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EUROPEAN REGIONAL INDUSTRIAL ENERGY CONSERVATION NETWORK

ENCONET

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Technical report: Energy auditing and management of industrial plants*

Manual - Volume I

Prepared for the Governments of the Member States of the Regional Network (Bulgaria, Czechoslovakia, Cyprus, Hungary, Malta, Poland, Portugal, Romania, Yugoslavia) and other participating States of the region, by the United Nations Industrial Development Organization, acting as executing agency for the United Nations Development Programme

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* This document has not been edited.

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TABLE OF CONTENTS

Abstract

The energy consumption has grown, depending on the industry development as well as population growth. Energy conservation measures lower specific energy consumption in the industry as well as in the public sector. Energy management in industrial plants shows main areas for continuous efforts to lower energy consumption and environmental polution.

Energy auditing is the important prerequisite for energy conservation and savings in industrial plants. The objective of energy auditing is to identify the losses in energy utilization (consumption and conversion) and then to determine the ways and means of their reduction or elimination.

The application of energy auditing does not require much investments and jointly it lowers energy consumption and manufacturing costs, as well as it increases the outputs and quality of the production. The Mobile Diagnostic Unit (Energy Bus) and its miniaturized version, Energy Kit, are the practical means for energy auditing. Systematic description of principles, measures, values, methods and instrumentation, including data processing, aside recommended measures for improvement, are presented in order to guide the auditing staff for effective measures in energy conservation. Selected measures for improvement are the guidance for particular case studies.

I. Introduction

The growing prices of energy resources in the world markets, the forecast of energy growth for the forthcoming period created the necessity for more efficient energy use in all developed as well as developing countries around the world. Many national programmes for energy conservation are being implemented by European countries in general, including those receiving technical assistance from the United Nations Development Programme (UNDP).

While in each country the most appropriate measures to achieve greater economy and efficiency in the use of energy will necessarily differ according to national conditions and policy goals, it is recognized that all of them could greatly benefit from systematic co-operation and joint efforts in this area.

Therefore, the United Nations Industrial Development Organization (UNIDO), the executing agency of UNDP, elaborated the project concept "Regional Co-operation in the Fiel of Industrial Energy Conservation", which received strong support at the Inter-Governmental Consultation on the UNDP Regional Programme for Europe in the Third Cycle, 1982-1986, held in Geneva in May 1981. Owing to this continuing strong interest, a project on energy conservation in industry was recommended for implementation by UNIDO in the Regional Programme for Europe for this cycle.

Preparatory Assistance activities designed to achieve a well planned detailed programme during the main project phase were carried out by UNIDO in 1984-1985. All European IPF countries(*) were contacted and nine (Bulgaria, Cyprus, Czechoslovakia, Hungary, Malta, Poland, Portugal, Romania and Yugoslavia) expressed interest and agreed to participate in the project.

(*) e.g.: Countries eligible for UNDP Technical Assistance

During the Preparatory Assistance Phase, seven areas of mutual interest were defined, of which three were cross-sectional, common for all industrial branches:

- energy conservation policy
- energy auditing
- secondary energy resources and waste materials

Four industrial sectors were defined as the most interesting for the participating countries:

- iron and steel production
- chemical industry
- building materials manufacture
- food processing industry

During the subsequently two years of the on-going phase of the project, a Regional Network on Energy Conservation in Industry was initiated (see Fig. I). The Network covers seven areas and nearly 40 institutions from the nine countries, involving approximately 200 specialists, who submitted more than 100 technical papers at the different group meetings, which were organized annually.

Due to good results, the project was extended for the period of 1988-1990 with the new target to achieve a self-sustainability of the Network by 1990, e.g. to operate without external support, relying on the common interests and benefits of the participating countries.

The Energy Auditing Sub-Network is being co-ordinated by the Czechoslovakian Research Institute for Ceramics, Refractories and Non-metallic Raw Materials, in co-operation with the UNIDO-Czechoslovakia Joint Programme for International Co-operation, Non-metallic Industries, Pilsen, having more than 10 years experience in energy management. The same body co-ordinates also the Sub-Network on Energy Conservation in the Building materials sector.

In 1985, immediately after the project was approved, the activities in the field of energy auditing started according to the work programme.

In the overall context of establishing national energy auditing systems, suitable for local conditions of each participating country, the concept of a Mobile Diagnostic Unit (MDU) or "energy bus" was analyzed. MDU is a self-sustained unit capable of visiting industrial, commercial and public service sites to perform on-site audits and present documented analysis of data and recommendations for energy saving measures. It comprises a mobile vehicle containing measuring instruments and a computer with associated programmes for analysing data, and an experienced energy audit crew of engineer/technical stage.

The experience of many advanced countries shows advantages of this kind of units, which can be adopted at a minimum cost for use in all branches of industrial activities and in different locations. These units also enable its crew to develop and analyze all necessary data for maintaining the energy conservation and eliminating energy losses.

This concept was recommended to the project countries as one of the most suitable means for energy auditing. A model MDU was constructed at the Institute in Pilsen and demonstrated to the specialists from the participating countries. This approach was also used for building MDUs in Romania and Yugoslavia. Some more MDUs would be expected in other countries.

Besides, different expert group meetings and study tours to selected countries were organized in order to demonstrate to the participating countries modern methods and results in energy auditing.

Many discussions and negotiations have already previously indicated that a Manual on Energy Auditing is badly needed as a guidance for the successful execution of auditing as well as for training purposes. Therefore, several national institutions of the project member countries produced their own version of the Manual, such as Czechoslovakia, Hungary, Romania and Yugoslavia. This paper represents the summary version, applicable in industries of all interested countries.

Volume I of the Manual is related to the general principles, measuring techniques, theoretical aspects of energy auditing and it gives general guidelines for factories' energy management. The next Volumes II and III will be related to different selected technologies and case studies, based on energy auditing.

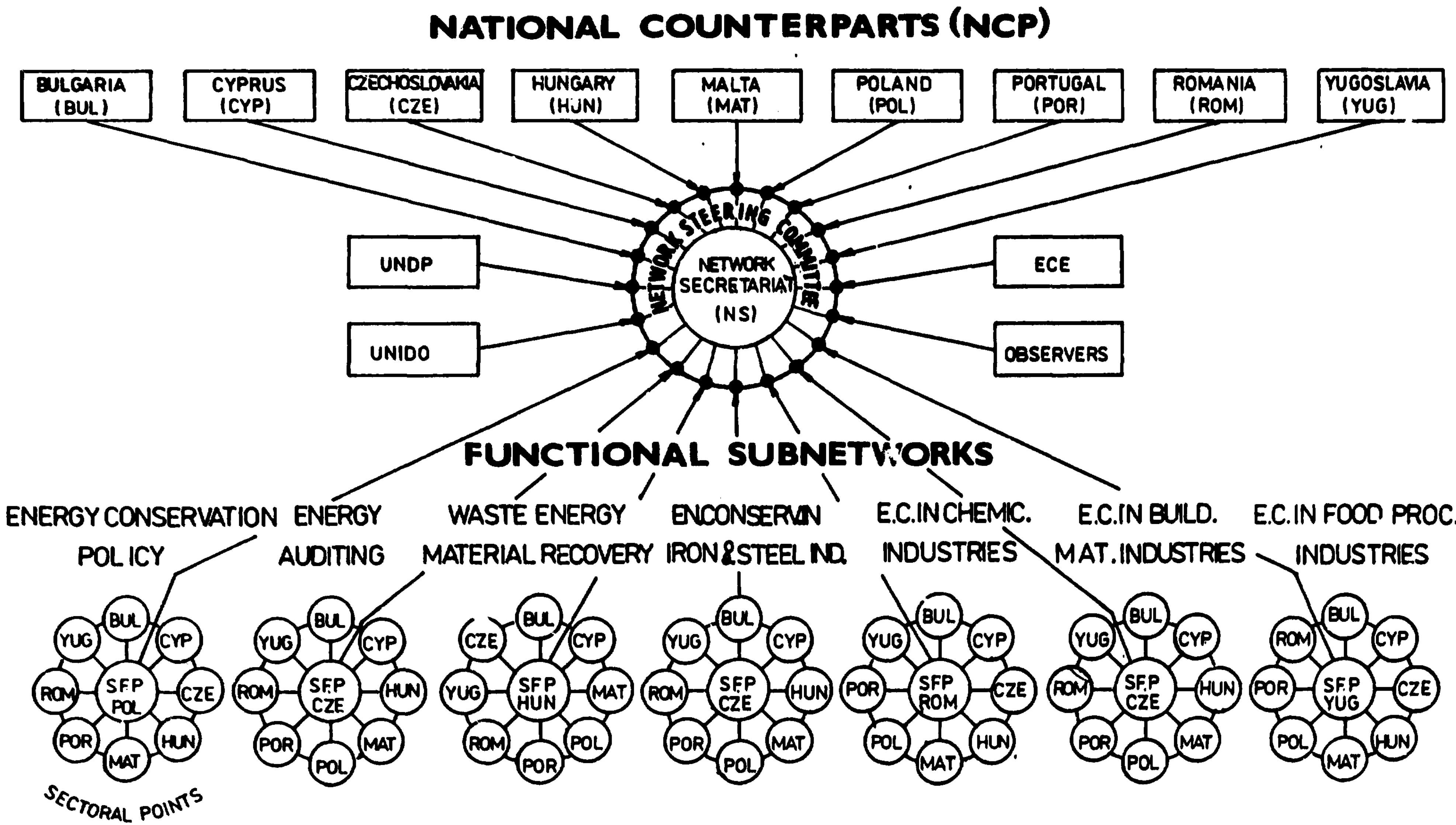


Fig. No 1 ORGANIZATIONAL STRUCTURE OF THE REGIONAL NETWORK FOR ENERGY CONSERVATION IN INDUSTRY

II. Energy Auditing of Industrial Plants

1. Principles and approach to energy audits

1.a. Purpose of Auditing

The energy costs form a large part of the budget of industrial plants. The necessity of energy conservation has resulted in the introduction of energy management systems in all industrialized countries. Energy auditing plays a significant role in the energy management programmes, as it provides the decision makers with all the necessary data about energy consumptions and efficiency of different manufacturing technologies, about the installed equipment, energy conservation and production intensification potential as well as with information how the production quality can be improved within the installed thermal process.

The primary purpose of energy auditing is to identify the losses in the use of energy (conversion and consumption) and then to find the way of reducing or eliminating those losses. Therefore, in the course of the energy audit, it is necessary to

- determine accurately the total consumption of every energy carrier
- examine why, at what equipment and in what volumes the different energy carriers are used
- determine how much of each energy carrier is consumed usefully, depending on the type of technology and manufacturing equipment, installed and how much is lost
- specify unavoidable losses, which occur due to the laws of physics and due to the nature of energy use and conversion and specify the other losses, volume of which can be affected, covered or fully avoided.

It is obvious that achievement of the above goals requires availability of both measuring instruments and devices as well as skilled personnel capable to do an audit.

Meanwhile, the instrumentation constantly installed in industrial plants is often insufficient and sometimes out of order. It can only indicate how much energy is consumed, however, it is not suitable for identification of the efficiency of energy use.

Even modern energy consuming units have problems caused by unsuitable operation, bad maintenance and shortage of spare parts. Technicians and workers in industrial plants are concerned mainly with production quality and quantity and they are not trained and experienced as specialists in energy auditing and conservation.

In this context, the concept of carrying out energy audits by an independent team of qualified specialists, equipped with necessary instrumentation, proved to be the most appropriate.

1.b Types of Energy Audits

Despite the common idea of energy savings, different approaches to energy auditing have existed since the beginning of its exercising. While some users promote orientation to entrepreneurial problems of energy conservation, the others base their activities on an engineering approach. The first type of audit usually involves a one day visit in a production plant, with the activities carried out in the following sequence:

- A preliminary discussion with the company's representatives to survey the situation in the energy related matters in the company,
- A tour through the plant during which the audit engineers pay attention to all cases of injudicious use of energy,

- Measuring and/or looking up necessary energy related data,
- Calculating and discussing the possible energy savings,
- Preparing a report and discussing it with management.

The company visited gets a complete audit report with all the required data and calculations. This type of audit concentrates on energy saving measures, excluding technological problems, and proposing simple technical solulutions. As to the more complicated technical problems identified, the client is usually recommended to contact a qualified consultancy company.

The engineering approach represents a combination of both energy saving measures and technological improvements. This type of audit lasts usually about one week and uses data obtained from the plant and, mainly, data produced by the auditing personnel. The audit results in a final report which includes, besides all the data and calculations, detailed recommendations of the measures to be taken to save energy, improve product quality and increase production. The final report is discussed with the plant management and the recommendations are realized by the client, if necessary with technical assistance of auditing personnel in a follow-up stage. The final report of the audit serves also as objective supporting material for decision-makers in planning reconstruction or modernization of the equipment, or substitution of one type of fuel by another.

Nevertheless, the complex engineering measurements are the most advisable for the purpose of energy management. Such a measurement provides the team of highly qualified experts (energy management expert, expert on measurements and evaluation, technologist) with complete information about the production facilities. Thus they can prepare to the producer the objective and complex statement, and draft all the suitable and recommendable adjustments and changes in detail, which are to be realized for perfect and effective service of the production equipment.

The following main expected contributions of diagnostic audits can be mentioned:

- energy conservation
- quality improvement and reduction of reject occurrence
- output increase of the production unit
- decision on the stage of modernization, waste heat utilization, etc.

According to the results obtained in different industrial plants of several countries, energy consumption of nearly any audited device can be reduced by 5-10%, with simple measures that require no or very low investments. In some cases the percentage of reductions can be higher, even 50-60%, as for example with putting the thermal devices in or out of operation.

The experience gained from various countries proved the usefulness of diagnostic audits, which strengthen significantly the capability of their users in surveying the industrial enterprises with the aim to identify the potential and also to recommend the measures for energ. conservation, production intensification and quality improvement. Moreover, the audits supply the necessary data for decisions on modernizations and reconstructions of equipment and on waste heat utilization in production plants.

1.c Process of Diagnostic Energy Audit

The activities performed within the diagnostic audits should comprise seven fundamental steps:

- collection and analysis of projected data and historical data
- collection of factual operational values through the diagnostic measurements
- calculations, data processing
- analysis of the current situation as far as the heat balance and technological conditions of the tested equipment are concerned
- working-out the technical report including proposals and recommendations for the improvement of the operation
- implementation of the recommended measures
- evaluation of results after the realization of the proposals and recommendations.

The scheme of effective energy audits is given in Fig. 2.

A great majority of energy in industry is consumed for technological purposes. The priority of energy audits ought to be determined from this point of view.

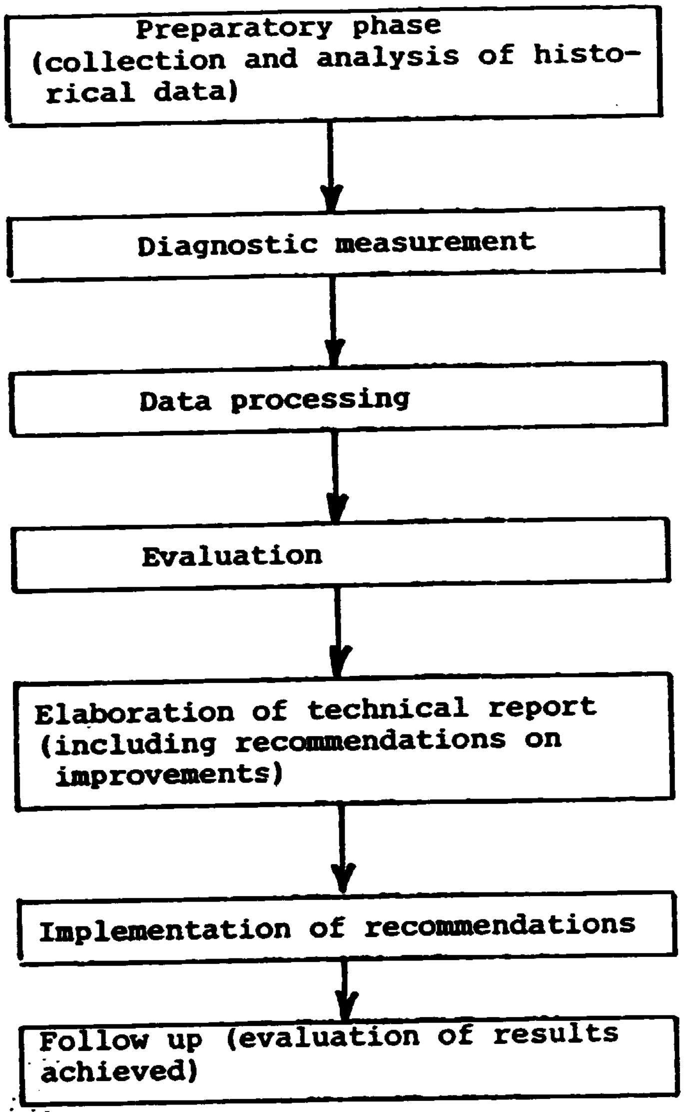


Fig. 2: Scheme of Effective Energy Audits

Depending on the type of main production processes, there can be large differences in the ways of determining energy consumption. In case of workshop-type production, because of the organization, energy consumption is examined in a combined form. During this process, both absolute consumption of the individual energy carriers has to be recorded and as far as possible, the consumptions broken down according to functions (heating, lighting, etc.). Because of the combined form, this is where measuring and recording can be performed most easily.

In case of batch production, energy consumption has to be examined of metered in the light of the recorded network map or material flow. Each group is generally specialized in the production of one given sub-unit, and energy consumption results.

The work can become more complicated with the involvement of an other unit or section, the so called co-operation activity. The consumption recorded here must be considered as part of the production energy demand.

In case of continuous production, it is practicable to determine the energy consumption of the production process with regard to the action plan by production cycles.

It is typical of the continuous production that in order to ensure steady capacity, with regard to the cycle periods, there are more than one parallel production units for many operations, and this must also be kept in mind when metering energy consumption.

Determination of the energy consumption of the main production process must be, however, completed by the determination of the processes and systems of other supporting and servicing plants, as the production process of any industrial plant is almost always supplemented by one or more other auxiliary activities, which are indispensable for the operation of the main production process. As auxiliary plants, the following processes are specified:

- boiler plants
- thermal and/or electric plants
- compressor houses
- tempering plants
- store-houses
- central assembly halls
- preventive maintenance plants
- water plants
- environmental protection and engineering plants
- cooling houses
- driers and other possible plants

When determining the energy consumption of the auxiliary plant it is again metering that comes first. The way of metering depends on the type of auxiliary plant. Metering has to cover both input and output data as these are necessary to form those specific values which, if applied into the production process, provide a truly reliable result. Thus, the dimension of the auxiliary plant energy consumption is MJ/m^3 of air, MJ/kg of cast, etc.

A remark is to be made here:

Undoubtedly, the auxiliary plant energy consumption adds to the energy consumption of the main production process, the way of distribution, however, is important. According to general financial practice, its volume and costs are usually distributed on the basis of the production value, which, from the national economy point of view is both understandable and acceptable. It would be a mistake, however, to do the same thing in the course of the audit as it would greatly distort the value of actual specific energy consumption of the main production process. In our experience, the energy consumption of the auxiliary plants have been taken into account and distributed in the light of the losses like:

- transmission loss
- distribution loss
- material loss
- processing loss
- natural loss, etc.

according to the user plant. Technical calculations and estimates as well as metering can all form the basis of the distribution.

The total energy consumption of the production can be obtained by summing up the consumption of the main production process and the consumption of the auxiliary plant connected to the main process.

2. Preparation for Energy Auditing

Auditing preplanning, including the duration of the energy measurements, is decided on the basis of the Technical Questionnaire, which is to be filled in by the customer in advance. This specification of initial information assists in planning and preparing the audit.

Description of the technical questionnaire for industrial energy audits is given below.

(1) Country, company (mailing address, phone and telex number), responsible manager, kind of production

(2) Type of equipment to be tested, producer of the equipment (if known)

(3) Characteristics of the equipment to be tested

(4) Technical parameters

(a) Energy supply (voltage, el. network frequency, gas pressure, temperature of delivered medium as e.g. drying air, etc.)

(b) Thermal process on the equipment

(5) Year of putting the equipment into operation or the last general repair

(6) Description of the present technical conditions of the equipment

(7) Kind of product, its qualitative or technological properties

(8) Firing (drying) curve of the thermal process

(a) Projected

(b) According to the current situation

(9) Average output of the equipment

(a) Projected

(b) Actual

(10) Technical parameters and consumption of fuel (energy)

(11) Method of current energy consumption measuring, available measuring equipment

(12) Contributions expected:

- Energy conservation
- Quality improvement
- Production intensification

(13) Basic drawings - assembly drawings, conception studies, prospectus of the producer, guaranteed parameters, layouts, etc. (if available).

