see 2.3.3) and Forecast of Price Trajectories of Coal (see 5.3.1) are relevant to this subproject.

4.1.5 Testing of PLM-2.5-1 boiler No. 3 in the Krzeslawice boiler house, Energoekspert, 1992.

4.1.5 Testing of PLM-2.5-1 boiler No. 3 in the Krzeslawice boiler house, Additional Measurements, Energoekspert, 1993.

4.1.5 Testing of the WR10-011 Boiler #2 in the Balicka Boiler House, Energoekspert, 1992.

4.2.1 Engineering Analysis of the Results of Testing of the Boiler Plant, Institute of Process and Power Engineering, Cracow University of Technology, 1994.

4.2.2 MPEC Steam Boiler House Modernization at Makuszynskiego St., Krzeslawice, Krakow Industrial Construction Design and Research Studios, March 1993.

4.2.4 List of Operating Stoker-Fired Boiler Houses Which Should be Modernized, BRK, January 1995.

4.2.5 Estimation of Air Quality Improvement Which Could be Reached after Modernization of the Krzeslawice Boiler House, EKOPOL, December 1993.

? Summary and Conclusions, Cracow Design and Research Office of Industrial Construction, October 1993.

4.3.2 Calculation of Fees to be Paid by the Boiler House User Due to the Emission of Pollutants into the Atmosphere According to the Regulations in Force, EKOPOL, September 1993.

Subproject 5 - Coal Stoves

5.1.1 - 5.1.10 Testing of Ceramic and Slow Combustion Stoves Fired with Solid Fuel, AGH, August 1992. (Test program results report)

5.1.1 - 5.1.10 Tile Stove Testing Using Briquettes Supplied by American Company, University of Mining and Metallurgy, January 1993.

5.1.1 - 5.1.10 Research on Possibilities of Reduction of Noxious Emissions Through Combustion Modification, University of Mining and Metallurgy, December 1993.

5.2.1 Engineering Analysis of Home Stove Tests Performed under the American-Polish Program for Elimination of Low Emissions Sources in Krakow, PPHU Tawimex, July 1994.

5.2.3 Investment Cost Analysis for Replacement of Home Stoves with Gas-Fired Central Heating Systems in Individual Apartments, BRK, March 1993.

5.2.5 Estimation of Air Quality Improvement at the Town, Which Could be Reached after Switch Over From Stove Heating to Electric or Gas Heating Combined with the Application of Improved Fuel Sorts, EKOPOL, December 1993.

5.3.1 Forecast of Price Trajectories of Coal Used for Heating Purposes and Anticipated Timetable of Price Rises, Polinvest, March 1992.

5.3.2 5.5.3 5.3.8 Analysis of the Availability of High Quality Coal and Smokeless Fuel for Krakow, Separator, Central Office for Coal Processing Research and Design, Katowice, February 1993.

5.3.7 Recommendation of possible actions of the town authorities for giving the inhabitants incentives to use more expensive smokeless briquettes and to prevent the combustion of the worst coal sorts, POLINVEST, September 1994.

Air Quality

Estimation of Air Quality Improvement at the Town, Which Could be Reached After Elimination of All the Low Emission Sources in Cracow, EKOPOL, June 1994.

See also air quality reports under individual Subprojects.

Public Relations

Focus Group Report - "Assessment of Attitudes Toward Low Emission Pollution Amongst Residents of Cracow," VRG Strategy Co. Ltd.

Assessment of Attitudes Toward Low Emission Pollution Amongst Residents of Cracow, Final Report, VRG Strategy Co. Ltd., April 1993.

Assessment of Attitudes Toward Low Emission Pollution Amongst Residents of Cracow, Final Report Appendix, Old Town and Łobzów, VRG Strategy Co. Ltd., April 1993.

Survey Results - Crosstabulated results, Tables, Volumes IA, IIA, IB, IIB, VRG Strategy Co. Ltd., April 1993.

Appendix II

Input for Spreadsheet Analysis of Options

During this program a spreadsheet program was used to compare options for reducing emissions from Kraków's low sources. This spreadsheet was originally prepared by U.S. DOE and several organizations contributed to it's develpment. The version of the spreadsheet program adapted for the analysis described in this report was written by Gilbert Commonwealth, Inc. Copies of the spreadsheet on disk as adapted to Kraków and an instruction manual for the spreadsheet can be obtained by contacting T. Butcher or B. Pierce at Brookhaven National Laboratory.