3. Measurement in Energy Auditing

3.a Analysis of Various Energy Consuming-Units

The important factor in energy auditing of different energy consuming units is the knowledge of all necessary variables, important for energy audit evaluation, and of the right place, where to measure those variables. Although case studies, which will be presented in Volume III of the publication, will describe details of energy auditing of particular consuming units, which are the most representative for specific industries, few examples are briefly described below. Selection of these cases is based on various experience, which shows that wide potentials exist for improvement in consumption of non-electric energies, while electric energy is usually used more effectively. That is why furnaces, driers, drying mills, heat exchangers, boilers, gas producers, etc., are very promising subjects for studying from the energy conservation point of view.

Tunnel kiln

- Temperatures: environment, surface, section in the kiln, streaming gases
- Pressure: section in the kiln, in pipings, chimney's draught
- Volume flows: fuel, air, flue gases
- Analyses of flue gases: CO, CO_2 and O_2 at the chimney, kiln atmosphere
- Weight balance: fired goods, kiln furniture, kiln cars and their lining
- Electric input and output of different engines: for gas, air transport, hydraulic pusher, door, etc.

Chamber kiln

- Temperatures: time and space distribution of temperatures during the firing cycles, lining's temperatures, goods, streaming gases
- Pressure: inside the kiln during the firing cycle, in pipings, chimney's draught
- Heat flow
- Electric inputs
- Volume flows: fuel, air, flue gases
- Weight balance
- Firing cycle and cooling time

Driers

- Temperatures: entry, exit and distribution
- Humidity: drying atmosphere, dried mass
- Volume flows: hot air
- Pressure
- Speed of flow
- Mass distribution
- Analysis of energy input: combustion ratio, efficiency of heat exchangers, etc.
- Electric input

Boiler

- Flue gases analyses: CO, CO_2, O_2
- Volume and mass flows: air, flue gases, fuel and steam
- Temperatures
- Pressures
- Heat flow

Drying mill

- Temperatures: entry, exit, surface, mass
- Humidity: mass and gases
- Volume flows: air, gases, mass
- Pressures
- Speed of flow
- Heat flow
- Revolutions
- Electric input
- Amount of dust in entdusting equipment

Gas-generator, Gas Producer

- Chemical analyses (coal, producer gas)
- Wobbe's number
- Temperatures distribution
- Pressures
- Volume and mass flows

3.b Instrumentation

The principal variables measured within energy audits are usually as follows:

- temperature (ambient temperature, surface temperature)
- pressure
- flow velocity and volume flow
- heat flux density
- gases composition (O_2, CO_2, CO, SO_2, ..)
- humidity (both in gases and in solids)
- electrical values (current, voltage, power, power factor, ..)
- others (mass, time, revolution, calorific value, Wobbe number, etc.).

The instrumentation for energy auditing should be portable and heavy duty type. It should have sufficient accuracy and reliability to identify operation of industrial energetic installations. Preference should be given to locally produced or easily available instruments. The ranges of instruments should be in accordance with the requirement to cover various industrial sectors. The accuracy of this instrumentation should be checked more often than it is compulsory or usual for equipment installed in plants.

One of the most effective means to carry out the energy audits is a Mobile Diagnostic Unit (MDU) or "energy bus" e.g., a mobile laboratory, equipped with all the necessary measuring instruments, recorders, data logger and a computer enabling to perform energy audits. Being mobile, these units are capable to perform the audits in various production plants and to utilize the measuring instruments effectively. The same importance consists in the experience of the crew of experts, who are able to analyse the obtained data and the results of measures and recommend the detailed measurements for the improvements. During the visits they can transfer the advanced ideas from plant to plant and thus help to spread them.

Another means of carrying out energy auditing, convenient mainly in countries where difficulties with vehicle transportation may occur (large area countries, least developed countries, technical assistance in oversea countries, etc.), is the so called energy kit. The energy kit is a miniaturized and minimized portable set of basic instruments necessary for energy audits, which can be easily transported by car, by plane, etc. It consists for example of:

- digital pocket thermometer
- thermocouples
- recorder
- infrared thermometer
- electronical micromanometer
- Pitot tube
- digital anemometer
- digital hygrometer
- electronic analyzer (either CO_2, or O_2; combustion efficiency monitor)
- auxiliary material

The total weight of the equipment, which is to be transported, is about 50-100 kg, according to the requirement of customers.

More specifically, the Mobile Diagnostic Unit and the Energy Kit are described in part 7 of this Chapter.

3.c Measured Values and Methods

It is supposed to leave the detailed principles of measurements to the conventional text-books and the operation instructions for the instruments as well as to the manuals prepared by those instruments manufacturers, since there are actually a lot of types of similar instruments and a slight difference in the same process factor measurements. Only some useful notes of measuring methods and equipment are described in order to prevent to obtain any incorrect data.

Temperature

The choice of a sensor for temperature measurements is affected by the type of temperature which is to be measured (ambient or surface temperature), by the temperature range, the degree of accuracy required, the type of installation and the cost of instrumentation, too.

The temperature ranges normally covered by common measuring instruments are given in Fig. 3.

Fig. 3 Measuring Instruments According to Temperature Ranges

Type of instrument	Range (oC)
mercury-in-glass thermometers	-35 to 450
bimetallic thermometers	-20 to 350
gas-pressure thermometers	-90 to 430
resistance thermometers	-200 to 800
radiation pyrometers	-20 to 1750
optical pyrometers	650 to 2750
thermocouples	
type J (iron - constantan)	-200 to 800
type K (chromel-alumel) or NiCr 12.5-Ni	-270 to 1200
type T (copper - constantan)	-270 to 400
type E (chromel - constantan)	-270 to 1000
type S (PtRh10-Pt)	0 to 1600
type B (PtRh30-PtRh6)	0 to 1850
types G,C (tungsten-tungsten rhenium)	0 to 2500

To measure a temperature by a thermocouple, one needs two thermocouples: one for the actual measuring point, and one for a known stable reference point, such as melting ice, or a melting metal depending on the range.

In practice, the reference couple is not used, but a so called "cold junction compensation" is integrated in the instrument. In modern electronic instruments the compensation is often done with a resistance thermometer, put in an isothermal box together with the cold junction. The thermocouple measures the differential temperature, the resistance thermometer measures the absolute temperature of the cold junction and both are electronically added. Nevertheless, for very accurate or laboratory measurements, preference is given to reference junction

The sensitivity of the thermocouple types is given by Fig. 4.

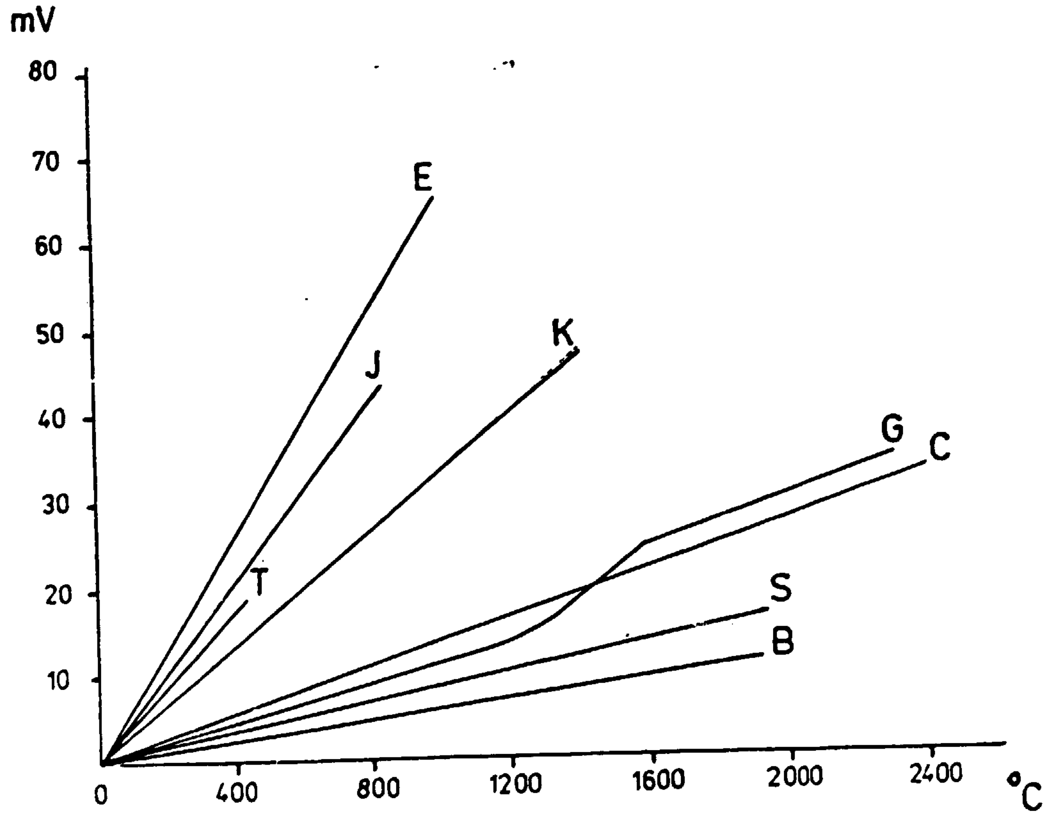


Fig. 4. Thermocouple Potentials

If the measuring point is not close to the red-out instrument, the use of a long thermocouple may become too expensive, that is why "thermocouple compesating leads" are introduced. These extension leads are generally made of the same type of thermocouple material but they are not submitted to the high temperature; so the alloy quality, the mechanical durability and the insulating material need not fulfil the requirements of the actual thermocouple. Connections are preferably made with the specially developed connectors, having a colour for every type (yellow = K) and preventing reversed connections. Thermocouples and leads have colour codes too, but these are unfortunately not universal.

Care should be taken that always the proper compensation cable is used and nothing else, that no polarity inversions are introduced and that the instrument is really one for the used thermocouple type. Any mistake of these types being introduced will lead to systematic errors.

The voltage output of a thermocouple has to be translated into temperature by the use of a thermocouple table. Of course an adapted scale or an electronic conversion simplifies the procedure.

Also for mobile measurements a voltmeter could be used for measurements without cold junction compensation, but one should not forget to add the cold junction temperature manually, after measurement with an absolute thermometer. Most practically and easily available nowadays is a pocket-size thermocouples read-out or thermosensor with cold junction compensation. Most thermosensors are supplied with a choice of thermocouple probes: universal probes, insertion probes, surface probes, molten metal probes, etc. ... and also extension leads with appropriate connectors.

Thermosensors can be used for own made thermocouples, if the precautions given above are respected.

As for the resistance thermometers, it is know that metals have an electrical resistance, dependent on temperature. This phenomenon can be used to achieve measurements with a better sensitivity and a better accuracy than thermocouples.

For universal use, materials and resistances are standardized. Most known is the Pt100, a platinum sensor with a resistance of 100 Ω at 0°C. All Pt 100's can be interchanged, as far as the read-out is concerned. Most Pt 100's have a limited temperature range (say - 200°C to + 200°C), a reproductivity of 0.1°C and an accuracy of 0.2°C. A sensor of up to 800°C will give ± 1°C resp. ± 1.4°C. Other sensors are Pt 10, Pt 1000, nickel or copper sensors and also thermistors. The latter are sintered metals or oxides, having a negative temperature coefficient.

Resistance measurement has an important disadvantage as it is never a zerocurrent measurement, so the connecting lead cause errors. With a two-wire connection, the resistance of the leads is simply added to the sensor resistance, being interpreted as a temperature rise.

Such errors can be made smaller by using shorter and better leads, but to avoid them one should use a four-wire connection where the measurement current is transported by one pair, the resulting voltage drop over the resistance is brought back by the second pair that does not need to bear a current and will not show losses. Voltage and current are electronically (or manually) computed to resistance and temperature.

An intermediate solution is presented by a three-wire connection, where the resistance of a single wire is measured and can be compensated.

Just as for thermocouples, there are convenient read-out instruments.

Due to the higher price, the smaller temperature range and flexibility, the longer stabilization time, greater sizes and less possibilities for repairs, resistance thermometry is not so popular as thermocouples, especially not for mobile measurements.

As far as the infrared thermometry is concerned, it is generally known, that every object emits heat radiation. The total amount of radiated heat is proportional to the fourth power of the absolute temperature (Kelvin temperature), and the emission coefficient of the surface. The latter one is situated between 0 and 1, for most materials somewhere about 0.9.

Infrared thermometry is based on the measurement of the radiation in a certain spectral range. Construction and choice of the instrument depend on:

- the absorption by the atmosphere between measured object and instrument
- the absorption by functional materials like glass and synthetic materials

Cheaper instruments have thermal detectors with an accuracy of 1 to 2% of full range. More expensive instruments use accurate photocells, but these have to be cooled with liquid nitrogen.

Portable infrared meters are generally hand gun shaped. They have a measuring angle of 0.5° to 3° generally, although instruments with tele-or wide-angle objectives are supplied too. The size of the measured spot depends on the instrument angle and the distance of the object, but the spot is never a point.

Although infrared thermometry looks very attractive, it is not very useful for real measurements, especially in the energy field:

- they only measure surface temperatures, which causes important errors for objects at high temperature
- the accuracy is not optimal in the low-temperature range, requiring a calibration every time
- the emissivity coefficient depends on the material and the surface condition, so it is never known exactly
- dust, vapours, smoke of flames influence the measurement
- zero setting is required before every measurement, to eliminate ambient condition influences.

Nevertheless, infrared measurements are conveniently used where:

- no alternative exists
- one is looking for certain temperature differences (rough indications, preventive maintenance).

To measure temperature peaks during a certain cycle, colour changing stickers, dimension changing tablets or pyrometric cones (as Seger cones) are available with a wide range of sensors.

For thermometers with circular scale bimetals are often used, not as flat plate composite, but spirally wound. In the instrument the bimetallic spiral is located in the bottom of the measuring tube. A spindle and gear transmission drives the needle.

Pressure

Generally speaking, as there are lots of methods and instruments for pressure measurements, for the optimum selection it is desirable to follow the suggestions of the instruments' manufacturers.

The generally known instruments for pressure measurements are as follows:

a) U-type manometers

b) inclined type manometers

c) annular balances

d) bell balances

e) Burdon tubes

f) diaphragms

g) differential bellows

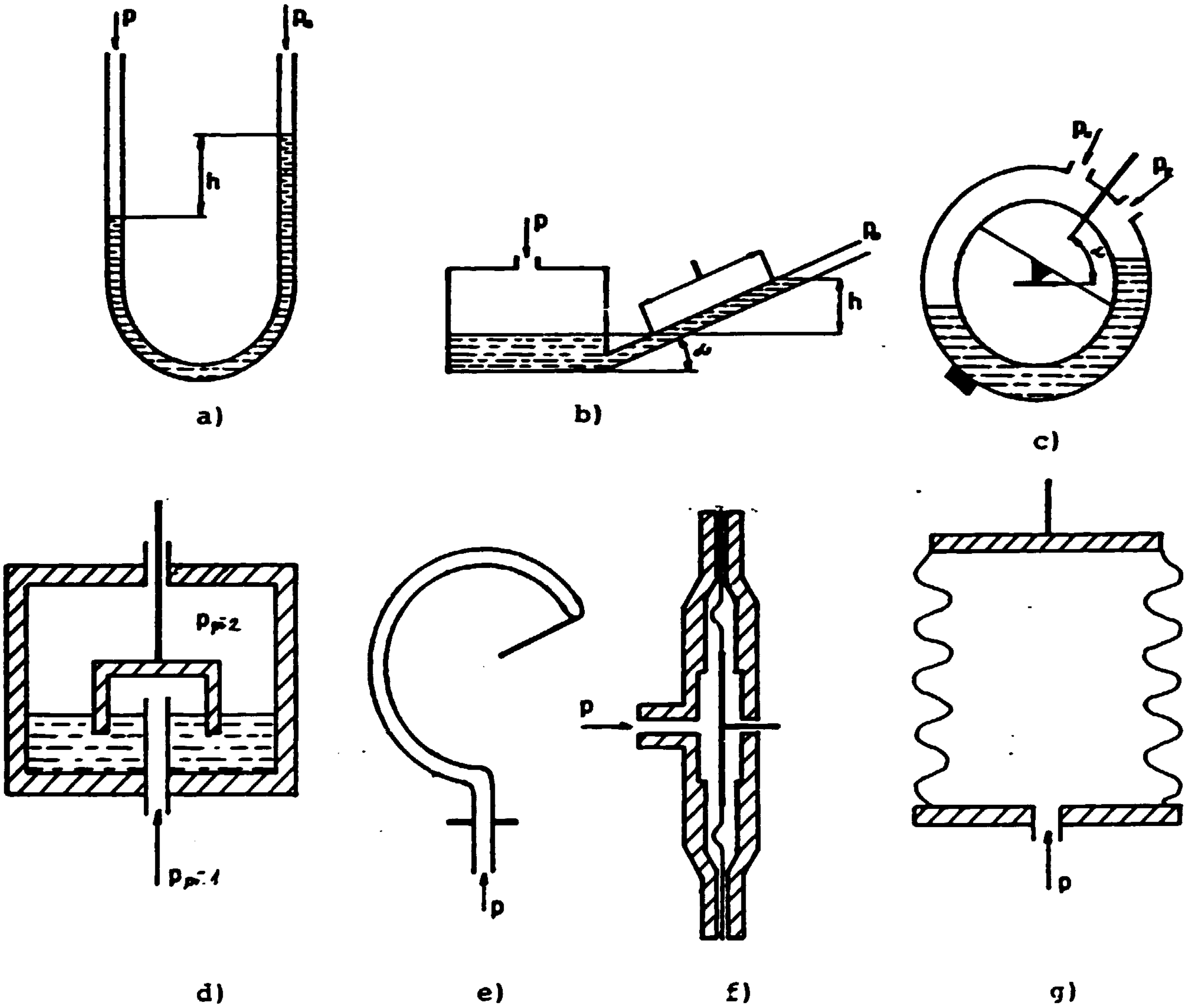
h) piezoelectric manometers

i) electronical micromanometers

Principles of some mentioned instruments for pressure measurements are presented in Fig. 5.

Fig. 5. Various Principles of Pressure Measurements

Fig. 5. Various Principles of Pressure Measurements



Pressure measurements are important from the energy conservation point-of-view, mainly the measurements of pressure distribution inside kilns and driers and chimney draught measurements. The instruments for pressure measurements are also necessary in connection with some instruments (Pitot tubes, orifices, ...) for flow velocity measurements (inclined manometers, electronical micromanometers - for differential pressure measurements).

Flow velocity and volume flow

Measuring liquids and gases is a very important and extensive field. Some of the following instruments are usually used:

- orifices, jets, Venturi's tubes) connected with differential
- Pitot's tubes) pressure measurements
- rotating flow-meters
- rotameters (variable area meters)
- electrical anemometers (hot-wire)
- mechanical anemometers (propeller, turbine)
- vortex-meters
- ultrasonic flow-meters
- annular flow-meters

The measuring methods by means of these instruments are standardized.

The proper instrument and method should be selected according to:

- the kind of fluid to be measured
- temperature and pressure
- the expected flow and the required measuring range and accuracy
- the pipe diameter
- conditions of installation and other circumstances

While liquids are practically not compressible, they are relatively easy to measure. Gases have great specific volumes, dependent on pressure and temperature which constitutes difficulties. The measurments of biphase flows, flows of evaporating liquids of condensable gases (of which saturated steam is the most common) are the most difficult.

Saturated steam is widely used for thermal processes. The energy input by means of steam is often a very difficult thing to measure.

Older steam measurement methods are:

- orifices
- condensate measurements.

An orifice is a plate with normalized bore, tightened between two flanges. The flow through the pipe is throttled by the contraction resulting in a pressure drop. Two pressure borings are made at both sides of the orifice plate and connected to a differential pressure meter. The differential pressure is, within certain limits, proportional to the square of the flow. Signal processing can be realized with dP-cells giving a proporational electric output. The measuring range is only 1 to 3 for an accuracy of 1%. Calibration is necessary - steam conditions should be well known. Orifices lose their accuracy if the steam is wet, variations of pressure inevitably lead to errors, too. To avoid flow disturbing, the steam pipe should be straight over a length of ten times the pipe diameter before the orifice and 5 x diameter behind it.