Included in this Apendix are selected extracts from the spreadsheet which define the baseline (existing) conditions in Kraków.

SYSTEM BASELINE INPUT DATA

0	1	2	3	4	5	6	7	8	9	10	11	12
Row/ Category Number	KRAKOW	Number of Units	Average MW per Boiler	Total Design MW for Boilers	Utilization Factor %	Annual Hours Operation	Capacity Factor %	Average Efficiency	Annual Fuel Use GJ/yr	Annual Fuel Use for Boilers	Annual Fuel Use Units	Fuel Number
1	BOILER HOUSES AND HOME HEATING											
2	Stoker Coal Boilers >= 3 MW with PCEs	38	5.903	224.328	24.11	6756	18.59	0.63	2,088,022	109,815,000	kg/yr	1
3	Stoker Coal Boilers < 3 MW with PCEs	147	1.563	229.798	23.35	5633	15.02	0.53	2,041,685	107,378,000	kg/yr	2
4	Stoker Coal Boilers < 3 MW w/o PCEs	44	1.285	56.519	18.10	5633	11.64	0.53	389,274	20,473,000	kg/yr	2
5	Hand-Fired Coal & Coke Blend Boilers with PCEs	42	0.408	17.129	32.30	5400	19.91	0.65	165,444	6,559,000	kg/yr	6
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs	643	0.239	153.683	24.91	5400	15.36	0.65	1,144,993	45,393,000	kg/yr	6
7	Hand Fired Coal Boilers with PCEs	42	0.820	34.439	52.67	5448	32.76	0.60	592,907	20,450,000	kg/yr	3
8	Hand-Fired Coal Boilers w/o PCEs	188	0.164	30.871	33.98	5448	21.13	0.60	342,871	11,826,000	kg/yr	3
9	Hand-Fired Coke Boilers with PCEs	10	0.367	3.671	36.22	5400	22.33	0.72	35,902	1,306,000	kg/yr	7
10	Hand-Fired Coke Boilers w/o PCEs	1,108	0.193	214.227	23.97	5400	14.78	0.72	1,386,651	50,442,000	kg/yr	7
11	Fuel Oil Boilers	7	0.795	5.564	45.00	7396	37.99	0.85	78,429	1,899,000	kg/yr	9
12	Diesel Oil Boilers	7	0.476	3.333	57.10	7200	46.93	0.85	58,032	1,387,000	kg/yr	10
13	Natural Gas Boilers	644	0.119	76.844	28.86	5808	19.13	0.85	545,534	15,324,000	Nm^3/yr	11
14	Home coal stoves	99,986	0.002	199.972	35.92	5328	21.85	0.55	2,505,205	85,000,000	kg/yr	4
15	Electric Heaters	25,467	0.002	50.934	41.09	5328	24.99	1.00	401,454	111,515	MWh/yr	12
16	Natural Gas Furnaces	16,320	0.017	277.440	18.09	5328	11.00	0.85	1,132,651	31,816,039	Nm^3/yr	11
17	Coal Boilers for Buildings	4,314	0.008	34.512	35.38	5328	21.52	0.60	390,391	13,245,713	kg/yr	4
18	Home stoves/Briquettes	0	0.000	0.000	0.00	5328	0.00	0.55	0	0	kg/yr	8
19	Stokers >=3MW / Graded Coal	0	0.000	0.000	0.00	6756	0.00	0.73	0	0	kg/yr	5
20	Modernized stokers	0	0.000	0.000	0.00	5633	0.00	0.80	0	0	kg/yr	14
21	Connection to DHS	0	0.000	0.000	0.00	5328	0.00	1.00	0	0	MJ/yr	13
22	Stokers < 3 MW with PCEs / Graded Coal	0	0.000	0.000	0.00	5633	0.00	0.73	0	0	kg/yr	15
23	Stokers < 3 MW w/o PCEs / Graded Coal	0	0.000	0.000	0.00	5633	0.00	0.73	0	0	kg/yr	15
24	Hand fired boilers with PCEs / briquettes	0	0.000	0.000	0.00	5448	0.00	0.71	0	0	kg/yr	16
25	Hand fired boilers w/o PCEs/ briquettes	0	0.000	0.000	0.00	5448	0.00	0.71	0	0	kg/yr	16
26												
27												
28												
30	Total for BOILER HOUSES AND HOME HEATING	149,007		1,613.26					13,299,445			
31	DH SYSTEM											1
32	DH - PC Fired Brown Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
33	DH - Large Grate Brown Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
34	DH - Small Grate Brown Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
35	DH - Existing Heavy Oil	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
36	DH - Existing Light Oil	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
37	DH - PC Fired Black Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
38	DH - Large Grate Black Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
39	DH - Small Grate Black Coal	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
40	DH - Future Gas Steam Boiler	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
41	DH - Future Gas Hot Water Boiler	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
42	DH - Future FBC Boiler	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
43	DH - Electric Generation	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
44	EC	0	0.000	0.00	0.00	0	0.00	0	0	0	kg/yr	1
46	Total for DH SYSTEM	0		0.000					0			
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM	149,007		1,613.264					13,299,445			
48	UTILITY COSTS											
49	Natural Gas Distribution	16,964	0.021	354	22.41	5328	13.63	1.00	1,623,042		Nm^3/yr	11
50	Boilers for CHP Heat Production	0	0.000	277	0.00	5328	0.00		0		MJ/yr	13
51	Electric Generation	25,467	0.002	51	39.96	5328	24.30	1.00	390,391		MWh/yr	12
53	Total for UTILITY	42,431		682.658					1,913,433			