Steam measurement difficulties could be avoided by measuring the flow after condensation by hot water counters. Condensate measurements can only be safely executed if the condensate is cooled under 100°C before the steam trap. Short term measurements can be performed by cooling the condensate, this however being contradictory to energy economy measures.

Newer methods for steam measurements are:

- vortex-meters
- Pitot's tube instruments.

Vortex meters work after the principle saying that a flow forms vortices at the edge of an obstacle. From a certain flow velocity these vortices are set free from the obstacle and they are dragged along with the flow. The frequency of the vortices is proportional to flow velocity. Every vortex leaving the "shedder" creates a force on it. These force pulses, and the resulting vibrations of the shedder are measured with a piezo-electric crystal giving a frequency signal proportional to flow. The advantages of a Vortex-meter for steam measurements:

- flow range is 1 to 10 or even 20
- it is a pure volumetric measurement; even though it is calibrated for a given condition, it can easily be used for other steam conditions
- the instrument is a semi-mobile
- the connection of the Vortex-meter to the read-out devices is purely electrical, so safety is much better.

A typical requirement for Vortex-meters is to avoid parasitic vibrations (electrical, mechanical, hydraulic) that could give signal pulses, too.

Pitot's tubes are well known for measuring flow velocities in miscellaneous conditions, but not in pressurized pipes. A variant has been introduced as an alternative to orifices, to measure in pipes. It is a straight Pitot's tube with four holes at the front side and one at the back side. It is mounted perpendicularly on the pipe axis, through the pipe with a bore and connecting valves. The inner pipe diameter is determining for the choice of the probe. This instrument is more mobile than an orifice. The signal is a differential pressure just like for orifices, but the measuring range is better. It is told not to be sensitive to flow disturbances from pipe curves etc.

Heat flux (density) measurement

Heat flux measurement should not be confused with temperature measurement, although it is always the base anyhow, because heat fluxes cannot be measured directly as we know from electric currents. A "heat current" can be measured with infrared instruments or with resistance probes.

Infrared measurement at the outside of buildings or apparatus measures the contact temperature at the outside of the wall which is supposed to be determining for the radiation losses. The relation between temperature and losses is however inaccurate because parameters like ambient air temperature and velocity, surface condition, moist and radiation of the sun have an undefined influence. This method should be rejected.

Infrared measurement at the inside of buildings determines the flux through the outside walls by measuring the ambient inside temperature and the inside temperature or the outside wall. This temperature difference is relatively accurate for flux measurement because the film resistance between wall and air is hardly influenced by external parameters.

Probes with a small but defined thermal resistance, placed on the wall to be measured, will show a temperature difference between both sides. The small ΔT is measured by a thermopile (thermocouples in series). After calibration the measurement is quite accurate, presumed that the addition of the probe did not essentially change the flux through the wall, which is so far insulation materials because their resistance is much higher than that of the probe.

Gases composition

The gases are analyzed either for energy conservation or technological or some other reasons

The essential step is to control excess air at an optimum level. The results will be significant savings in reduced fuel consumption, maintenance will be reduced with the decreased formation of corrosives, and emission of pollutants will be minimized.

In practical terms the products of combustion are numerous. The selection of the key flue gas constituent to be measured involves several considerations, including relationship to excess air, to flame stechiometry and applicability to various fuels and loads. Pertinent are also the design, reliability and cost of the measuring device.

Too much excess air wastes fuel because even the air not participating in the actual burning process must be heated from ambient temperature to normal flue gas temperatures during combustion. Too little excess air wastes fuel because the air and fuel do not mix and unburned fuel goes up the stack. It can be seen in Fig. 6 that, for a slight deviation from the optimum point of operation, the losses due to incomplete combustion can be much greater than those from high excess air operation.

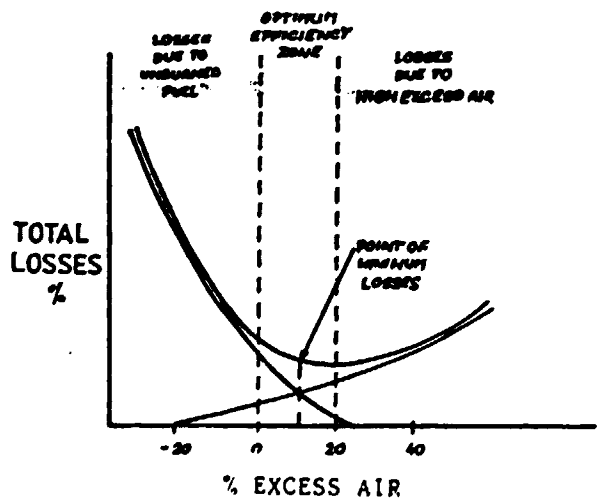


Fig. 6. Curve "Heat Losses vs. Excess Air".

The primary indication of excess air levels was traditionally CO_2. The systems were of the sampling type and required a great deal of maintenance. The CO_2 versus excess air relationship changes for each type of fuel and it is a function of the hydrogen-to-carbon ratio in the fuel (coal has the lowest H/C ratio and natural gas the highest one). Figure 7 shows examples of differences between types of fuel and a particular level of excess air:

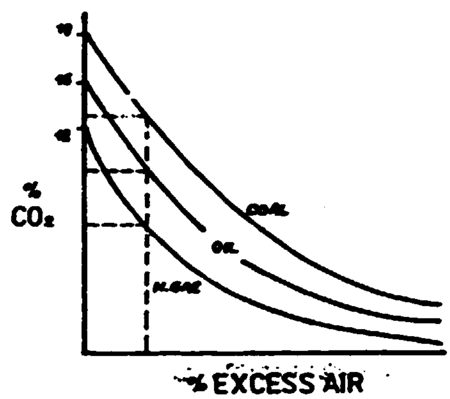


Fig. 7. CO_2 in Flue Gas vs. Excess Air for Various Types of Fuel

In addition, the same level of CO_2 in flue gas can exist both for excess air and a deficiency of air. This can be confusing; as presented in Fig. 8.

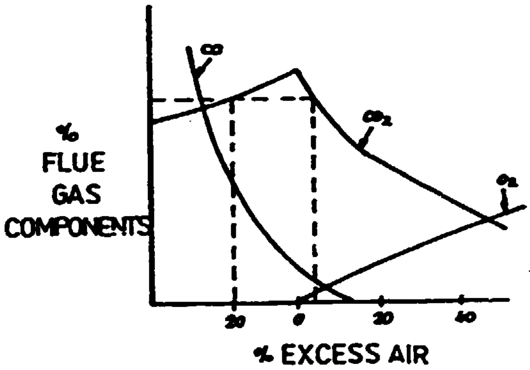


Fig. 8. Excess Air vs. Flue Gas Components

The complete test for flue gas constituents is an Orsat apparatus. This test consists of taking a measured volume of stack gas and measuring successive volumes after intimate contact with selective absorbing solutions. The volume reduction after each absorption is the measure of each constituent.

The Orsat has a number of disadvantages, the main ones are: it requires considerable time to set up and use, its operator must have a good degree of dexterity and be in constant practice. Instead of an Orsat, there are portable and easy-to-use electronic and absorbing instruments, which can determine the concentration of the constituents of interest easily on an individual basis. Set-up and operating times are minimal and anyone can learn to use them.

The typical ranges of concentrations are CO_2:0 - 20%, O_2:0 - 21% and CO - 2000 PM. The CO_2 or O_2 content alone with knowledge of flue gas temperature and fuel type allow the flue gas loss to be determined from standard charts.

The most common and inexpensive gas analysis units are :

- Fyrite carbon dioxide and oxygen analyzers
- Drager gas analysis tubes.

The fyrite sensors accept a fixed volume of gaseous sample via a manual hand pump. This sample is dry and when completely mixed with the chemicals will give a direct reading of concentration in percent of carbon dioxide or oxygen.

The drager multi gas detector consists of a hand pump and a variety of glass tubes for measuring gas concentrations from acetylene to natural gas and others in between.

The unit is extremely easy to use, compact, portable and very versatile as to the type of gases which may be measured.

In recent times a number of portable electronic flue gas analyzers have become available.

These units employ a fuel cell to sense the oxygen content in a sample of gas which is extracted from the main flow stream by a battery operated-pump. An electrical signal is generated proportional to the oxygen content. The oxygen concentration is indicated on a calibrated linear scale.

Portable infrared analyzers for checking carbon monoxide and carbon dioxide are now available. Used with care these instruments can be used to very accurately adjust fuel-fired equipment. As they continuously sample the stack gas, they have an advantage over the Fyrite and Drager sets described earlier, in that the appliance can be set over its operating range not just at one operating condition.

In recent years oxygen has gained popularity as an adequate representation of combustion conditions. With the improved electronics technology as well as the development of the non-sampling (in-situ) analyzers, O_2 has become very reliable, and is the most popular measurement employed to indicate and control excess air.

Humidity

Moisture content may be given in absolute humidity, relative humidity, dew point or water-activity in a material.

Instruments can be classified in several categories:

- Hair hygrometers: based on natural hairs, or nowadays synthetic strips that show a length variation as a function of ambient moisture; these instruments measure relative humidity.

- Psychrometers measure dry and wet bulb temperatures which, by means of a psychrometric diagram, show all other humidity factors. Modern electronic psychrometers make the conversion internally.
- Direct dew point meters measure the real dew point, which is the best physical definition of humidity. A cell with cooling regulated on the dew point indicates its temperature. Dew point control is based on electrical or optical assessment. The temperature depression by the cell is limited, but the accuracy is very high.
- Indirect dew point meters measure the dew point on a salt (lithium chloride) because this temperature is always higher than ambient, so needs a heated cell instead of a chilled cell, which makes the instrument cheaper. As salt dew point and real dew point are related, a calibrated scale finishes the job, but accuracy is lower.
- Electric humidity measuring uses cells with a material changing its electric resistance or capacitance. These instruments are the most popular ones now. There are also instruments measuring dielectric losses of materials, the losses in water being much higher than in dry materials; these instruments are specially made for material drying control.
- Infrared absolute humidity meters, based on absorption of infrared rays in water vapour.
- Neutron humidity meters (convenient for loose materials).

Electrical values

Within the measurements of electrical values, strict safety measures and limitations have to be respected. Only well trained and skilled people who have appropriate instruments can carry out these measurements.

The electricity measurements can be split into three fields:

- direct current: this field is not important for industrial energy supply
- single-phase alternating current: in this case we have to measure the power factor (cos φ)current (I) and voltage (u) or to use a wattmeter to be able to express the factual active power value
- three-phase alternating current: these systems can be measured with single-phase instruments three times, or just by assuming that the three phases are equally loaded; of course the real three-phase instruments are more convenient and more accurate; they need more connection work because they have three voltage inputs and three current inputs.

If we have to measure high powers of high currents and high voltages, we cannot use the wattmeters directly, but we have to use measuring transformers. Current and voltage measuring transformers are used to reduce the relevant values to standardized instrument values (mostly 5A and 110 V).

As the measurements of voltage, current and resistance are generally known, we would mention the power and power factor measurement only.

The cos φ - or power factor-meter measures the phase between an AC-current and an AC-voltage which is principally a single-phase phenomenon.

The usual instruments are electrodynamic or ferrodynamic where the measured current runs through the indicator, and the voltage feeds two perpendicular turning coils, the one over a series resistance, the other over a series inductance.

Cos φ - meters have a high power consumption and a poor accuracy if the voltage is not nominal or if current drops under 20% of nominal

In a single phase line the power is given by:

$$P = U \cdot I \cdot \cos\varphi$$

In a balanced 3-phase system power is

$$P = 3 \cdot U_0 \cdot I \cdot \cos\varphi$$

or

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$$

with: U = voltage between two lines
Uo = voltage between line and neutral
I = line current

cos φ has to be measured between Uo and the corresponding I

In an unbalanced system the three powers have to be added:

$$P = U_{RO} \cdot I_R \cdot \cos\varphi_R + U_{SO} \cdot I_S \cos\varphi_S + U_{TO} \cdot I_T \cdot \cos\varphi_T$$

In many situations no cos φ - metering is available, and the value shown on the tag is used. This leads often to important errors, however.

Wattmeters for single-phase measurements are electrodynamic or eventually ferrodynamic instruments; current signal through the indicator, voltage signal through the moving coil.

Wattmeters for three-phase without neutral have two instrument units on one shaft, wattmeters for three-phase + neutral have three units on one shaft. Three-phase balanced systems can be measured with a single-phase instrument, by mutliplying the result with a factor 3, and again one should not forget: voltage between line and neutral. If there is no neutral line, earth may do if the neutral point of the transformer is put at earth. Some modern electronic instruments have an additional solution on the missing neutral problem: current should be taken from one line, the voltage between the other two.

Electricity counters are inductive instruments with the same principles as wattmeters, but with a turning disc as measuring element. The disc drives a counting work.

Accuracy: 1 to 2%; under unfortunate conditions of voltage, current and cos φ the instruments are quite reliable.

The billed work factor is calculated from active and reactive consumptions (A and R):

$$\cos\varphi = \frac{A}{\sqrt{A^2 + R^2}}$$

Using kilowatthour counters as mobile instruments, one should pay much attention to make good connections, especially when measuring transformers are used. Namely, if the measuring transformers are used, then the transofmer ratio has to be taken into account to correct metters readout.

More particular material on electric energy supply systems was elaborated by Romanian Energy Auditing Sectoral Point within this project ICPE Bucharest = (Research Institute for Electrotechnical Industry) and Faculty of Electrical Engineering, University of Zagreb. It can be found as Appendix I to this manual. It deals mainly with:

- tariff system for electricity pricing
- peak load shaving
- power factor correction
- electrical power transformers
- electrical distribution networks
- electrical driving motors
- measuring means and-methods.

Other values

Some other variables have to be sometimes determined within energy audits, as for example:

- geometric dimensions
- weight
- density
- time
- revolutions
- calorific value
- Wobbe number.

Most of them are determinable with simple and/or well known standardized methods and apparatuses. The only less traditional apparatus (applied also in the prototype mobile diagnostic unit) is the Wobbe number meter. It determines the Wobbe number

$$Wo = \frac{H_G}{\sqrt{\varrho}}$$

(H_G - gross calorific value
ϱ - gaseous fuel density)

by measuring the temperature rise of a constant quantity of the air flowing through the combusted gas. The output signal is the voltage of the thermobattery which is registered by a recorder directly in values of the Wobbe number. The instrument can be adjusted for measuring of natural gas, town gas and/or generator gas. It can be successfully applied in measuring furnaces where the causes of fluctuating firing temperature are to be ascertained. The real burner output is proportional to Wobbe number.

4. Data Processing and Evaluation

Compilation of an energy balance is a fundamental step for analysis of the energy consumption situation. All forms of energy, such as thermal, electric, chemical, etc., may be involved in any process. Thermal energy is usually the most important matter when dealing with combustion, calcination, firing or similar processes. Therefore, this part would be mainly concerned with calculations of thermal energy. Some basic formulas concerning electric energy calculations have been mentioned before, in the section dealing with electric values measurements.

For energy balance compilation, the process schematic flow sheets or the block flow sheets should be drawn first, with the directions of inlet and outlet flows of energy, raw materials, fuel, steam, air cooling medium, products, etc., around the facilities. The balance boundary barrier should be chosen properly with considering the available data so as to lessen unkown factors. The individual items of the balance should be determined under defined (if possible stable, average) conditions of the process. Some of them can be measured directly, other ones must be calculated.

Besides energy balance other important matters are to be determined within energy audits as for example combustion process efficiency, technological parameters (temperature distribution, moisture, pressure, chemical composition of the atmosphere in the measured device), etc.

As case studies, several examples of most frequent calculations should be mentioned.

4.2. Examples of calculations

a) Gas density

$$\varrho^{o}_{g} = (1.257\ N_2 + 1.429\ O_2 + 1.25\ CO + 1.977\ CO_2 + 0.0899\ H_2 + 0.717\ CH_4 + 1.26\ C_2H_4 + 2.019\ C_3H_8 + 2.668\ C_4H_{10} + m_{H_2O} + m_T) \cdot (1 + m_{H_2O}/0.804)^{-1}\ [kg/m_n^3]$$

N_2, O_2, ...-ratio of N_2, O_2, ... in gas $[m_n^3/m_n^3]$

m_{H_2O} - water content in gas $[kg/m_n^3]$

m_T - tar content in gas (for generator gas mainly) $[kg/m_n^3]$

$$\varrho_g = \varrho^{o}_{g} \cdot \frac{273}{101,325} \cdot \frac{p_g}{t_g + 273}\ [kg/m^3]$$

p_g, t_g - pressure (kPa) and temperature (°C) of the gas

b) Net calorific value of gaseous fuel

$$H_n = 12\ 645\ CO + 10\ 750\ H_2 + 35\ 850\ CH_4 + 64\ 019\ C_2H_4 + 93\ 570\ C_3H_8 + 123\ 550\ C_4H_{10} + 59\ 950\ C_nH_m + 36\ 430\ m_T\ [kJ/m_n^3]$$

(denotations as in a))

c) Net calorific value of liquid fuel

$$H_n = 418,7 \cdot [81\ C + 290\ (H - 0/8) + 25\ S - 54\ H]\ kJ/kg$$

C, H, O, S - weight ratio of the elements in the fuel $[kg/kg]$

d) Combustion of gaseous fuels

$$V_{O_2t} = 0.5\ CO + 0.5\ H_2 + 2\ CH_4 + 3\ C_2H_4 + 5\ C_3H_8 + 6.5C_4H_{10} + $$
$$+ 3.67\ C_nH_m - O_2 + 1.96\ m_T$$

$V_{N_2t} = V_{O_2t} \cdot 79/21$ (if no additional oxygen is supplied besides air)

$V_{at} = V_{O_2t} \cdot 100/21$ (if no additional oxygen is supplied besides air)

$$V_{N_2CPt} = N_2 + V_{N_2t}$$

$$V_{CO_2CPt} = CO + CO_2 + CH_4 + 2C_2H_4 + 3\ C_3H_8 + 4\ C_4H_{10} + 2.45C_nH_m +$$
$$+ 1.57\ m_T$$

$$V_{H_2OCPt} = H_2 + 2CH_4 + 4C_3H_8 + 5C_4H_{10} + 2.45\ C_nH_m +$$
$$+ 0.884\ m_T + m_{H_2O}/0.804$$

$$V_{CPdt} = V_{N_2CPt} + V_{CO_2CPt}$$

$$V_{CPt} = V_{CPdt} + V_{H_2OCPt}$$

$$CO_{2\ CP\ max} = V_{CO_2CPt}/V_{CPdt}$$

$$V_{CPd} = V_{CO_2CPt}/CO_2\ CP$$

$$V_{CP} = V_{CPd} + V_{CP\ H_2Ot}$$

$$n = (V_{CPd} - V_{CPdt}) / V_{at} + 1$$

$$V_a = n \cdot V_{at}$$

$CO, H_2, \ldots, m_T, m_{H_2O}$ - as in a)

$CO_{2\ CP\ max}$ - maximum possible content of CO_2 in combustion products (stochiometric conditions) $[m_n^3 / m_n^3]$

$CO_{2\ CP}$ - real content of CO_2 in comb. products $[m_n^3 / m_n^3]$

V_{O_2t}, V_{at} - theoretical columes of oxygen and air for combustion of 1 m_n^3 of gas $[m_n^3 / m_n^3]$

$V_{N_2\ CPt}, V_{CO_2CPt}, V_{H_2O\ CPt}$ - theoretical volumes of N_2, CO_2 and H_2O in combustion products from 1 m_n^3 of gas $[m_n^3 / m_n^3]$

V_{CPdt}, V_{CPt} (V_{CPd}, V_{CP}) - theoretical (real) volumes of dry and wet combustion products from 1 m_n^3 of gas $[m_n^3 / m_n^3]$

n - air excess coefficient

V_a - real volume of air supplied for combustion of 1 m_n^3 of gas $[m_n^3 / m_n^3]$

e) Vogel´s formulas for combustion of natural gas

$$V_{at} = 2.651 \cdot 10^{-4}\ H_n$$

$$V_{CPt} = 2.938 \cdot 10^{-4}\ H_n$$

$$V_{CP} = (2.651\ n + 0.287) \cdot 10^{-4}\ H_n$$

H_n - net calorific value of natural gas $[kJ/m_n^3]$
other denotations as in d)

f) Rosin´s formulas

- for solid fuels, $H_n > 21\ 000$ kJ/kg:

$$V_{at} = 2.41 \ .\ 10^{-4}\ H_n + 0.5 \left[m_n^3\ /\ kg\right]$$

$$V_{CPt} = 2.19 \ .\ 10^{-4}\ H_n + 1.5 \left[m_n^3\ /\ kg\right]$$

$$V_{CP} = (2.41\ n - 0.23)\ .\ 10^{-4}\ H_n + 0.5\ (n+2) \left[m_n^3\ /\ kg\right]$$