SYSTEM BASELINE INPUT DATA

0	1	2	13	14	15	16	17	18	19	20	21
Row/ Category Number	KRAKOW	Number of Units	Fuel Name	Capital Cost Existing Unit $/MW USA	Annual Oper. Cost factor	Annual Main. Cost factor	Existing SO2 % Removal	Existing Particulate % Removal	Existing CO % Removal	Existing VOC % Removal	Existing NOx % Removal
1	BOILER HOUSES AND HOME HEATING										
2	Stoker Coal Boilers >= 3 MW with PCEs	38	Stoker Coal I	$21,887	0.2080	0.1760	0.00	75.00	0.00	0.00	0.00
3	Stoker Coal Boilers < 3 MW with PCEs	147	Stoker Coal II	$34,676	0.2019	0.1704	0.00	75.00	0.00	0.00	0.00
4	Stoker Coal Boilers < 3 MW w/o PCEs	44	Stoker Coal II	$31,240	0.2240	0.1890	0.00	0.00	0.00	0.00	0.00
5	Hand-Fired Coal & Coke Blend Boilers with PCEs	42	Coal & Coke blend	$17,691	1.5673	0.3340	0.00	70.00	0.00	0.00	0.00
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs	643	Coal & Coke blend	$15,108	1.8350	0.3910	0.00	0.00	0.00	0.00	0.00
7	Hand Fired Coal Boilers with PCEs	42	Lump Coal	$20,833	1.3310	0.2836	0.00	70.00	0.00	0.00	0.00
8	Hand-Fired Coal Boilers w/o PCEs	188	Lump Coal	$18,939	1.4640	0.3120	0.00	0.00	0.00	0.00	0.00
9	Hand-Fired Coke Boilers with PCEs	10	Coke	$17,691	1.5673	0.3340	0.00	70.00	0.00	0.00	0.00
10	Hand-Fired Coke Boilers w/o PCEs	1,106	Coke	$15,108	1.8350	0.3910	0.00	0.00	0.00	0.00	0.00
11	Fuel Oil Boilers	7	Fuel oil	$52,085	0.3229	0.0610	0.00	0.00	0.00	0.00	0.00
12	Diesel Oil Boilers	7	Diesel Oil	$52,085	0.3229	0.0610	0.00	0.00	0.00	0.00	0.00
13	Natural Gas Boilers	644	Natural gas	$52,085	0.3229	0.0610	0.00	0.00	0.00	0.00	0.00
14	Home coal stoves	99,986	Home Coal	$206,727	0.1688	0.0308	0.00	0.00	0.00	0.00	0.00
15	Electric Heaters	25,467	Electricity	$324,719	0.0000	0.0176	0.00	0.00	0.00	0.00	0.00
16	Natural Gas Furnaces	16,320	Natural gas	$308,295	0.0000	0.0212	0.00	0.00	0.00	0.00	0.00
17	Coal Boilers for Buildings	4,314	Home Coal	$299,818	0.0813	0.0152	0.00	0.00	0.00	0.00	0.00
18	Home stoves/Briquettes	0	Briquettes	$206,727	0.1288	0.0308	0.00	0.00	0.00	0.00	0.00
19	Stokers >=3MW / Graded Coal	0	Improved coal I	$21,887	0.2080	0.1760	0.00	75.00	0.00	0.00	0.00
20	Modernized stokers	0	Coal for modernized stokers	$86,090	0.3543	0.1772	0.00	75.00	0.00	0.00	0.00
21	Connection to DHS	0	Heat from DHS	$17,644	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
22	Stokers < 3 MW with PCEs / Graded Coal	0	Improved coal II	$34,676	0.2019	0.1704	0.00	75.00	0.00	0.00	0.00
23	Stokers < 3 MW w/o PCEs / Graded Coal	0	Improved coal II	$31,240	0.2240	0.1890	0.00	75.00	0.00	0.00	0.00
24	Hand fired boilers with PCEs / briquettes	0	Briquettes for boilers	$20,833	1.3310	0.2836	0.00	0.00	0.00	0.00	0.00
25	Hand fired boilers w/o PCEs/ briquettes	0	Briquettes for boilers	$18,939	1.4640	0.3120	0.00	0.00	0.00	0.00	0.00
26											
27											
28											
30	Total for BOILER HOUSES AND HOME HEATING	149,007									
31	DH SYSTEM										
32	DH - PC Fired Brown Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
33	DH - Large Grate Brown Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
34	DH - Small Grate Brown Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
35	DH - Existing Heavy Oil	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
36	DH - Existing Light Oil	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
37	DH - PC Fired Black Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
38	DH - Large Grate Black Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
39	DH - Small Grate Black Coal	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
40	DH - Future Gas Steam Boiler	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
41	DH - Future Gas Hot Water Boiler	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
42	DH - Future FBC Boiler	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
43	DH - Electric Generation	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
44	EC	0	Stoker Coal I	$0	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
46	Total for DH SYSTEM	0									
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM	149,007									
48	UTILITY COSTS										
49	Natural Gas Distribution	16,964	Natural gas	$0	0.0250	0.0250	0.00	0.00	0.00	0.00	0.00
50	Boilers for CHP Heat Production	0	Heat from DHS	$0	0.0250	0.0250	0.00	0.00	0.00	0.00	0.00
52	Electric Generation	25,457	Electricity	$0	0.0250	0.0250	0.00	0.00	0.00	0.00	0.00
53	Total for UTILITY	42,431									