- for solid fuels, $H_n > 21\ 000$ kJ/kg:

$$V_{at} = 2.41 \ .\ 10^{-4}\ H_n$$

$$V_{CPt} = 2.63 \ .\ 10^{-4}\ H_n + 0.4$$

$$V_{CP} = 2.63 \ .\ 10^{-4} n\ H_n + 0.4$$

- for liquid fuels (oils):

$$V_{at} = 2.10 \ .\ 10^{-4}\ H_n + 1.65$$

$$V_{CPt} = 2.65 \ .\ 10^{-4}\ H_n$$

$$V_{CP} = (2.10\ n + 0.55)\ .\ 10^{-4}\ H_n + 1.65\ (n-1)$$

(denotations as in d))

g) Enthalpy (thermal content)

- for solids and liquids:

$Q = m\ .\ c\ .\ (t-t_e)$ (kJ)

m - weight (kg)

c - specific heat (kJ / kg·K)

$(t - t_e)$ - temperature difference (K)

- for gases:

$$Q = V \cdot c \cdot (t - t_e)$$

V - volume (m^3)

c - specific heat ($kJ / m^3 \cdot K$)

note: c is not a constant value - it depends on temperature; for example for dry air:

$$c_{da} = 1.294 \cdot 10^{-3} \cdot (996 + 0.095\, t_a) \left[kJ / m_n^3 . K\right]$$

h) Calculation of mean flow velocity and volume flow from Pitot's tube measurements

$$v_i = \sqrt{2 p_{dyn\ i} / \rho_g} \quad (m/s)$$

$$\bar{v} = \frac{1}{A} \cdot \int_A v\, dA \longrightarrow \frac{1}{A} \cdot \sum_i v_i \cdot \Delta A_i \quad (m/s)$$

if $A_1 = A_2 = \ldots = A_N$, then

$$\bar{v} = \frac{1}{N} \cdot \sum_{i=1}^{N} v_i \quad (m/s)$$

$$V = A \cdot \bar{v} \quad (m^3/s)$$

$$V_e = V \cdot \frac{p_g}{t_g + 273} \cdot \frac{273}{101,\ 325} \quad (m_n^3\ /s)$$

ρ_g, t_g, p_g - density (kg/m^3), temperature (°C) and pressure (kPa) of the measured gas

$p_{dyn\ i}$, v_i - dynamic pressure (Pa) and velocity (m/s) in certain point of the piping

$\bar{v}$ - mean flow velocity in cross-section of the piping (m/s)

A - area of the piping cross-section (m^2)

V, V_o - volume flow (m^3/s) and normal volume flow in the piping

i) Static draught of a chimney

$$p = L\,(\rho^{\circ}_{a} \cdot \frac{273}{t_a + 273} \cdot \rho^{\circ}_{CP} \cdot \frac{273}{t_{CP} + 273}) \cdot 9.80665 \text{ (Pa)}$$

L = chimney height (m)

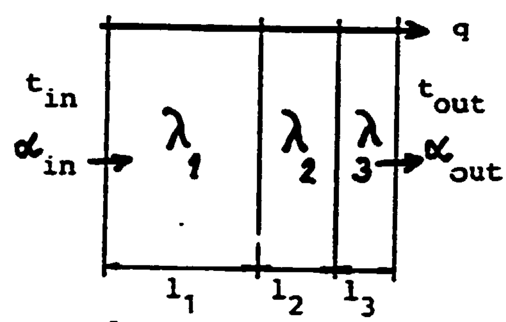
ρ°_{a}, ρ°_{CP} - normal density of air and combustion products (kg/m^3_n)

j) Heat transfer through a several-layers wall

$$q = k \cdot (t_{in} - t_{out}) \quad (W/m^2)$$

$$1/k = 1/\alpha_{in} + \sum_i \frac{l_i}{\lambda_i} + 1/\alpha_{out}$$

$(m^2\ K/W)$



k, α - heat transfer coefficients (W/m^2K)

λ_i - thermal conductivity coefficient (W/mK)

l_i - thickness of insulation layers (m)

k) Heat transfer coefficient

Calculations of these values are rather difficult and not very accurate. They are usually based on relations between non-dimensional criterias

$$Nu = f\,(Fo, Pr, Re, Gr, \Gamma, \ldots)$$

which can be found in great number in specialized literature.

There are also many empiric equations, as for example:

$\alpha = 7.9 + 0.053\ t_w \quad (W/m^2K)$

(for brick vertical walls)

t_w - surface temperature of the wall (°C)

$\alpha = 7.0 + 0.043\ t_w$

(for vertical walls with alumina surface)

<u>1) Heat for drying a material (theoretical amount)</u>

$$Q = m_d \cdot \frac{w_{in}}{1 - w_{in}} \cdot \left[4.19\ (100 - t_{in}) + 2\ 258\right] \quad \text{(kJ)}$$

m_d - weight of dry material (kg)

w_{in} - humidity of inlet material (kg/kg)

t_{in} - temperature of inlet material (°C)

The calculations that have been mentioned and other similar simple ones can be carried out with a pocket programmable calculators, which enable quite prompt compilation of the energy balance items.

4.b. Computerized Data Processing

To facilitate complex calculations and evaluation of energy consumption situation, a number of computer programs has been developed and widely applied. The exact software package is usually determined on the basis of actual needs and specific conditions of the industries to be audited. As an example, a computerized system for energy auditing in ceramic industry is described in Part 7 of this Chapter.

Another example may be a set of computer programs which are being used within the European Economic Community Energy Bus Programme. The EEC Energy Bus Programme aims at assisting mainly small and medium-sized industrial companies and it is oriented towards carrying out one day preliminary energy audits. A set of computers analysis programs, especially designed for such audits, enables the audit team to analyse and calculate potential energy and cost savings by processing the data which are relatively easy to obtain. The software package can only give rough estimates of the energy conservation potential. It does not investigate the internal efficiency of industrial processes or equipment.

The following computer programs of the EEC Energy Bus package may be listed:

Insulation

Calculations of possible energy savings can be made:

- insulation
- reducing temperatures
- avoiding stratification
- assuring certain operation changes
- double glazing

<u>Ventilation</u>

This program permits the calculation of possible energy savings if the operating parameters of the existing equipment are changed and if a heat recovery unit can be used or its efficiency increased.

The following modifications may be examined:

- equipment improvement
- ventilation volume reduction
- stratification reduction
- temperature set-back
- infiltration reduction
- solar gain increase
- reduction of operating hours
- combustion efficiency improvement
- heat recovery improvement or installation.

<u>Process heat</u>

Application program which calculates the theoretical heat losses and potential energy recovery from hot air discharged into the atmosphere. If recovered heat can be used, the corresponding fuel savings may also be calculated.

This calculation program examines:

- heat recovery installation
- combustion efficiency improvement
- hot water use reduction
- process water use reduction
- process efficiency improvement.

Hot liquid tanks

This program calculates the possible advantages of insulating the walls of tanks and covering the surface of open tanks by floating spheres. It is suitable for closed or open tanks, rectangular or circular tanks. The estimations are made assuming number of fixed data in the case of open tanks. Energy saving possibilities are based on calculation of heat losses, before and after insulation and expressed as the difference in the amount of fuel.

The hot liquid tanks program can also be used to calculate heat losses and potential savings from heat distribution systems (hot water or steam pipes).

Water recovery

Calculation of this program can show the energy savings obtained when the heat content of waste water is used, either by recuperation or by recirculation.

For calculation are considered:

- temperature of the water at the intake
- temperature of hot waste water
- costs of water and sewage.

Energy savings may be estimated assuming:

- different heat recovery efficiencies, and
- different recirculation volumes.

Savings can be expressed as fuel savings or as reduction in water volume heated. The program can lead to recommendations in the areas of domestic hot water and process water reduction and also heat recovery installations.

The possibility for reuse of recovered heat or the feasibility of recirculation of the temperature, sufficiently high for exchange, are to be considered.

Heating of buildings

This program calculates the total energy use for heating a building. Total energy use is based on calculation of respective the transmission losses, infiltration losses and ventilation losses. In contrast to the insulation and ventilation program, by which only simple buildings or systems can be calculated, the heating program allows the calculation of complex buildings or systems and calculates the combined effect of transmission, ventilation and infiltration losses on the heating bill.

Efficiency of boilers

This program computes actual and improved flue gas losses and annual energy and cost savings resulting from reduced flue gas losses.

Data input includes:

- fuel type: gasoil, light, medium or heavy oil, natural gas (Slochteren or rich natural gas) and coal
- flue gas temperature
- carbon dioxide content
- combustion air temperature
- annual fuel consumption (actual)
- fuel costs

Program output contains:

- actual energy use in MJ or Mcal and actual costs
- improved energy use in MJ or Mcal and costs
- energy and cost savings
- coefficient of Siegert (actual and improved)
- boiler efficiency (actual and improved)

<u>Compressed air</u>

This program computes actual energy use and energy costs for compressed air production. Improved energy use and resulting energy and cost savings can be calculated for five different energy saving methods:

- reduction of compressed air consumption
- temperature reduction of the aspirated air
- reduced compressed air pressure
- replace compressor by more efficient compressor
- heat recovery on compressor

Data input includes: compressed air pressure, compressed air output volume, aspirated air temperature, compressor power, idle power (off-power), total operation time, loading factor, electricity cost and data on heat recovery and on heat demand.

Program output contains:

- actual and improved energy use and costs
- specific energy consumptions per m^3_n compressed air
- annual production of compressed air
- recovered compressor heat and fuel savings in boiler house.

<u>Molier</u>

This program computes essential the enthalpy difference between two points on the Molier diagram for wet air. Also relative humidity specific volume and enthalpy of the starting and the end point are calculated.

The program can be used to calculate operation conditions for:

- heat recovery on wet gas streams
- recirculation on drying systems
- economizer on boiler
- condensating heat recuperating systems of both indirect and direct contact type
- air conditioning heat exchangers
- heat pump heat exchanger components
- air heating or humidification systems.

Data input: absolute humidity and temperature of starting point, temperature after recuperation, type of recuperator (direct or indirect), fuel type and fuel cost, exhaust volume, operating hours, atm. pressure.

Program output: conditions at starting and at end point, recovered latent and sensible heat, annual savings.

5. Audit Report

All the projected data, gathered historical data, measured data and calculated results are the base for the elaboration of the Audit report by qualified and experienced experts. This report contains the major energy characteristics of the economic unit under review, the analysis and synthesis of the audit and the recommendations aiming to reduce or eliminate energy losses.

Taking into account that auditing is a complex activity and summing up and analyzing the results, it is important to make the report using a uniform structure and presentation. The following paragraphs outline the recommended structure of Audit reports made for industrial plants. In case of economic units belonging to other sectors of the national economy, it is also necessary to write reports of a similar structure and the "Action Plan" made in a tabular form will be uniform.

Structure of Audit report for industrial plants

1. Comprehensive comments and proposals (Fig. 8)

2. Action plan for reducing energy losses (Fig. 9)

3. Description of activity

   3.1 Background

   3.2 Aim of the study

   3.3 General information

      3.3.1 Name of the enterprise and its supervisory authority

      3.3.2 Brief description of the activity of the factory

      3.3.3 Structure of the energy organization

      3.3.4 Description of production data (for 2-3 years)

4. Tehcnical and economic analysis of the energy consumption of the factory (based on data from 2-3 years; (see: Figures 10 & 11)

   Analysis and evaluation of the tables

5. Energy analysis of technological processes and equipment

   5.1 Description of technological processes and equipment

   5.2 Energy analyses of technological processes and equipment (metering, calculation, comparison, etc.)

   5.3 Evaluation of technological processes and equipment with a view to energy

6. Study of instrumentation and control

7. Examining the level of capacity utilization and organization

8. Study of auxiliary plant equipment

   8.1 Analysis of heat performance of buildings

   8.2 Study of heating system

   8.3 Study of hot water management

   8.4 Study of boiler plant

8.5 Examination of boiler-feed make-up

8.6 Study of condense network

8.7 Study of ventilation

8.8 Study of cooling system

8.9 Study of water pipeline network

8.10 Examination of sewage treatment

8.11 Study of energy distribution systems (steam, electric)

8.12 Study of internal and external lighting

8.13 Examination of power factor improvement

8.14 Study of compressed air system

9. Study of peak load control

9.1 Examination and load limitation

9.2 Study of power purchase from supply system

10. Examination of possibilities for co-operation in the field of energy

11. Study of operational and maintenance activities

12. Summary and economic analysis of proposals

Fig. 9. Comprehensive Comments and Proposals

No.	Sources of loss	Loss		Eliminat. method	Loss elimination potential		Cost of imple-mentation in currency unit/yr	Payback time year	Remarks Code No.
		GJ/yr	in currency unit /yr		GJ/yr	in currency unit/yr			

Fig. 10 Action Programme for Reducing Energy Losses

No.	Proposed measures	Proposed schedule	Name of person responsible	Expected saving		Estimated cost of the taken measure in currency unit	Payback time year	Remarks
				GJ/yr	in currency unit /yr			

Fig. 11 Energy Turnover in 1986 and 1987

No. Energy carrier	year 1986			year 1987		
	t	GJ	in total %	t	GJ	in total %
1. Natural gas						
2. Petrol						
3. Gas oil and fuel oil						
4. Electric power MWh						
5. Other						
Total						

Fig. 12 Energy Consumption on a Monthly Basis in the Years 1986 and 1987

	1986						1987					
Month	electric power			natural gas			electric power			natural gas		
	KWh	GJ	%	m^3	GJ	%	KWh	GJ	%	m^3	GJ	%

6. Measures for improvement

6.a General considerations

Proposals of technical, technological, operational and/or organizational measures for improvement of economic efficiency are to be elaborated as the most important part of each energy audit. They are presented to the owner of the tested device to enable him to reach energy conservation, quality improvement and/or production intensification.

To decide the priority of carrying out energy conservation measures, it is necessary to review the following conditions:

- amount of energy used in technical and financial units
- energy consumption rate, in technical and financial units
- total of investments, necessary for energy savings
- payback period of invested capital
- degree of difficulty or technical feasibility
- effects reached from financial, technical, market and other points of view
- continuity and stability of energy savings and products processing

However, it is general to carry out the energy conservation measures in the following order:

- first step: intensification of energy consumption control (review and observation of operation standard, facility control standard and maintenance standard; elimination of uselessness, unreasonableness and irregularity; training and motivation of employees)
- second step: introduction of energy conservation equipment (automation of energy consuming processes, waste energy recovery, etc.) A short overview of the methods for energy consumption control and monitoring is given in Appendix II by the Faculty of Electical Engineering, University of Zagreb.

- third step: improvement of process and/or system (introduction of up-to-date technologies and facilities having high energy consumption efficiency).

Selected measures for thermal energy and electric energy conservation are recommended in the following paragraphs.

6.b Thermal energy

a. Control of combustion conditions (O_2 or OC_2 control in a flue gas).

Some methods how to calculate air excess coefficient have been described in previous chapters. Nevertheless, it could be interesting to state as an example the standard criteria of air excess coefficient, which are presented in Japanese standards for boilers (Fig. 13)

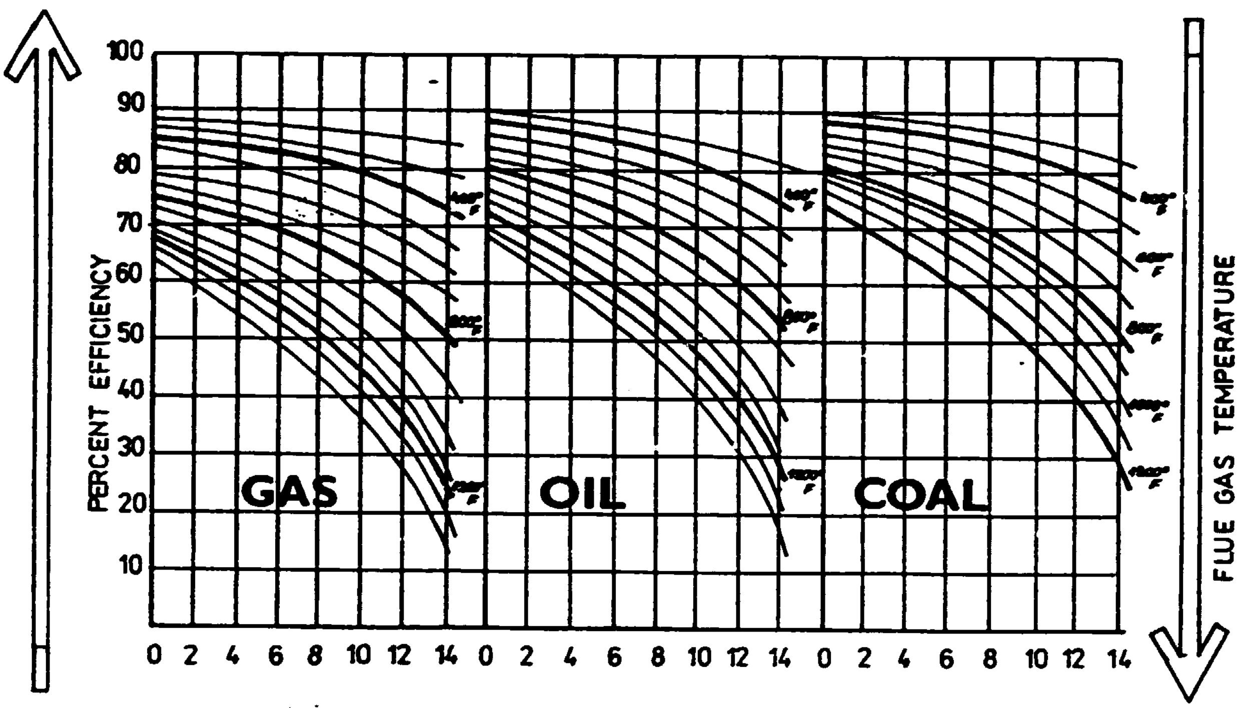
Fig. 13 Air Excess Coefficient

Item	Loading (%)	Air Excess Coefficient		
		Solid fuel	Liquid fuel	Gaseous fuel
Boilers for Electricity Supply	75-100	1.2-1.3	1.05-1.1	1.05-1.1
Other Boilers:				
- over 30 t.h	75-100	1.2-1.3	1.1-1.2	1.1-1.2
- 10-30 t.h	75-100		1.2-1.3	1.2-1.3
- under 10 t.h	75-100		1.3	1.3

5. Effects of the temperature of flue gases.

The higher the flue gas temperature, the worse the thermal process efficiency (Fig. 14)

Fig. 14 Flue Gas Exit Temperature Effect



% O_2 in flue gas

The decrease of flue gas temperature is limited by the dew point (because of corrosive effects).

c. Effects of waste heat recovery

Waste heat is heat which is generated in a process but then is dumped to the environment even though it could still be reused for some useful and profitable purpose.

Waste heat is normally available in the form of sensible heat of work (i.e extra heat content of work which is hotter than the environment) or jacket heat losses of the furnace. It is normally released to and degraded in the surroundings and quickly loses its value. In fact, it is the value of that heat being discharged which should be identified and - if possible - recovered. The utilization can include a simple heat exchanger for preheating combustion air, oil, water or reactants, or it could include the operation of a heat engine such as waste heat boiler or a turbine to obtain steam or electricity.

Sources of waste heat can be divided according to their temperature into three temperature ranges. The high temperature range refers to temperature above 650°C. The medium range is between 230°C and 650°C and the low temperature range is below 230°C.

High and medium temperature waste heat can be used to produce process steam. If one has high temperature waste heat instead of producing steam directly he should consider the possibility of using the high temperature energy to do useful work before the waste heat is extracted. Both gas and steam turbines are useful and fully developed heat engines.

In the low temperature range, waste energy, which would be otherwise useless, can sometimes be made useful by application of mechanical work through a device called the heat pump.

The combustion of hydrocarbon fuels produces flue gases in the high temperature range. The maximum theoretical temperature in atmospheric burners is somewhat under 1650°C, while measured flame temperatures in practical burners are just under 1500°C. Secondary air or some other dilutent is often admitted to the burner to decrease the temperature of the combustion products to the required process temperature, for example to protect equipment, thus decreasing the practical waste heat temperature.