Baseline Data
Baseline Total System

	0	1	2	3	4	5	6	7
Row/ Category Number	KRAKOW		Number of Units	Total Design MW for Boilers	Annual Fuel Use GJ/yr	Average SO2 Emissions mg/Nm^3	Total SO2 Emissions tonnes/yr	Ave. Particulate Emissions mg/Nm^3
1	BOILER HOUSES AND HOME HEATING							
2	Stoker Coal Boilers >= 3 MW with PCEs		38	224.328	2,088,022	4,016.55	3,212.1	856.45
3	Stoker Coal Boilers < 3 MW with PCEs		147	229.798	2,041,685	4,016.55	3,140.8	289.05
4	Stoker Coal Boilers < 3 MW w/o PCEs		44	56.519	389,274	4,016.55	598.8	1,156.22
5	Hand-Fired Coal & Coke Blend Boilers with PCEs		42	17.129	165,444	2,058.84	130.5	167.62
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs		643	153.683	1,144,993	2,058.84	902.9	558.74
7	Hand Fired Coal Boilers with PCEs		42	34.439	592,907	1,633.15	370.9	509.14
8	Hand-Fired Coal Boilers w/o PCEs		188	30.871	342,871	1,633.15	214.5	1,697.12
9	Hand-Fired Coke Boilers with PCEs		10	3.671	35,902	1,685.40	23.2	43.08
10	Hand-Fired Coke Boilers w/o PCEs		1108	214.227	1,386,651	1,685.40	895.1	143.60
11	Fuel Oil Boilers		7	5.564	78,429	3,564.83	81.1	133.59
12	Diesel Oil Boilers		7	3.333	58,032	2,021.03	34.0	74.17
13	Natural Gas Boilers		644	76.844	545,534	0.72	0.2	21.78
14	Home coal stoves		99986	199.972	2,505,205	814.62	781.6	1,594.59
15	Electric Heaters		25467	50.934	401,454	0.00	0.0	0.00
16	Natural Gas Furnaces		16320	277.440	1,132,651	0.72	0.3	21.78
17	Coal Boilers for Buildings		4314	34.512	390,391	814.62	121.8	1,594.59
18	Home stoves/Briquettes		0	0.000	0	389.03	0.0	112.53
19	Stokers >=3MW / Graded Coal		0	0.000	0	1,145.79	0.0	279.37
20	Modernized stokers		0	0.000	0	522.19	0.0	58.83
21	Connection to DHS		0	0.000	0	0.00	0.0	0.00
22	Stokers < 3 MW with PCEs / Graded Coal		0	0.000	0	1,365.80	0.0	38.58
23	Stokers < 3 MW w/o PCEs / Graded Coal		0	0.000	0	1,365.80	0.0	38.58
24	Hand fired boilers with PCEs / briquettes		0	0.000	0	248.04	0.0	180.13
25	Hand fired boilers w/o PCEs/ briquettes		0	0.000	0	248.04	0.0	180.13
26						0.00	0.0	0.00
27						0.00	0.0	0.00
28		0				0.00	0.0	0.00
30	Total for BOILER HOUSES AND HOME HEATING		149,007	1,613.26	13,299,445		10,507.6	
31	DH SYSTEM							
32	DH - PC Fired Brown Coal		0	0.000	0	0.00	0.0	0.00
33	DH - Large Grate Brown Coal		0	0.000	0	0.00	0.0	0.00
34	DH - Small Grate Brown Coal		0	0.000	0	0.00	0.0	0.00
35	DH - Existing Heavy Oil		0	0.000	0	0.00	0.0	0.00
36	DH - Existing Light Oil		0	0.000	0	0.00	0.0	0.00
37	DH - PC Fired Black Coal		0	0.000	0	0.00	0.0	0.00
38	DH - Large Grate Black Coal		0	0.000	0	0.00	0.0	0.00
39	DH - Small Grate Black Coal		0	0.000	0	0.00	0.0	0.00
40	DH - Future Gas Steam Boiler		0	0.000	0	0.00	0.0	0.00
41	DH - Future Gas Hot Water Boiler		0	0.000	0	0.00	0.0	0.00
42	DH - Future FBC Boiler		0	0.000	0	0.00	0.0	0.00
43	DH - Electric Generation		0	0.000	0	0.00	0.0	0.00
44	EC	0	0	0.000	0	0.00	0.0	0.00
46	Total for DH SYSTEM		0	0.000	0		0.0	
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM		149,007	************	13,299,445		10,507.6	
48	UTILITY COSTS							
49	Natural Gas Distribution		25474	56.498	1,523,042	0.72351421189	0.4	0.00
50	Boilers for CHP Heat Production		16320	277.440	0	0	0.0	0.00
51	Electric Generation		4314	34.512	1,183,003	0	0.0	0.00
53	Total for UTILITY		46108	368.450	2,706,045		0.4	

Baseline Data
Baseline Total System

0 Row/ Category Number	KRAKOW	1	2 Number of Units	8 Total Particulate Emissions tonnes/yr	9 Average CO Emissions mg/Nm^3	10 Total CO Emissions tonnes/yr	11 Average VOC Emissions mg/Nm^3	12 Total VOC Emissions tonnes/yr
1	BOILER HOUSES AND HOME HEATING							
2	Stoker Coal Boilers >= 3 MW with PCEs		38	684.9	678.85	542.9	0.00	0.0
3	Stoker Coal Boilers < 3 MW with PCEs		147	226.0	2,780.68	2,174.4	0.00	0.0
4	Stoker Coal Boilers < 3 MW w/o PCEs		44	172.4	2,780.68	414.6	0.00	0.0
5	Hand-Fired Coal & Coke Blend Boilers with PCEs		42	10.6	7,702.35	488.1	647.51	41.0
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs		643	245.0	7,702.35	3,377.7	647.51	284.0
7	Hand Fired Coal Boilers with PCEs		42	115.6	4,710.18	1,069.6	368.15	83.6
8	Hand-Fired Coal Boilers w/o PCEs		188	222.9	4,710.18	618.5	368.15	48.3
9	Hand-Fired Coke Boilers with PCEs		10	0.6	6,647.56	91.4	52.22	0.7
10	Hand-Fired Coke Boilers w/o PCEs		1108	76.3	6,647.56	3,530.4	52.22	27.7
11	Fuel Oil Boilers		7	3.0	41.75	0.9	0.00	0.0
12	Diesel Oil Boilers		7	1.2	24.72	0.4	0.00	0.0
13	Natural Gas Boilers		644	4.6	21.78	4.6	0.00	0.0
14	Home coal stoves		99986	1,530.0	2,294.44	2,201.5	230.33	221.0
15	Electric Heaters		25467	0.0	0.00	0.0	0.00	0.0
16	Natural Gas Furnaces		16320	9.5	21.78	9.5	0.00	0.0
17	Coal Boilers for Buildings		4314	238.4	2,294.44	343.1	230.33	34.4
18	Home stoves/Briquettes		0	0.0	1,963.12	0.0	129.55	0.0
19	Stokers >=3MW / Graded Coal		0	0.0	138.38	0.0	0.00	0.0
20	Modernized stokers		0	0.0	34.33	0.0	0.22	0.0
21	Connection to DHS		0	0.0	0.00	0.0	0.00	0.0
22	Stokers < 3 MW with PCEs / Graded Coal		0	0.0	1,738.08	0.0	0.16	0.0
23	Stokers < 3 MW w/o PCEs / Graded Coal		0	0.0	1,738.08	0.0	0.16	0.0
24	Hand fired boilers with PCEs / briquettes		0	0.0	4,054.81	0.0	185.20	0.0
25	Hand fired boilers w/o PCEs/ briquettes		0	0.0	4,054.81	0.0	185.20	0.0
26				0.0	0.00	0.0	0.00	0.0
27				0.0	0.00	0.0	0.00	0.0
28		0		0.0	0.00	0.0	0.00	0.0
30	Total for BOILER HOUSES AND HOME HEATING		149,007	3,541.2		14,867.7		740.8
31	DH SYSTEM							
32	DH - PC Fired Brown Coal		0	0.0	0.00	0.0	0.00	0.0
33	DH - Large Grate Brown Coal		0	0.0	0.00	0.0	0.00	0.0
34	DH - Small Grate Brown Coal		0	0.0	0.00	0.0	0.00	0.0
35	DH - Existing Heavy Oil		0	0.0	0.00	0.0	0.00	0.0
36	DH - Existing Light Oil		0	0.0	0.00	0.0	0.00	0.0
37	DH - PC Fired Black Coal		0	0.0	0.00	0.0	0.00	0.0
38	DH - Large Grate Black Coal		0	0.0	0.00	0.0	0.00	0.0
39	DH - Small Grate Black Coal		0	0.0	0.00	0.0	0.00	0.0
40	DH - Future Gas Steam Boiler		0	0.0	0.00	0.0	0.00	0.0
41	DH - Future Gas Hot Water Boiler		0	0.0	0.00	0.0	0.00	0.0
42	DH - Future FBC Boiler		0	0.0	0.00	0.0	0.00	0.0
43	DH - Electric Generation		0	0.0	0.00	0.0	0.00	0.0
44	EC	0	0	0.0	0.00	0.0	0.00	0.0
46	Total for DH SYSTEM		0	0.0		0.0		0.0
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM		149,007	3,541.2		14,867.7		740.8
48	UTILITY COSTS							
49	Natural Gas Distribution		25474	0.0	0	0.0	0	0.0
50	Boilers for CHP Heat Production		16320	0.0	0	0.0	0	0.0
51	Electric Generation		4314	0.0	0	0.0	0	0.0
53	Total for UTILITY		46108	0.0		0.0		0.0