The brief list below gives some examples of temperatures of waste gases from various industrial processes:

- glass melting furnace	800 - 1200°C
- cement rotary kiln	600 - 750°C
- open hearth furnace	650 - 750°C
- annealing furnace cooling system	430 - 650°C
- drying and baking ovens	250 - 650°C
- heat treating furnaces	420 - 650°C
- steam boiler exhausts	250 - 500°C
- process steam condensate	55 - 90°C
- cooling water	30 - 90°C
- air-conditioning and refrigeration condensers	30 - 45°C

To use waste heat from sources such as those above mentioned it is necessary to transfer the heat in one fluid stream to another (e.g. from flue gas to feedwater or combustion air). The device which accomplishes this transfer is called a heat exchanger.

Heat exchangers used to recover waste heat can range from something as simple as a pipe, a furnace channel or duct to something as complex as a waste heat boiler.

Several types of heat exchangers and other possibilities of waste heat utilization are given in the following figures:

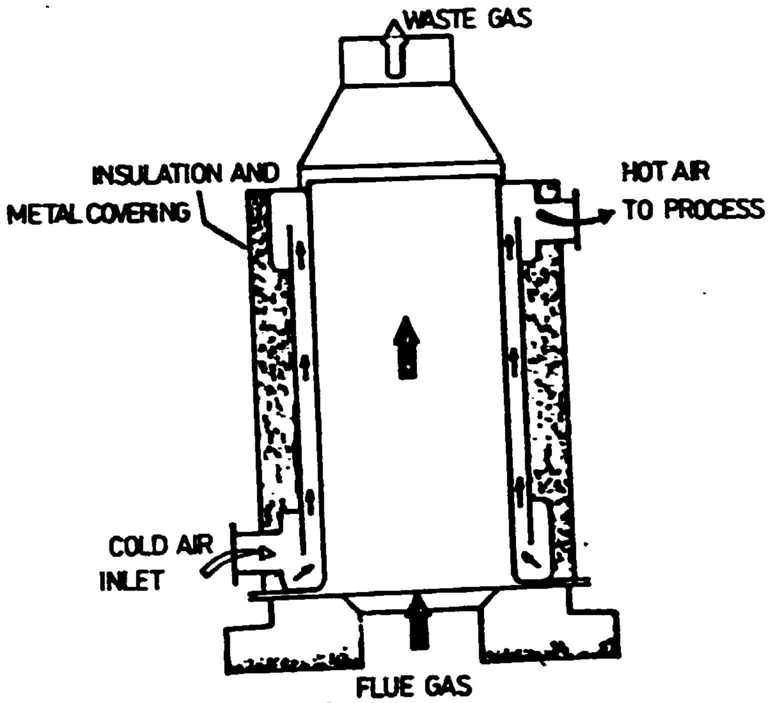


Fig. 15 Metallic Radiative Recuperator

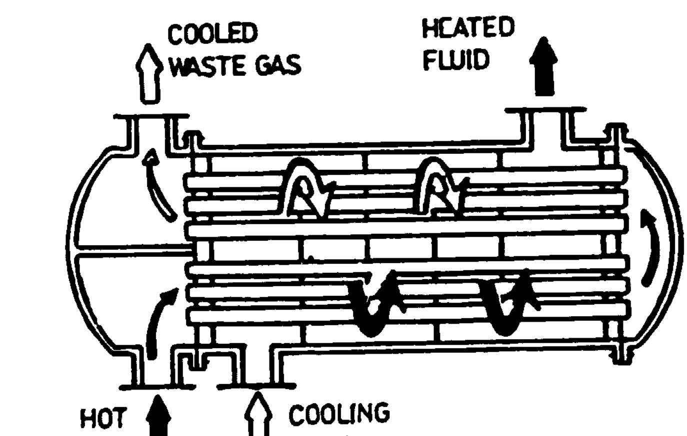


Fig. 16 Convective Type Recuperator

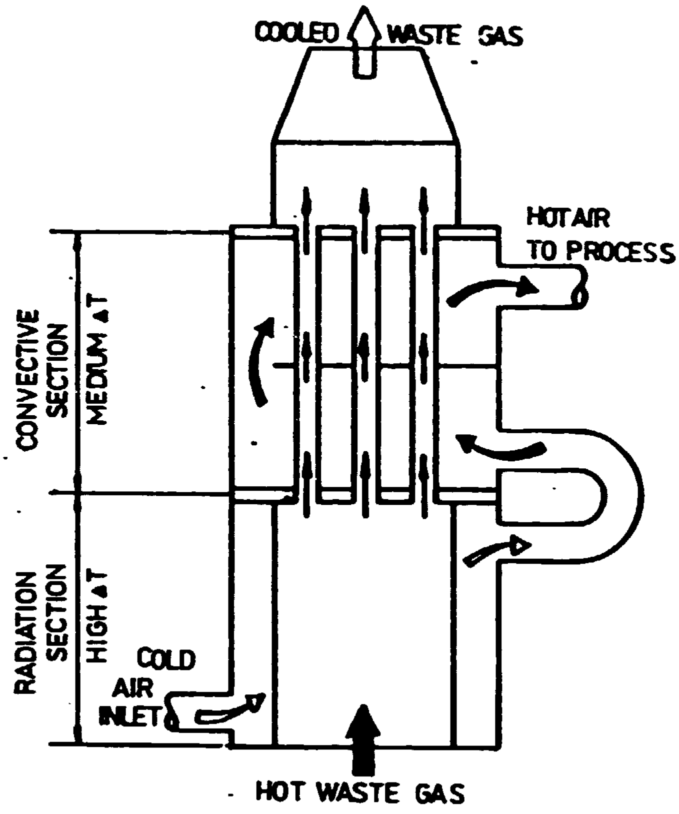


Fig. 17 Combined Radiative and Convective Recuperator

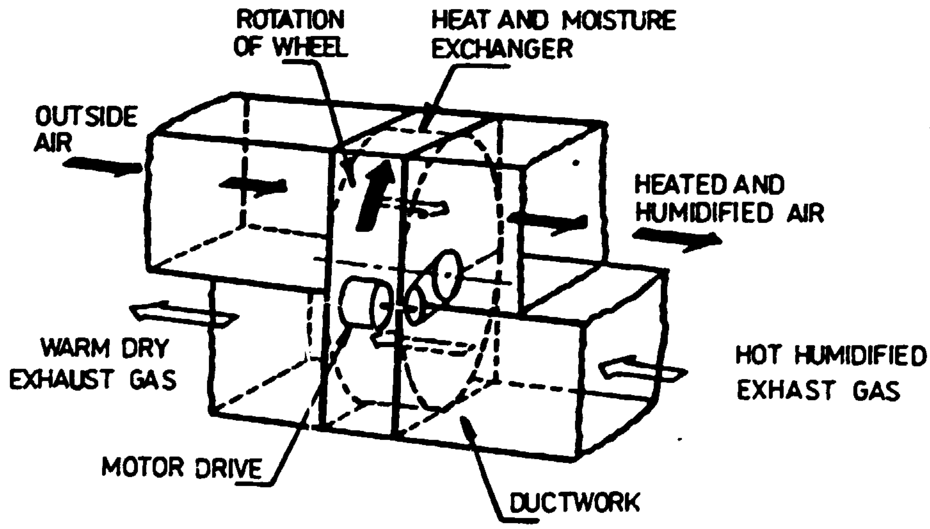


Fig. 18 Heat Wheel Type Recuperator

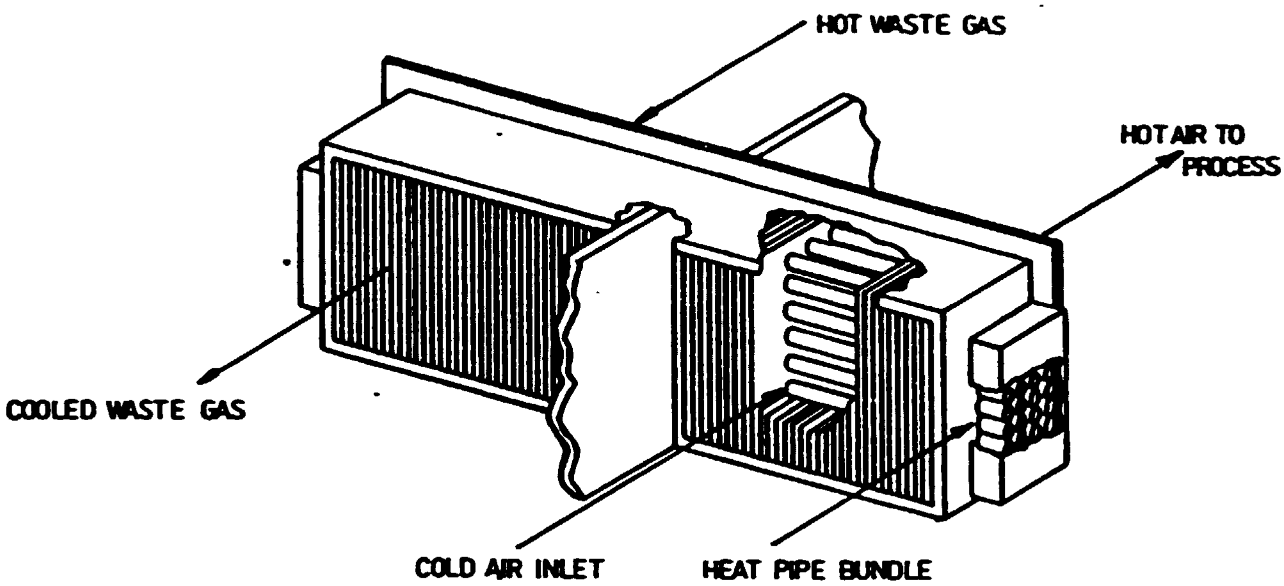


Fig. 19 Heat Pipe Bundle Incorporated in Gas to Gas Regenerator

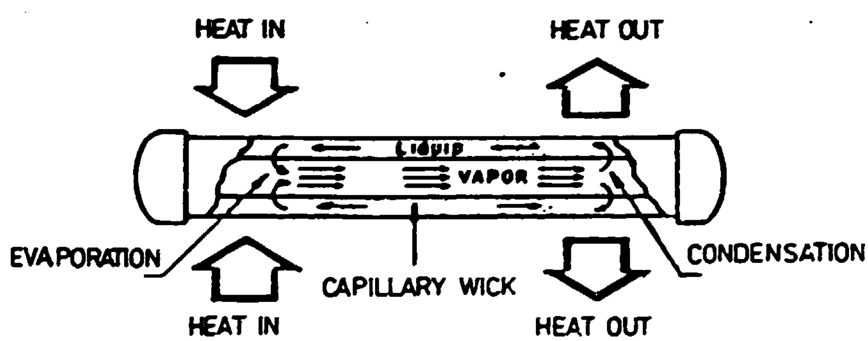


Fig. 20 Heat Pipe Schematic

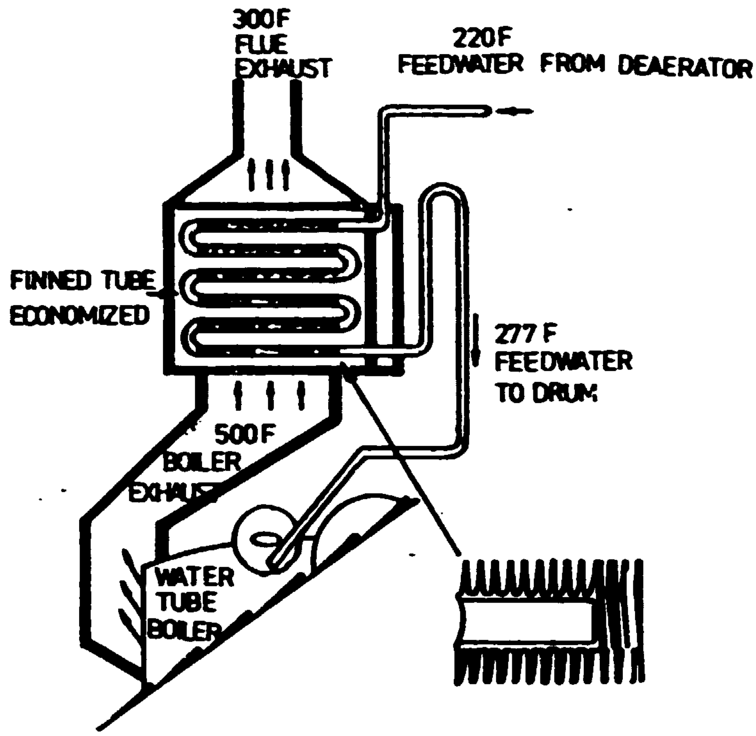


Fig. 21 Finned-tube Gas to Liquid Regenerator (Economizer)

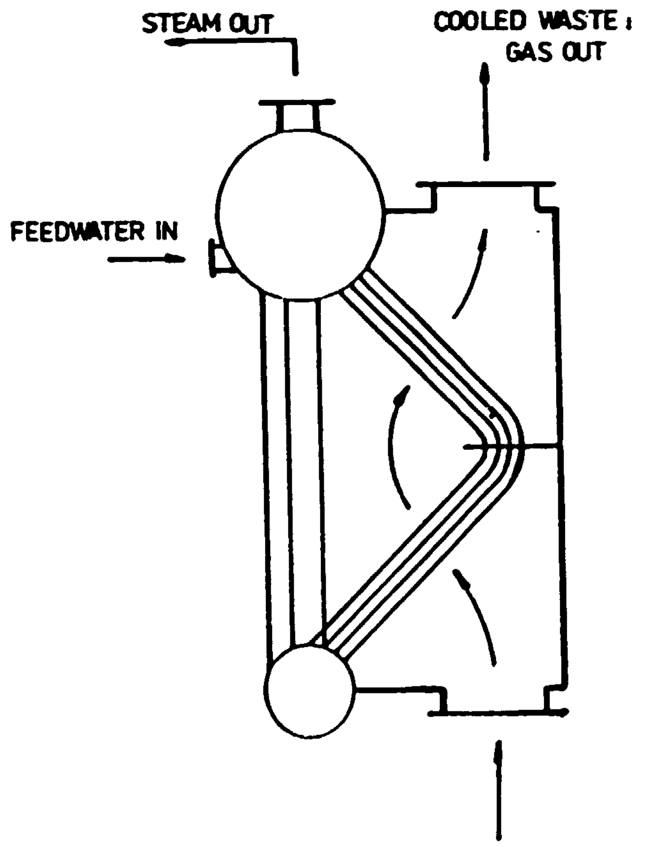


Fig. 22 Waste Heat Boiler

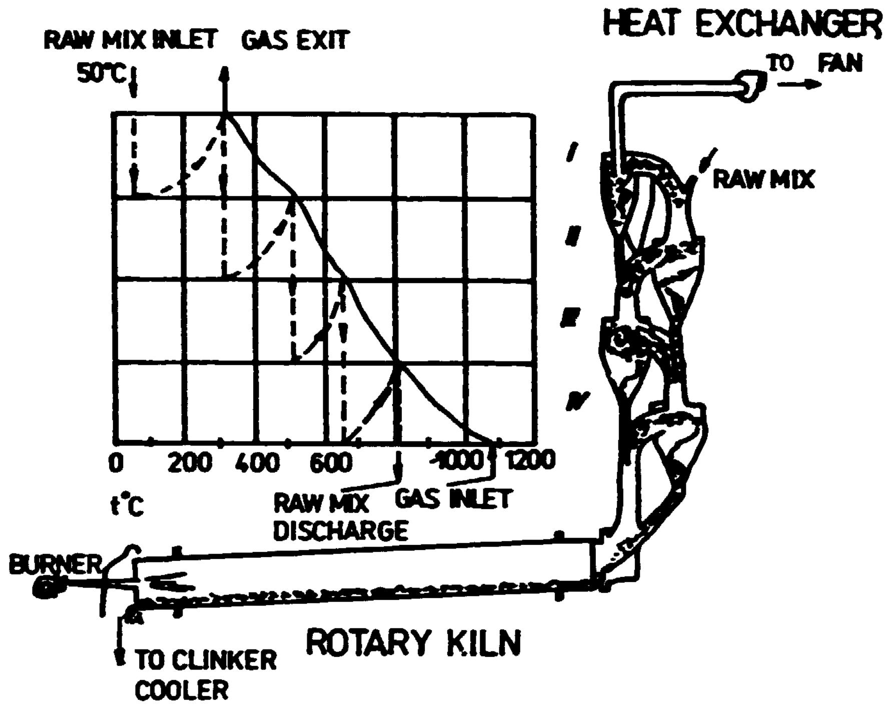


Fig. 23 Waste Heat Recovery in a Cement Rotary Kiln by a Preheater

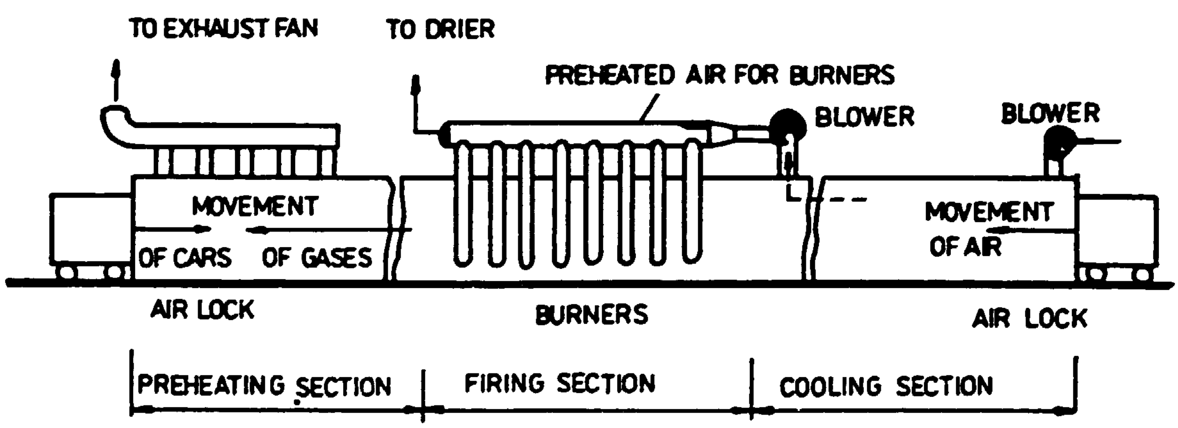


Fig. 24 Heat Recovery in a Tunnel Kiln

The capital requirement for waste heat recovery is sometimes greater than this one for other energy saving opportunities. Thus, decisions about individual projects become more difficult to make. On the other hand rewards in the form of reduced energy costs can also be greater and this constitues the incentive for the efforts to recover waste heat.

Every plant has some waste heat. A waste heat management programme is a systematic study of the sources of waste heat in a plant and opportunities for their use.

The economical recovery of waste heat depends on five factors:

- There has to be a use for the waste heat. This point is not treated in this work; it is assumed that such a use has been located.
- There has to be an adequate quantity of waste heat. To estimate the quantity of available waste heat one uses the first law of thermodynamics.
- the heat must be of adequate quality for the purpose in question. For example, heat available at 150°C cannot be used directly to heat steam to 200°C. The problems of heat quality and availability are treated using the second law of thermodynamics.
- The heat must be transferred from the waste stream to the material of work piece where it is to be used. This is a problem in heat transfer and heat exchangers.

- The waste heat must be used profitably - this is a question of economics

d. Effects of an extensive insulation

To reduce the existing dispersion heat loss from the surface of a device or a piping system an additional layer of insulation or some more effective insulating materials can be installed.

Thermal conductivity of an insulating material is the decisive parameter for insulation of continuous thermal processes.