Baseline Data
Baseline Total System

Row/ Category Number (0)	KRAKOW (1)	Number of Units (2)	Average NOx Emissions mg/Nm^3 (13)	Total NOx Emissions tonnes/yr (14)	Annual Fuel Cost $/yr (15)	Total Capital Cost in U.S.A. (16)
1	BOILER HOUSES AND HOME HEATING					
2	Stoker Coal Boilers >= 3 MW with PCEs	38	381.74	305.3	3,393,130	$4,909,867
3	Stoker Coal Boilers < 3 MW with PCEs	147	486.11	380.1	3,317,830	$7,968,475
4	Stoker Coal Boilers < 3 MW w/o PCEs	44	486.11	72.5	632,587	$1,765,654
5	Hand-Fired Coal & Coke Blend Boilers with PCEs	42	120.10	7.6	463,852	$303,029
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs	643	120.10	52.7	3,210,193	$2,321,843
7	Hand Fired Coal Boilers with PCEs	42	198.12	45.0	1,587,307	$717,468
8	Hand-Fired Coal Boilers w/o PCEs	188	198.12	26.0	917,921	$584,666
9	Hand-Fired Coke Boilers with PCEs	10	135.77	1.9	83,349	$64,944
10	Hand-Fired Coke Boilers w/o PCEs	1108	135.77	72.1	3,219,208	$3,236,542
11	Fuel Oil Boilers	7	0.00	0.0	640,913	$289,801
12	Diesel Oil Boilers	7	0.00	0.0	468,113	$173,599
13	Natural Gas Boilers	644	203.23	42.9	3,309,984	$4,002,420
14	Home coal stoves	99986	487.24	467.5	6,597,607	$41,339,612
15	Electric Heaters	25467	0.00	0.0	2,915,002	$16,539,238
16	Natural Gas Furnaces	16320	203.23	89.1	6,872,264	$85,533,365
17	Coal Boilers for Buildings	4314	487.24	72.9	1,028,118	$10,347,319
18	Home stoves/Briquettes	0	169.27	0.0	0	$0
19	Stokers >=3MW / Graded Coal	0	417.78	0.0	0	$0
20	Modernized stokers	0	443.86	0.0	0	$0
21	Connection to DHS	0	0.00	0.0	0	$0
22	Stokers < 3 MW with PCEs / Graded Coal	0	326.37	0.0	0	$0
23	Stokers < 3 MW w/o PCEs / Graded Coal	0	326.37	0.0	0	$0
24	Hand fired boilers with PCEs / briquettes	0	96.61	0.0	0	$0
25	Hand fired boilers w/o PCEs/ briquettes	0	96.61	0.0	0	$0
26			0.00	0.0	0	$0
27			0.00	0.0	0	$0
28	0		0.00	0.0	0	$0
30	Total for BOILER HOUSES AND HOME HEATING	149,007		1,635.5	38,657,377	$180,097,839
31	DH SYSTEM					
32	DH - PC Fired Brown Coal	0	0.00	0.0	0	$0
33	DH - Large Grate Brown Coal	0	0.00	0.0	0	$0
34	DH - Small Grate Brown Coal	0	0.00	0.0	0	$0
35	DH - Existing Heavy Oil	0	0.00	0.0	0	$0
36	DH - Existing Light Oil	0	0.00	0.0	0	$0
37	DH - PC Fired Black Coal	0	0.00	0.0	0	$0
38	DH - Large Grate Black Coal	0	0.00	0.0	0	$0
39	DH - Small Grate Black Coal	0	0.00	0.0	0	$0
40	DH - Future Gas Steam Boiler	0	0.00	0.0	0	$0
41	DH - Future Gas Hot Water Boiler	0	0.00	0.0	0	$0
42	DH - Future FBC Boiler	0	0.00	0.0	0	$0
43	DH - Electric Generation	0	0.00	0.0	0	$0
44	EC 0	0	0.00	0.0	0	$0
46	Total for DH SYSTEM	0		0.0	0	$0
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM	149,007		1,635.5	38,657,377	$180,097,839
48	UTILITY COSTS					
49	Natural Gas Distribution	25474	0	0.0	9,240,928	$0
50	Boilers for CHP Heat Production	16320	0	0.0	0	$0
51	Electric Generation	4314	0	0.0	8,589,914	$0
53	Total for UTILITY	46108		0.0	17,830,843	$0