In the case of periodic processes an optimum must be determined between surface heat loss and the loss by accumulated heat (light weight insulating materials are very convenient for this purpose).

e. Effects of the condensate recovery

The thermal energy contained in a generated steam consists of a latent heat (of about 80% of total heat content of steam) and a sensible heat. If the sensible heat of condensate completely is recovered as a boiler feed water, the fuel saving of about 10-20% might be expected, according to the temperature of the return water.

f. Effects of inner pressure control in a furnace

When the pressure in furnace is in the plus side (overpressure) and too higher than ambient pressure, resultant flame causes heat loss. When the pressure is in the minus side, the cold air outside the furnace enters into it and cools down the inside of the furnace, which results in heterogenity of temperature pattern and in fuel loss. The leakages of a furnace (inspection holes, doors, ...) should be as small as possible. (Fig. 25)

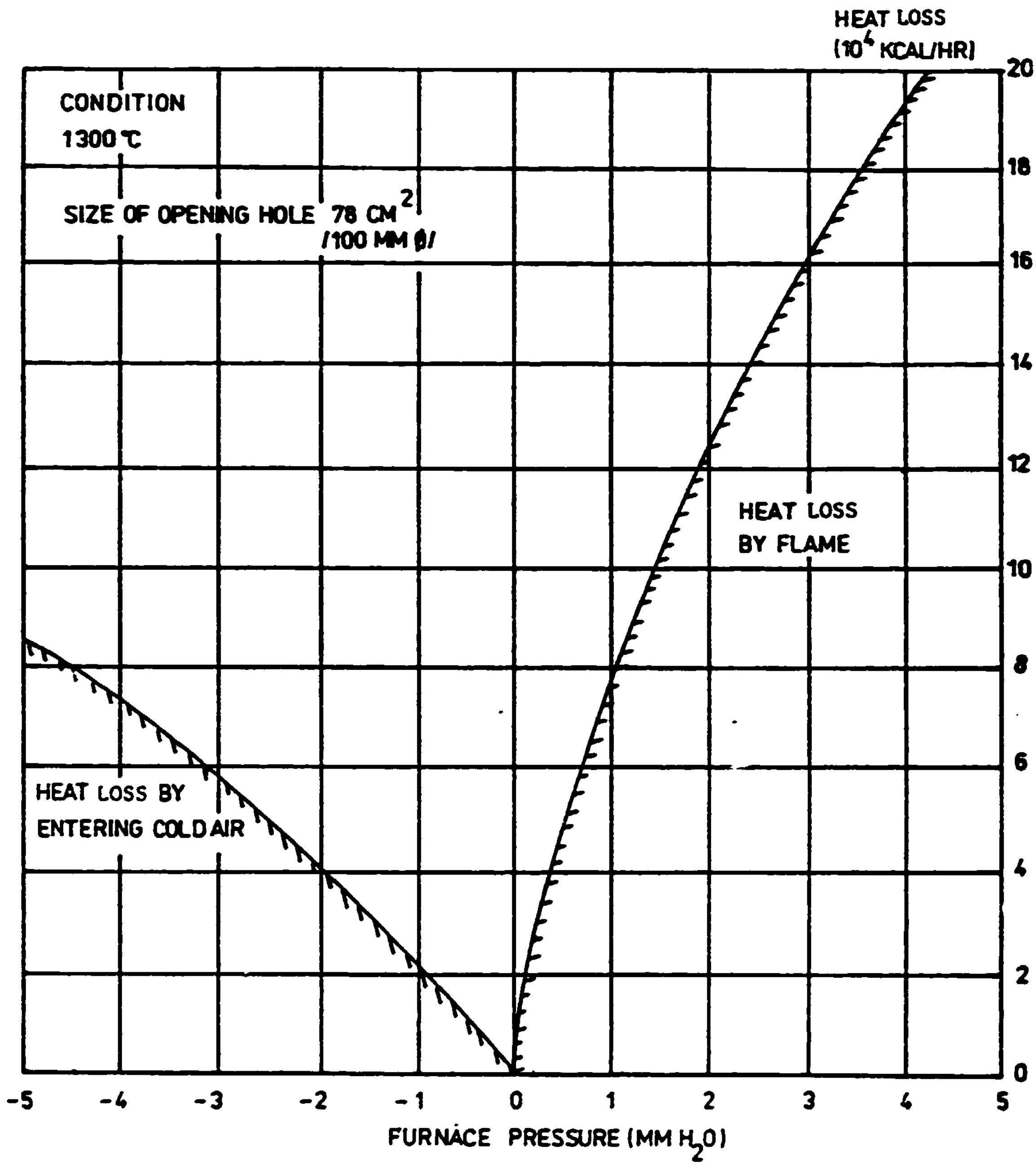


Fig. 25 Heat Loss Around Opening Hole

g. Effects of burners system

Significant Energy Conservation can be reached through utilization of automatic burning systems (microprocessors controlled) or by replacement of obsolete burners with modern ones (high velocity burners, recuperative burners, etc.).

6. c. Electric power

1. To switch off equipment when not necessary (transformers, motors, air conditioning, lighting with low or no load).
2. Periodical maintenance
3. To review contracted power when actual power demand is much different.
4. To optimize capacity of transformers if load factor is less than 0.5.
5. To rationalize transformer voltage on low-voltage side (in case the difference between actual and rated voltage ≥ 3%).
6. To raise power factor of entire factory (in case the power factor falls under 0.9 to install adequate condensers for improvement of power factor).
7. To minimize voltage-drop on distribution line.
8. To watch maximum demand automatically (for larger plants).
9. To select an adequate motor capacity (if the load factor is too low to replace the motor by smaller one).
10. To keep high power factor of main facilities.
11. To optimize capacity and revolution speed of large motors of pumps, blowers, fans, etc.
12. To optimize the exhaust pressure of compressors and to repair leakages on compressed air lines.
13. To supervise lightload automatically.
14. To optimize and control temperature of rooms.
15. To limit electrical heating to special use (to change to heating with fuel or steam).
16. Good maintenance and introduction of high efficiency lamps.

6.d. Practical examples of energy conservation

When analysing technological process to identify energy losses and saving possibilities, there are several possibilities in each manufacturing plant, which lead to considerable reduction of energy consumption.

In spite of the fact, that main steps of energy management in the industrial plant are analyzed in the chapter III of this Manual, practical selected examples are presented in the following as a tool for quick orientation of energy management factory´s team. The recommended measures are divided into two groups, related to the

a. technological examples for energy savings
b. general recommendations applicable in any case studies of energy conservation.

a. Technology

a 1. Replacing gas or oil fired melting tank by electric heating

The new technology, using electric heating of melted batch by electrods (such as Molybden) reduces losses by 25% to 30% and higher melting temperature can be reached. Since electrods are covered by the fresh batch the chimney losses are lowered to the minimum.

a 2. Lowering the maximum grain size of the batch

By melting the melting time depends very much on the size of the batch particles. If, in the glass production, the silica grain size is lowered from 0.8 - 1.0 mm to the smaller grain size that 0.6 mm, about 40% of energy is saved due to the shortened time of melting. Similar effect is reached in the red-brick manufacture, if body raw materials are ground to the appropriate grain size.

a 3. Fired or melted reject recirculation

In case that fired reject in ceramics or broken glass (cullet) in the glass production is blended into the batch composition, reduced amount of energy is needed to achieve finished products. In the glass production, each 10% of cullet in the batch composition will reduce the heat energy for batch melting by about 2-3% from total.

a 4. Single layer firing technology

Single layer firing technology of products which must be thermally treated in order to reach requested properties, reduces the heat consumption upto 60-70%, since the speed of firing is very high and closer to the critical firing curve. In the contrary, piling of products extends the time of heat treatment and increases the heat consumption.

a 5. Simplification of the technology

Different examples exist in any industrial technology. Continuous steel casting and shaping of metallic products, single firing technology in ceramics, non-shrinking body in different manufacturing processes, non-fired chemically or hydraulically bounded refractories, shaped and/or unshaped, modern shaping technologies such as tape casting and vibrating shaping and other similar examples lower the heat and electric energy consumption very much and they are great reserves for further steps in energy conservation and technology development.

a 6. Increasing the heating surface of evaporators in different food and chemical industries

By extending the hea surface of evaporators the specific load and specific steam consumption of evaporating units are reduced, the heating steam demand can be reduced by 3-5%.

a 7. Continuous pasteurizers instead of autoclaves

Continuous belt-type pasteurizing equipment replacing autoclaves for controlled heat treatment in the food industries, milk, soft drinks and beer manufactures, in canneries and other industries brings about considerable energy savings and promotes continuous work as well.

a 8. Storage of grain crops in tower bins with ventilation

In tower bins fitted with ventilators it is not necessary to lower the moisture content of the product below the equilibrium level, some additional moisture reduction results from ventilation. This way shows the possibility of 20% energy savings.

a 9. Reduction of grinding time and energy consumption of grinding mills

With roller mills of larger weight and surface implemented instead of traditional ball mills grinding time is reduced from about 16 hours to about 6-8 hours which results into considerable power saving. Replacing the internal silex lining by rubber will extend the time of operation by twice to three time without repairs. In ball mills as such the grinding time can be reduced to one half if silex balls are replaced by high density balls or cilinders with the volume weight about 3.6 $g.cm^{-3}$. Again, considerable energy saving is reached.

a 10. Up-dating of curing concrete elements

Traditional curing is made in uninsulated plate tubs with manual feeding of steam. Energy saving can be achieved by using insulated tubs and programmed steam feed. By using a proper design condense utilization is also possible.

a 11. Keeping breeding poultry in greater floor

Instead of using the traditional straw beds, greater floor is built into the hen-houses. Manure is removed every day or several times in a day and this reduces the amount of ammonia, therefore heat removal by ventilation can be reduced. Heating of the building is only necessary at lower temperatures.

a 12. Production of bitumen emulsion

By replacing traditional, gas oil diluted bitumen used for road maintenance with cold treated bitumen emulsion a considerable amount of gas oil and energy can be saved.

a 13. Cold storage of grain crops

The grain crops are pre-dried by reducing the moisture content down to 18-20% and then cool air is ventilated into them while additional moisture content is extracted. This method shows the way how to avoid the overdrying and the possibility to save the thermal energy, which equals to about 6% of moisture content reduction.

a 14. Heat utilization of binder driers

On the flue gas and on the drying air side of the driers liquid-air heat exchangers are built in, which on the liquid side are fitted with circulating heat carrier cycles. The exhausted heat is then exploited for the preheating of air used for the burners.

a 15. Reducing heat consumption of sugar drying by a more intensive centrifugal operation

The traditional method of removing the thin layer of syrup remaining on the crystal grains with water and steam and then the drying with overheated steam in a centrifuge. In case of a more intensive centrifuging operation the steam demand of drying can be lowered by blowing in warm air preheated with the condense water of the evaporation station.

a 16. Waste gas utilization by built in compressors

Chemical processes often produce waste gas which can be exploited. Instead of blowing off the waste hydrogen gas generated in the course of chlorine production it can, by a built in compressor, be condensed to reach the pressure of the synthesis gas and after cleaning it can be utilized. This way some of the natural gas demand of ammonia production can be saved.

a 17. Patenting of wires by direct heating

Patenting of rolled or drawn wires is traditionally made in furnaces with heat transfer. In a protective atmosphere patenting can be made with direct heating. In this case a significant amount of energy, reaching upto 40% from total, can be saved.

a 18. Application of liquid fillers

The paper industry uses refined kaolins as coating and filling matters. Since kaolin is applied in a slurry, lot of heat and electric energy can be saved if a kaolin plant does not dewater and does not dry kaolin, which is then moistured in a paper mill again.

a 19. Application of liquid fertilizers

The agricultural sector is used to apply chemical fertilizers for soil reclaiming in a solid form. Disadvantages of solid fertilizers are: a storage loss of about 15%, multiphase of spreading with uneveness of spreading, wash out and higher energy demand in production. If liquid fertilizers are applied the following advantages come into account: lower energy demand in production, no storage loss, even spreading, low wash-out and single-phase spreading.

a 20. Utilization of non-metallic sorbents in agriculture and environmental protection

The application of non-metallic sorbents for sandy soil reclaiming lowers the penetration through the soil layer and it increases the retaining soil capacity. As a result the dosage of chemical fertilizers is lowered, the need of virigating water goes down up to one half, contamination of underground waters is improved and the harvest is increased by 20% to 100% depending on the type of crop, soil and climate.

Specially activated non-metallic sorbents, such as bentonites, illites and zeolites purify industrial ore contaminated as well as other waste waters and enable the factory to recirculate purified waters on one side and to exploit in non-waste technologies the sedimented impurities. Since non-metallic sorbents are natural materials, no secondary contamination is caused. Newly developed methods are cheap and efficient not only from the financial point of view, but also from the view of the electric and thermal energy consumption.

a 21. Energy saving processing of slaughterhouse wastes into protein fodder

From the majority of slaughterhouses slaughtering wastes are transferred to the site of the processing firm where, with the involvement of steam and power consumption, they are processed into meat meal. By installing a waste processing production like the slaughterhouse wastes can be with the addition of conserving germicidal agents processed into meat pulp on the spot. Biological value of meat pulp is higher than that of meat meal and considerable amount of energy can be saved.

a 22. Reducing heat demand of drying beet slices

By replacing traditional slice process with two-spindle process, the extracted content of the beet slice can be increased from about 14-15% up to 20% from total. Specific energy consumption is reduced accordingly.

a 23. Improving the technology of tobacco drying

The specific energy consumption of driers used traditionally for tobacco drying is high. By applying special types of driers drying air is of a more favourable fluid mechanical distribution, thus temperature and humidity can be controlled and specific energy demand is reduced. By programmed temperature control of driers further savings can be achieved.

a 24. Application of electric cooling belts in glass making

In order to lower the stress from hot shaped glass products during cooling, annealing kilns of different designs are used with a gas or oil fired cooling belt. Energy can be saved by exploiting waste heat from glass melting tanks and by using owing to control. By using a tyristor controlled electric cooler, control becomes very accurate and this results in energy savings.

a 25. Application of induction heating

In metal processing plants oil or gas firing or electric resistance heated furnaces are used to heat components up to forging temperature. By installing medium-frequency induction furnaces fitted with semi-conductor control, waste heat can be reduced up to about 40% from total.

a 26. Modernization of fruit juice condensation

Fruit juice processing plants using traditional technology process fruit juice of 11-12° Bé extract content in two stages in order to reach 72° Bé extract content using a great amount of steam. By doing this in four stages, with up-to-date centrifugal final condensation technology, the same quality will be obtained with much lower energy consumption.

b. General recommendations

b 1. Establishment of motor vehicle diagnostic station

Instrumental tests are made on vehicles, transportation machines and engines. When required they are serviced what results into the reduction of fuel consumption.

b 2. Establishment of energy consumption standards

Considerable energy savings can be achieved by service people of kilns, driers, boilers, vehicles and other energy consuming units, if objective energy consuming standards are established and if servicing people are properly motivated for energy conservation.

b 3. Converting steam heating network into hot water heating

Hot water heating system utilizes different types of waste heat even with a relatively low temperature. By conversion it is possible to build in an automated unit also sensing external temperature and to achieve energy savings.

b 4. Up-dating compressed air generating system

By replacing uncontrolled reciprocating compressors with air demand controlled screw-type compressors blow-in losses and power consumption can be reduced.

b 5. Replacement of centrifugal pumps

Considerable energy savings can be achieved by using up-to-date higher efficiency pumps instead of the obsolete ones at technologies in chemical industries, requiring a lot of pumping.

b 6. Heat supply of driers with flue-gas generators

By applying thermoventilation for the heat supply of drying furnaces instead of traditional steam-to-air heat exchangers a higher efficiency can be obtained.

b 7. Up-dating and automation of heat generating and distribution systems

By implementing an external temperature controlled regulating system which takes into account internal temperature as well, heating of plant buildings can be programmed and a very significant energy saving can be achieved.

b 8. Design of factories buildings

The height of the production hall should not exceed the necessary technology and security requirements. Well insulated walls, but also doors and windows with doubled or trippled glass screens contribute to energy savings very much. For such production halls in which entries and exits are changed frequently because of the technological reason, pneumatical blowing closing system is established in order to divide the temperature gradient inside and outside the hall. Therefore, the building industry had developed several different types of doors and windows with very good parameters.

b 9. Speed control of conveyer-belts

The speed of high capacity conveyer-belts is practicable to be adjusted to the level of production since sometimes considerable part of the operation time the capacity of the drive is not exploited. By using a tyristor-type control it can be achieved that the belts operate with the speed demanded by the feed. This saves a considerable amount of energy.

b 10. Return waste-water utilization by purification

Different types of waste-waters leaf the industrial processing. By implementing a return water purifier, the waste water can be cleaned, what contributes sometines not only to energy savings, but also to the environmental protection.

b 11. Modernization of water softening

At many boiler plants, continuous alkalitreatment and frequent sliming are applied to avoid thickening of feed water. By implementing a lime by pre-softener the slime can be r moved by sedimentation and pretreated feed water becomes less hard. The frequency of slime and alkali removal and thus the volume of emitted waste heat can be considerably reduced.

b 12. Utilization of waste heat from cooling systems

The heat absorbed by ammonia-operated cooling equipment and the heat equivalent of compressor work can be utilized in an ammonia-water heat exchanger for warming or pre-heating water.

b 13. Up-dating steam separators

In some equipment still the old type of steam separators are used which emit large amounts of steam into open air. Such devices are to be replaced by thermal and thermodynamic steam separators. This way major energy savings can be achieved.

b 14. Water side automation of steam boilers

In several plants steam boilers are fitted with Hanneman-type level controllers and Agua Control-type dauger indicators. Alkali and slime removal is made by the operator. By installing Gestra type electronic control systems, alkali and slime removal can be programmed, what results in savings of thermal energy.

b 15. Application of gas infra-radiators

In several fields of industry and agriculture air heating is done by using hot-air blowers. This method supplying heat is applied in halls, animal breeding and plant growing sites. Due to large doors and windows and due to occasional intensive air exchange, significant amount of heat gets out into open air. By using infra-radiators the necessary heat level can be reached with approximately 60% energy consumption only.

b 16. Additional thermal insulation

In the recent years additional thermal insulation of buildings, within that the problem of insulating doors and windows, has been in the limelight. Different studies prove that by subsequent fitting of rock cotton and by foaming aminocell, 30-60% of the energy used for heating can be spread.

It has to be mentioned that the heat transmission of doors and windows of traditional design is about twice as much as should be 6 W/m^2K for windows and 4 W/m^2K for doors. Heat loss is considerably increased by heat bridges within the structures which are in particularly great numbers in mass-produced building units. The degree of thermal insulation has an economic optimum value. In case of great loss it is the energy cost of heating, in case of little loss it is the capital cost of insulation that increases the cost above the optimum value.

b 17. Heat supply centres

One way to reduce operational energy losses is improving heat centres. Instrumentation, automation and thermal insulation of heat centres are generally insufficient. For lack of metering, consumption of individual plant units cannot be checked, plant operation cannot be evaluated. Often 10-15% of total energy consumption can be spared by the thermal insulation of the heat supply centre with automation weather conditions can also be taken into account. The units on the condense side of heat centres are also of particular importance.

b 18. Road transport

Almost all plants are interested in solving the energy problems of all road transport. The primary reason for low efficiency is the unfavourable energy consumption of motor vehicle engines. Insufficient loading of the vehicle and non-rational choice of transportation speed can add to the problem. Attention should be given to the reduction of air resistance. Air resistance is proportional to square speed, performance to cubic speed. It is also important to reduce bending resistance by adjusting type pressure (3-4%) and to regularly adjust carburation and ignition which can ensure a fuel saving of 5-10%. Special attention is to be given to winter operation. The efficiency of cold engines is much smaller, e. g., the 21% average efficiency of petrol engines drops down to 15% in urban transport in cold weather. Because of the above factors, diagnostics has particular significance in reducing losses.

b 19. Electric drive

When talking of technological equipment, electromotors are of great importance. From the energy point of view individual drive is the most advantageous, as the drive only operates when there is actual demand for it, besides the loss from the central gears and the low efficiency partial load operation of the central power machine are avoided. From energy side it is also very important that a motor of adequate performance has to be selected in which case an efficiency of 85-95% - depending on size - can be ensured. It can be considered a general principle that the replacement of a motor loaded below 45 % of its performance is always cost-effective and necessary. The internal and power losses of a lower capacity motor always cover the costs of replacement. In case of variable speed drives, changing is a frequent requirement. The main disadvantage of asynchronous motors is that in case of a squirrel-cage design, the number of revolutions can be reduced to 40% of the synchronous revolution. The development of power current electronics have resulted in a radical change in the field of speed changing. Frequency control can be made both by DC and by AC motors with a very high efficiency.

From rectifiers and control components developed from semi-conductors such drives have been obtained which, applied with DC motors, provide very flexible drives. The one single disadvantage of the drives is that they generate overtones on the mains which have to be suppressed. With tyristor connections parameters and frequency of currents can be changed almost optionally and with very little loss, thus the revolution number of asynchronous motors can be easily controlled. The efficiency diagram of governable drives shows good performance in a very wide range, but again attention has to be given to avoid permanently low efficient partial load operation caused by overdimensioning.

b 20. Boiler efficiency

A significant part, about 35% of technological steam is generated in boilers. Therefore, the efficiency of boilers is of great importance. Boiler efficiency depends on the used fuel and on the size and condition of the boiler. In case of a brand new boiler, efficiency of coal firing is 72-75%, that of oil firing is 82-86% and that of gas firing is 92-94%.

Efficiency is very much dependent on the condition and the maintenance of the boiler and operation practices. With full load, each mm of soot deposited on the heating surface reduces efficiency by 3-4%, while with partial load the reduction is bigger. As shown by the results of different audits by proper maintenance and operation practice the average efficiency of boilers can be increased even by 15-20%. Certain devices, such as automatic draft check plates, prevent the water space of the boiler from cooling down and provide accurate control of the water level as well.

b 21. Chemical processes

A considerable number of the chemical processes take place in autoclaves and reactors. Heating of these - often pasteurized - vessels can be made by firing, electric heating or thermal transmission of heat carriers (steam, fluids, etc.). The way they generate energy and their structural design usually conform to the technological process easily, material and energy often form one integral unit. At a low temperature steam has the greatest importance among different heat carriers. The use of steam - as opposed to direct firing - is often justified by technological and other aspects (e. g. danger of explosion).

b 22. Lighting

It is a general demand on all plant levels that artificial lighting of the rooms must be sufficient and cost-effective. Seeing it as complex process, therefore, the quality of lighting depends on several factors which all have their effects on energy consumption. Resolving power depends on the degree of lighting measured by the volume of light radiated onto unit surface area (its dimension is lux, which is equal to lumen/m^2).

Identification of shapes which is of primary importance, depends on the degree of illumination, but the spatial distribution of light also has a role in the proper development of light and shadow effects.

Colour identification, essential in several technologies, depends on how the spectrum of artificial light approximates that of natural light: this is characterized by a colour response index or by the colour temperature of the light source. Colours of surroundings objects and surfaces are also important: they can either help or retard shape recognition, thus either reduce or increase energy demand of lighting. Desirable degree of lighting depends on the activity: for not too requiring, general illumination often 10 lx is enough, for a precise work, occasionally 1000 lx is necessary.

The following can be accepted as general recommendations:

storehouses	60-120	lx
workshops	250	lx
reading, writing	500	lx
technician´s work	1000 - 2000	lx

Too high briliance of a light source causes dazzlement since the differences in light intensity are beyond the adaptability of human eyes. Most working places must only be illuminated in very cloudy weather and at the beginning of dusk but this happens to be just at the peak period. Therefore, energy management is of great importance in this field as well. This does not mean that the level of lighting has to be reduced. In present practice plants are illuminated poorer than necessary. This has an unfavourable effect on general health conditions, increases the feeling of tiredness and hazards of accidents at the same time unfavourably effects productivity and the quality of products. Results of ergonomical tests show that when illumination level is increased from 500 lx to 900 lx, speed and accuracy of calculation is increased by 5%, logical thinking by 9.5% and memorizing capability by 16%. In plants where precise work is required, increasing illumination from 500 lx to 1000-1200 lx resulted in a 10-25% rise in performance, more than 20% reduction in waste production and also a considerable reduction in the number of accidents.

So the task is to produce sufficient illumination with low energy consumption. Tools of economical lighting are high-quality light sources and lamps. The efficiency of light sources vary considerably:

bulb lamp	4-8%
neon lamp	20%
high-pressure metal vapour lamps also	20%

Thus, by replacing light sources and energy saving of 30-75% can be achieved. It has to be noted, however, that the light flow of neon lamps dramatically drops after 4000 hours of operation so it is worth programming their replacement.

The efficiency of fittings ranges from 10 to 90%. Losses partly result from the fact that covering surfaces either absorb or scatter parts of the light. Loss from fittings designed with the necessary competence is only 10-20%. Particular attention has to be given to dirt deposited of fittings which often cause a 20-35% reduction in luminous flux. Regular cleaning therefore is a considerable potential for energy saving. Spatial efficiency depends on the spatial distribution of luminous flux. Depending on the optical design and spatial arrangement of fittings spatial efficiency depends on the ratio of light directed onto areas to be illuminated and light falling onto areas not requiring illumination.

in lamps a major source of loss can be improper cooling which reflects the light source itself. In case of overheating it is not only life expectancy that is reduced but also their luminous flux. Relative reduction of luminous flux can be as much as 50%.

Degree of natural and artificial lighting is also greatly effected by the colour of walls which determine reflection according to the following:

Colour of wall	Reflection %
light cream	75
light yellow	73
light apricot	64
bright yellow	58
light green	55
light blue	50
bright green	26
orange	23
blue	19
dark grey	12
dark red	7

With regard to all the above mentioned factors, we can say that there is a lot of saving potential in this field as well.

7. Mobile Diagnostic Unit of the Czechoslovak Research Institute for Ceramics, Refractories and Non-metallic Raw Materials in Pilsen (Case Study I)

7.a General Description

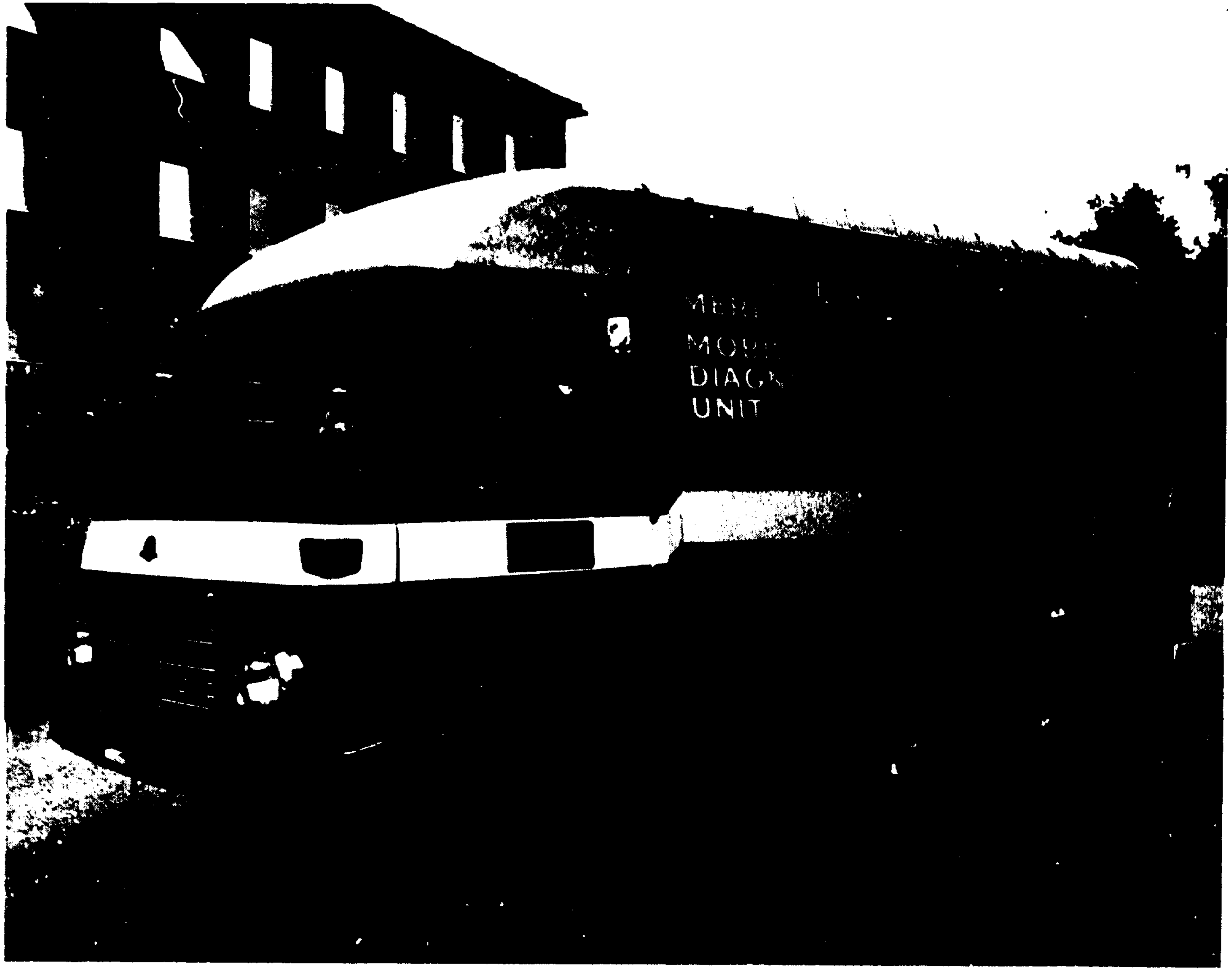
Performance of diagnostic measurements requires the application of modified measuring and recording instruments and techniques. The optimal solution of the problem represents the use of the mobile diagnostic unit (MDU) equipped with required apparatuses and with the data processing centre.

The concept of mobile diagnostic units (energy buses) was adopted independently in different advanced countries throughtout the world as it is the most effective means to carry out the energy audits.

The diagnostic measurements within Czechoslovak ceramic industry using MDU were introduced by the Research Institute for Ceramics, Refactories and Non-metallic Raw Materials in Pilsen more than ten years ago. The first mobile diagnostic unit (MDU) of the Institute has been in service since 1976. Therefore, it was decided to construct the second and third MDU, equipped with modernized instrumentation. Both units are used parallely at present.

The MDU of the Research Institute for Ceramics, Refractories and Non-metallic Raw Materials in Pilsen, used in non-metallic industries is a mobile measuring laboratory installed in a special van and used by the team of specialists. It is capable to find out directly, under the operating conditions all the outside and inside circumstances and conditions which influence the optimal energy consumption of a heat consuming unit.

The equipment of the mobile laboratory enables to perform all types of the above mentioned measurements, i.e. the determination of heat balances, the ascertainment of technological conditions in thermal processing of ceramic materials and the complex measurements. The evaluation centre of the MDU contains the data logger and computer, enabling evaluation of measurements in the field. The equipment contains also devices for checking and calibrating the measuring instruments and for minor repairs.



The third mobile diagnostic unit of the Research Institute in Pilsen

Interior of the mobile diagnostic unit

7.b Measured Factors and Applied Instrumentation

The most important equipment available and its applications is as follows:

(A) Temperature Measurements

The measurements of atmosphere and surface temperature are most frequent. The temperature of atmoshpere is measured usually by orthodox sensors:

for the range up to

- 600°C resistance Pt thermometers
  mercury thermometers
  Cu-Ko thermocouples
- 1200°C Ni-NiCr thermocouples
- 1400°C Pt-PtRh10 thermocouples
- 1600°C PtRh6-PtRh30 thermocouples

Besides standard Ni-NiCr thermocouples with protective ceramic tubes other ones, so called jacketted thermocouples, are used to a great extent. The advantage of these thermocouples is a considerable shorter time constant in comparison to orthodox wells. Jacketted thermocouples are also flexible and measurements can be taken in points with difficult access. For example when temperature distribution in cross-section of a kiln is measured, these thermocouples are successfully used. These thermocouples are delivered in length up to 5 m, on special request even longer. The possibilities of application are very wide. For example the firing curves in the multi-channel kilns can be measured by means of these thermocouples (Fig. 26)

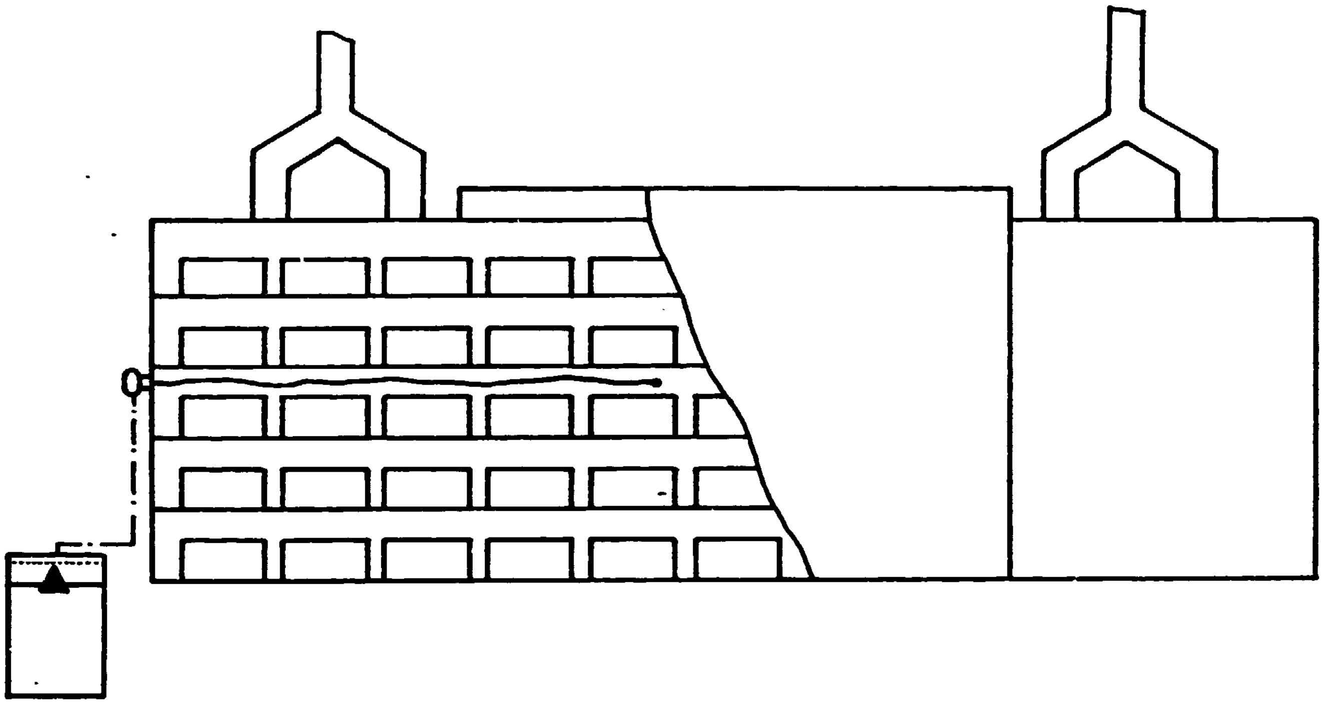


Fig. 26 Multi-channel Kiln - Measuring of Firing Curves

By inserting the thermocouple into the kiln and its gradual withdrawing the firing curve of the channel is obtained within a few minutes. The measurement by the usual method would take some tenths of hours.

For the measuring proper and for recording of indications through the resistance and thermocouple sensors the equipment of mobile laboratory is provided by the data logger with high precision. The data are stored in digital form here. The first MDU is equipped with compensation recorders. One recorder has 12 inputs, so it can record the information from 12 measuring points simultaneously.

Besides temperature indications the data logger as well as the recorders are provided by standard ranges in mV. Thus the other values can be recorded when transferred into voltage.

For the surface temperature measurements the mobile laboratory is equipped with contact thermometers with Ni-NiCr sensors and digital measuring instrument, usable up to 1200°C. This instrument with high precision can be used for atmosphere temperature measurements as well. Besides there are thermoelectric contact thermometers (up to 250°C) and three fully radiating pyrometers with mutually overlaping ranges from 700 to 2000°C.

The most advantageous device for surface temperature measurements is the radiometer Thermopoint, with measuring range from -30 to 1100°C. Its operation is based on microprocessor technology, allowing the data accumulation from one series of measurements to another. It may be used to measure different surfaces at different times and places and still determine the average, maximum, minimum and differences of these surfaces. Up to 10 000 points may be accumulated. This radiometer enables to measure the temperature of inaccessible points.

(B) Gas Flow Measurements

The MDU is equipped with orthodox mechanical anemometers and with mechanical-electrical anemometers for measuring the flows in driers and the sucking of fans. The anemometers can be connected to a specially adjusted recorder which enables to conduct a long-term investigation of flow conditions. These anemometers can be applied also in measuring cars in channel driers (Fig. 26). The mobile laboratory is also equipped with several types of Pitot's tubes for gas flow measurements in ducts.

(C) Pressure Measurements

A very frequent task during operation tests is the measurement of low pressures both in pneumatic equipment and in the ascertainment of draught conditions. For this purpose precisious liquid micromanometers are applied.

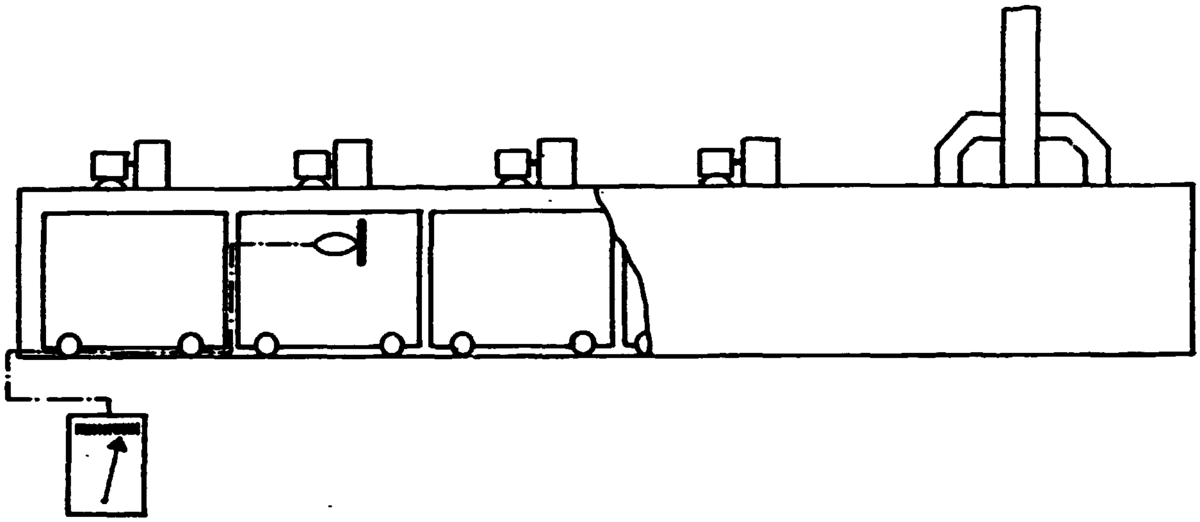


Fig. 27 Measuring Car in Channel Drier

These devices have changeable measuring ranges. In case the record of measured pressure is needed the indication annular balance with the basic range ∓ 50 Pa can be applied. For measuring higher pressures the equipment contains series of precise manometers.

(D) Dew Point Measurements

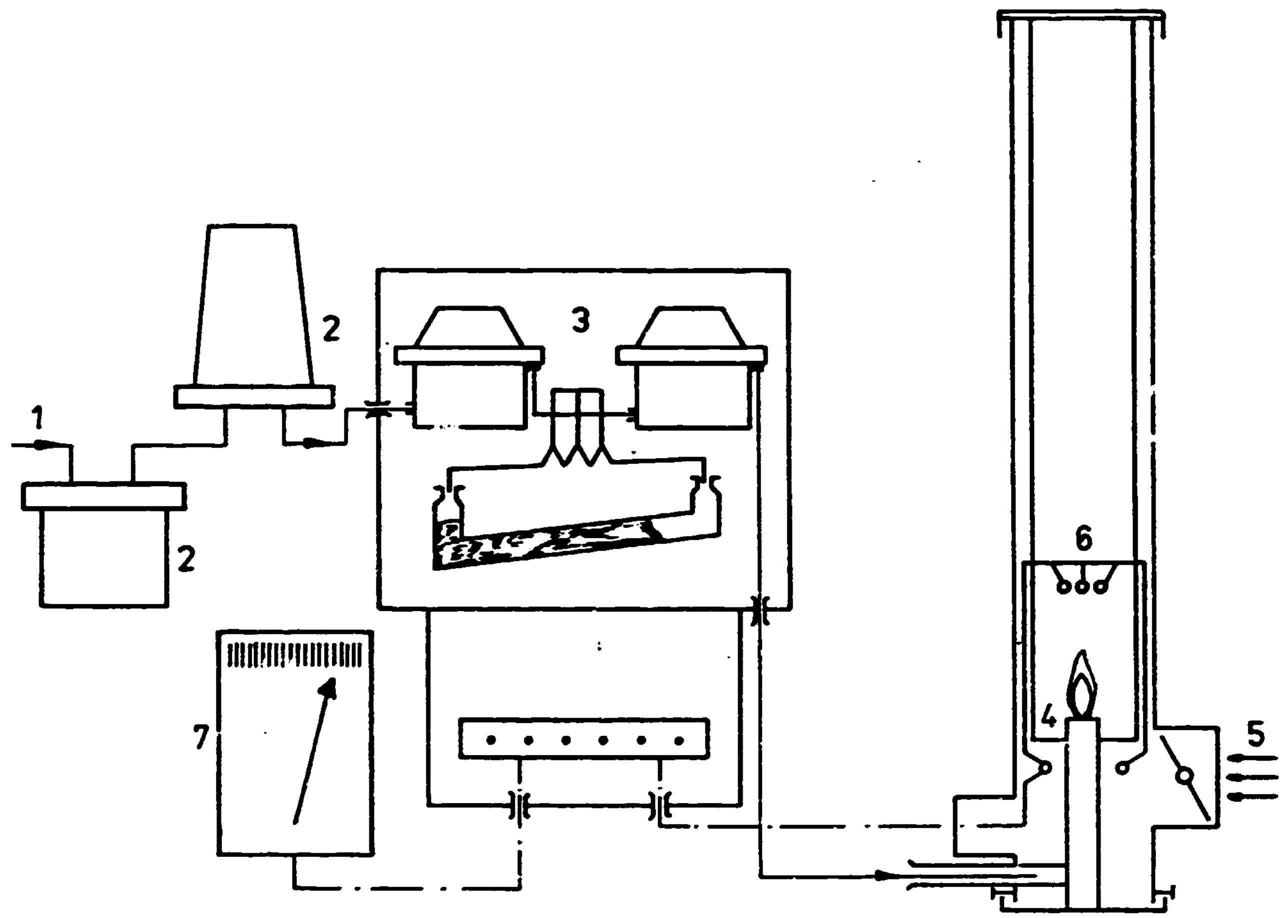
The knowledge of the dew point in drying equipment is of a great importance. Together with temperature and flow velocity it gives the basic information about drying process. For dew point measurements the transportable sets are applied. The equipment consists of three probes and one plotting recorder. Every probe has a temperature resistance sensor (temperature of dry thermometer) and a dew point sensor (temperature of wet thermometer). The sensor of the dew point is based on the tension compensation of vapour produced by the LiCl electrolyte and vapour of the ambient. The stabilized temperature equilibrium corresponds to the temperature of the dew point. This set in connection with mechanical-electrical anemometers represents the equipment by which the basic parameters of the drying process - - the temperature, the dew point and the flow velocity of the drying medium - can be measured and recorded.