Baseline Data
Baseline Total System

0		1	2	17	18	19	20
Row/ Category Number	KRAKOW		Number of Units	Total Capital Cost in POLAND ($)	Total Annual Oper. Cost in POLAND ($)	Total Annual Main. Cost in POLAND ($)	Total Annual O&M Cost Inc.Fuel ($)
1	BOILER HOUSES AND HOME HEATING						
2	Stoker Coal Boilers >= 3 MW with PCEs		38	4,909,867	1,021,252	864,137	5,278,519
3	Stoker Coal Boilers < 3 MW with PCEs		147	7,968,475	1,608,835	1,357,828	6,284,493
4	Stoker Coal Boilers < 3 MW w/o PCEs		44	1,765,654	395,506	333,709	1,361,802
5	Hand-Fired Coal & Coke Blend Boilers with PCEs		42	303,029	474,938	101,212	1,040,002
6	Hand- Fired Coal & Coke Blend Boilers w/o PCEs		643	2,321,843	4,260,581	907,841	8,378,615
7	Hand Fired Coal Boilers with PCEs		42	717,468	954,949	203,474	2,745,730
8	Hand-Fired Coal Boilers w/o PCEs		188	584,666	855,951	182,416	1,956,288
9	Hand-Fired Coke Boilers with PCEs		10	64,944	101,786	21,691	206,826
10	Hand-Fired Coke Boilers w/o PCEs		1106	3,236,542	5,939,054	1,265,488	10,423,750
11	Fuel Oil Boilers		7	289,801	93,577	17,678	752,167
12	Diesel Oil Boilers		7	173,599	56,055	10,590	534,757
13	Natural Gas Boilers		644	4,002,420	1,292,381	244,148	4,846,513
14	Home coal stoves		99986	41,339,612	6,978,126	1,273,260	14,848,993
15	Electric Heaters		25467	16,539,238	0	291,091	3,206,093
16	Natural Gas Furnaces		16320	85,533,365	0	1,813,307	8,685,572
17	Coal Boilers for Buildings		4314	10,347,319	841,237	157,279	2,026,634
18	Home stoves/Briquettes		0	0	0	0	0
19	Stokers >=3MW / Graded Coal		0	0	0	0	0
20	Modernized stokers		0	0	0	0	0
21	Connection to DHS		0	0	0	0	0
22	Stokers < 3 MW with PCEs / Graded Coal		0	0	0	0	0
23	Stokers < 3 MW w/o PCEs / Graded Coal		0	0	0	0	0
24	Hand fired boilers with PCEs / briquettes		0	0	0	0	0
25	Hand fired boilers w/o PCEs/ briquettes		0	0	0	0	0
26				0	0	0	0
27				0	0	0	0
28		0		0	0	0	0
30	Total for BOILER HOUSES AND HOME HEATING		149,007	180,097,839	24,874,230	9,045,146	72,576,753
31	DH SYSTEM						
32	DH - PC Fired Brown Coal		0	0	0	0	0
33	DH - Large Grate Brown Coal		0	0	0	0	0
34	DH - Small Grate Brown Coal		0	0	0	0	0
35	DH - Existing Heavy Oil		0	0	0	0	0
36	DH - Existing Light Oil		0	0	0	0	0
37	DH - PC Fired Black Coal		0	0	0	0	0
38	DH - Large Grate Black Coal		0	0	0	0	0
39	DH - Small Grate Black Coal		0	0	0	0	0
40	DH - Future Gas Steam Boiler		0	0	0	0	0
41	DH - Future Gas Hot Water Boiler		0	0	0	0	0
42	DH - Future FBC Boiler		0	0	0	0	0
43	DH - Electric Generation		0	0	0	0	0
44	EC	0	0	0	0	0	0
46	Total for DH SYSTEM		0	0	0	0	0
47	Total for BOILER HOUSES AND HOME HEATING & DH SYSTEM		149,007	180,097,839	24,874,230	9,045,146	72,576,753
48	UTILITY COSTS						
49	Natural Gas Distribution		25474	0	0	0	9,240,928
50	Boilers for CHP Heat Production		16320	0	0	0	0
51	Electric Generation		4314	0	0	0	8,589,914
53	Total for UTILITY		46108	0	0	0	17,830,843