(E) Measuring of the Properties of Combustion Gases, Analysis of Combustion Products

For ascertainment of fuel gases composition the mobile laboratory was equipped with an Orsatchromatograph. With regard to the difficult transportation of this instrument the application of Wobbe´s number-meter proved to be more practicable. This instrument determines the Wobbe´s number (the ratio of the heating value and the second root of the gas density) by measuring the temperature rise of a constant quantity of the air flowing through the combusted gas (Fig. 28). The output signal is the voltage of the thermobattery which is registered by the recorder directly in values of the Wobbe´s number. The measurement precision reaches from 5 to 10% with regard to the applied calibration. The precise calibration is carried out by means of calibration gas mix delivered by the producer of the instrument. The instrument can be adjusted for measuring the Wobbe´s number of natural gas, generator gas and town gas.

The Wobbe´s number meter was successfully applied in measuring tunnel kilns in the plant where the causes of fluctuating firing temperature had to be ascertained.

For checking the firing process the mobile laboratory is equipped with transportable analyzers and by instruments installed in the van. The second MDU is equipped with modern transportable analyzers. They are applied for the determination of CO, CO_2 and SO_2 content, each of them with two ranges - for high and low concentration of checked gas.



1 .... Tested gas
2 .... Filters
3 .... Pressure regulation
4 .... Burner
5 .... Air flow
6 .... Thermobattery
7 .... Recorder

Fig. 28 Wobbe's Number Meter

The selective absorption of the infra-red radiation by the measured gas is utilized for the determination of the content of the component looked for. The instrument working on the increased permeability of oxygen with regard to other gases is used for measurements of oxygen content. All the analyzers can be connected with plotting recorders or with data logger to store the measured data.
The extraction of combused products is conducted by built-in pumps (transportable analyzers CO, CO_2, SO_2) or by an extra pump (O_2 analyzer) through probes of a corrundum material.

Analyzers are used for checking combustion conditions and for inspecting the function of burners. The ascertainment of the air sucked in by leakage of the kiln is important, too. It is applied especially in tunnel kilns where the tightness of sand grooves can be checked. The analysis of the kiln atmosphere in the preheating zone shows the economy of kiln operation and potential reasons of great temperature differences in cross-section of the kiln.

7.c <u>Computerized Data Processing System</u>

The system was developed in co-operation with the British National Industrial Fuel Efficiency Service (NIFES) for the prototype mobile diagnostic unit of the Research Institute for Ceramics, Refractories and Non-metallic Raw Materials in Pilsen, Czechoslovakia:

1. Description of the hardware

The system is shown diagramatically in Fig. 29. It basically comprises of:

- IBM XT SFD computer
- Biodata Microlink Computer Interface
- Epson LX 86 Dot Matrix Printer
- Sensors for temperature, pressure etc.

1.1. IBM computer

The IBM XT SFD computer has the following facilities:

- Based on an Intel 8088 microprocessor
- 40 kB of ROM
- 640 kB of user memory
- Memory access time is 250 ns
- Cycle time is 345 ns
- There are 8 expansion slots
- One 5.25 inch double sided slimline diskette drive of 360 kB
- One 20 MB fixed disk drive, with 85 ms average access time

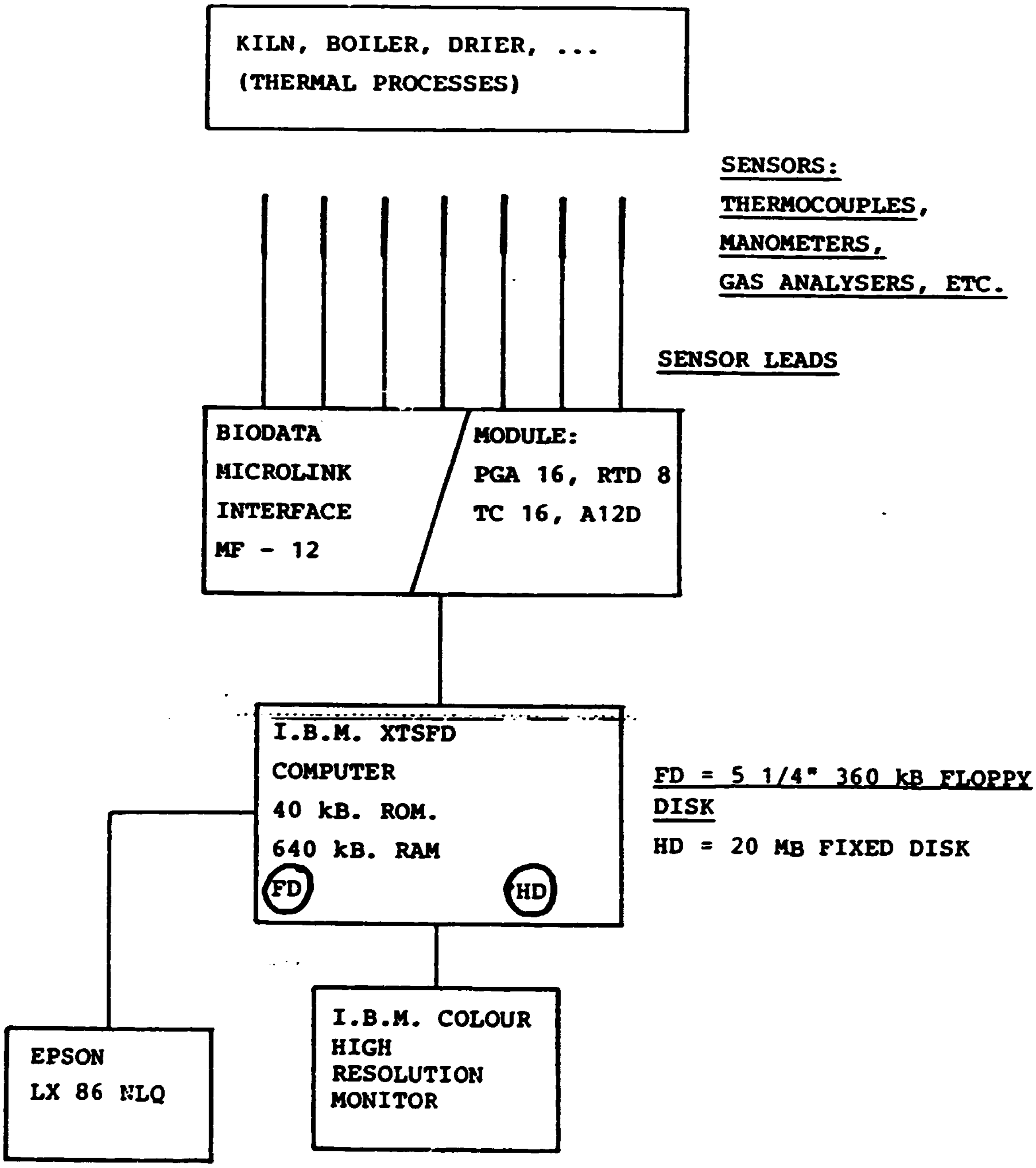


Fig. 29 Scheme of the Computerized System

- Asynchronous Communications adaptor
- Facility to add a further 360 kB, 5.25 inch diskette drive

The computer is supplied with:

- IBM personal computer enhanced keyboard
- IBM enhanced graphics display
- IBM enhanced graphics adaptor
- IBM parallel printer adaptor
- IBM maths coprocessor 8087
- Hercules graphics board

1.2. Biodata Microlink system

Microlink is a modular hardware interface, designed for connecting laboratory instruments to microcomputers using the IBM-488 instrumentation interface.

Microlink has a large number of modules available which can be plugged into the rack and then connected to the computer by a single cable. The range of modules is listed in the following. The hardware and modules installed in the system supplied under the UNIDO contract are as follows:

MF - 12 mainframe

The mainframe is supplied complete with power supply module, control module, mains lead, User's Manual and any necessary blanking panels for unfilled slots. It has slots for 12 single-width MICROLINK modules.

A12D module

12-bit analogue-to-digital converter module. This module accepts the signals from the PGA 16, TC 16 and RTD8 modules.

PGA 16 module

This module accepts upto 16 channels of differential analogue voltage input. Each channel has programmable zero cffset and gain enabling unipolar positive, unipolar negative and bipolar signals to be measured. The full scale ranges are 10 mV, 100 mV, 1V and 10V. This module will accept the various analogue voltages to be logged. (Note that current signals have to be converted to voltages).

TC 16 module

Upto 16 thermocouple channels can be monitored with this module. It is supplied complete with an isothermal box into which the thermocouple leads are terminated using screw connections. Also included in the isothermal box is an encapsulated RTD mounted on a copper block which can be monitored as one of the 16 input channels to provide a cold--junction reference temperature. The module contains a programmable gain amplifier that allows gains of x 100, x 200, x 500 and x 1 000 to be selected by software.

RTD8 module

Each module will monitor temperature from upto 8 reference temperature detectors. 2, 3 or 4 wire configurations can be used. The module has two resistance ranges which are software-selected. The nominal accuracy of the RTD8 is 0.1 Ohm and higher accuracy can be obtained by autocalibration techniques.

1.3. Epson LX86 printer

80 column near letter quality dot matrix.

The printer is connected to the computer with a centronics (parallel) cable.
The printer can be used either with the tractor feed attachment or by friction feed for fan fold and single sheet of paper respectively.

2. Description of the software

2.1. Microlink Scientific Software Entry Level Data Logging (ELDL) package

This package is used to drive the Microlink hardware during data logging.

Its operation is in two stages:

- data collection
- data review

2.2. NIFES thermal programs

NIFES thermal programs have been designed to be run after the various stages of the ELDL review software have taken place.

NIFES programs are as follows:

2.2.1. THERMINA. BAS

This program sets up a data file on disk of the options within the thermal program to use the data from the ELDL.

2.2.2. THERMAL. BAS

This program uses the data from THERMINA, BAS data file and the ELDL data review.

The data is used to access any or all of the thermal subroutines which calculate:

- radiation and convection loss
- flue gas loss above 0°C.
- moisture in air loss for driers
- air volume measurements

Data input review for each module type is as follows:

a) Radiation and convection module

  - for each section of the hot surface - temperature (°C)
  - Ambient temperature (°C)
  - Type of sensor and conversion from measured units to degrees Celsius.

b) Flue gas loss module

  - Flue gas temperature (°C)

- Oxygen content of flue gas (%)
- Ambient temperature (°C)

Options within the module:

- Carbon dioxide content of the flue gas (%)
- Sulphur dioxide content of flue gas (%)
- Flue gas volume (m^3/h)
  (from Pitot/anemometer module)
- Type of sensor and conversion type from measured units to appropriate engineering units.

c) Humidity in air loss module

- Air streamdry bulb temperature (°C)
- Air streamwet bulb temperature (°C)
- Ambient dry bulb temperature (°C)
- Ambient wet bulb temperature (°C)
- Air stream volume (m^3/hr)
  (from Pitot/anemometer module)

d) Pitot/anemometer air volume measurement

- For Pitot measurement: for each Pitot tube-differential pressure (mbar)
- For anemometer measurement airstream velocity (m/s)
- Type of sensors and conversion types measured units to appropriate engineering units.

2.2.3. Data output from THERMAL.BAS program

Disk Storage

a) Radiation and convection loss module

For each section of hot surface and each time increment.

- Surface number
- Surface temperature (°C)
- Surface convection loss (MJ)

- Surface radiation loss (MJ)
- Total surface loss (MJ)
- Ambient temperature
- The total plant loss (sum of surfaces) (MJ)

b) Fire gas loss module

For each time increment

- Flue gas temperature (°C)
- Ambient temperature (°C)
- Mean oxygen content (%)
- Mean carbon dioxide content (%)
- Mean sulphur dioxide content (%)
- Excess air (%)
- Flue gas volume at 0°C (m^3/h)
- Fuel flow rate
- Heat loss (MJ)
- Heat loss (%)

c) Moisture loss module

For each time increment

- Air stream dry bulb temperature (°C)
- Air stream wet bulb temperature (°C)
- Ambient dry bulb temperature (°C)
- Ambient wet bulb temperature (°C)
- Air volume flow rate at air temperature (m^3/h)
- Air stream relative humidity (%)
- Air stream specific volume (m^3/kg dry air)
- Air stream moisture content (kg/kg dry air)
- Air stream saturation (%)
- Air stream enthalpy (kJ/kg dry air)
- Heat loss (MJ)
- Increase in moisture content (kg/hr)
- Heat in air stream (kJ/h)
- Moisture in air stream (kg/h)

2.2.4. Print Out

An option to print cut the reduced data it is computed on the printer is available during the compuatation.

a) FLUGASA

This is a flue gas program where the data is input by hand for single calculations.

b) SUR LOSS

This is a radiation and convection loss program where the data is input by hand for single calculations.

c) HUMIDITY

This is a program to calculate the properties of air. Wet and dry bulb temperatures are input by hand for single calculations.

d) LOTUS 123

Lotus 123 is a sophisticated spreadsheet with graphics facilities. Lotus 123 is provided to enable special file handling to take place at a subsequent date from data converted from the ELDL data review and from THERM or input by hand.

e) THERMDEM

This is a demonstration program for the ELDL, THERMINA, THERM system.

The data measured by MDU are afterwards generalized by the data logger, printed and evaluated with the use of portable computer. This evaluation centre can be used either in the field, installed in the measuring laboratory or at home, after returning back. The evaluation centre is successfully applied in the field for the events of trouble-shooting to be able to provide the user of the equipment with complete information as soon as possible. Thus the duration of undesirable situation in production can be minimized. The evaluations of various measurements cannot be covered by a single computer program due to high variability of thermal units used and diagnostic measurements performed. Therefore the system of partial programs was worked out. Special combinations of these programs are used in individual cases.

Example of the partial program:

Program "FUEL"

Entering data:

- type of fuel (town gas, generator gas, natural gas, oil, etc.)
- composition of fuel, obtained by laboratory tests

Results:

- calorific value of the fuel
- theoretical air demand for combustion 1 m^3 (1 kg) of the fuel
- heoretical volume of combustion gases originated by firing 1 m^3 (1 kg) fuel with air excess 1.0, 1.2, 1.4 etc.

7.d Practical Example - Diagnostic Measurements on Tunnel Kiln for Bisque Firing of Wall Tiles

Technical parameters of the kiln

Type:	tunnel semimuffle kiln	
In operation since:	1978	
Fired product:	bisque firing of wall tiles 150 x 150 mm	
Fuel:	town gas 14 455 kJm^{-3}	
Number of burners:	58 (29 from each side of the kiln)	
Internal dimensions of the kiln:	l x w x h; 119 x 1.14 x 1.35 m	
Firing temperature:	1050 - 1060°C	
Number of kiln cars in the kiln:	67	
Output:	projected	reality
	4800 m^2/day	4114 m^2/day

Setting on a kiln car:	152 m^2	150 m^2
kiln car advance interval:	45 min.	52.5 min.
Reject:		6.8%
Specific consumption:	3770 kJ . kg^{-1} $\pm$ 10%	

Target of measurement:

- improvement of firing conditions
- reduction of specific consumption
- creation of conditions for output increasing

Diagnostic method used:

For the investigation of firing conditions the measuring kiln car with four thermocouples Pt-PtRh was used. The location of measuring points presents Fig. 29.. The thermocouples were connected with the recorder and compensation box by the compensating lead-wire through the inspection tunnel. The pressure of the kiln atmosphere as well as the concentration of carbon dioxide were measured through the sight holes of the kiln. Samples of the kiln atmosphere were sucked off the kiln by ceramic tube. The kiln atmosphere pressure was measured by the precise micromanometer with changeable response, the CO_2 concentration by the analyzer Infralyt.

The heat balance of the kiln was determined in order to find possibilities of specific consumption reduction. Consumption of town gas was measured by the installed gas meter, the fluctuation of gas quality by Wobbe´s number meter. Gas composition and its average calorific value were determined in laboratories of the West Bohemian Gas Works. The air flow velocity at suckings of fans was measured by anemometers, the air flow velocity in the pipeline was calculated from Pitot´s tube measurements. The tempera[illegible] of kiln cars and that of the ware leaving the kiln was measured by contact thermometers.

The testing was accomplished during the steady operation of the kiln, the adjustment of regulation elements was not changed. The advance of kiln cars was uniform.

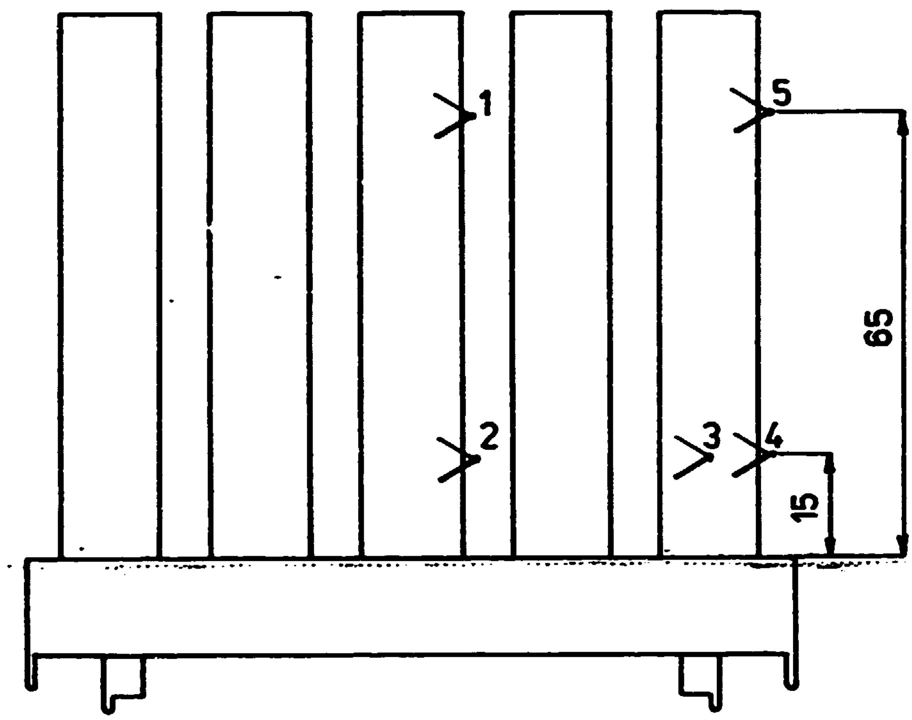


Fig. 30 Location of Measuring Points

Results of measurement:

Firing curves, pressure of kiln atmosphere, CO_2 concentration:

The course of temperatures in measuring points of the cross-section, pressure of the kiln atmosphere and CO_2 concentration presents Fig. 31.

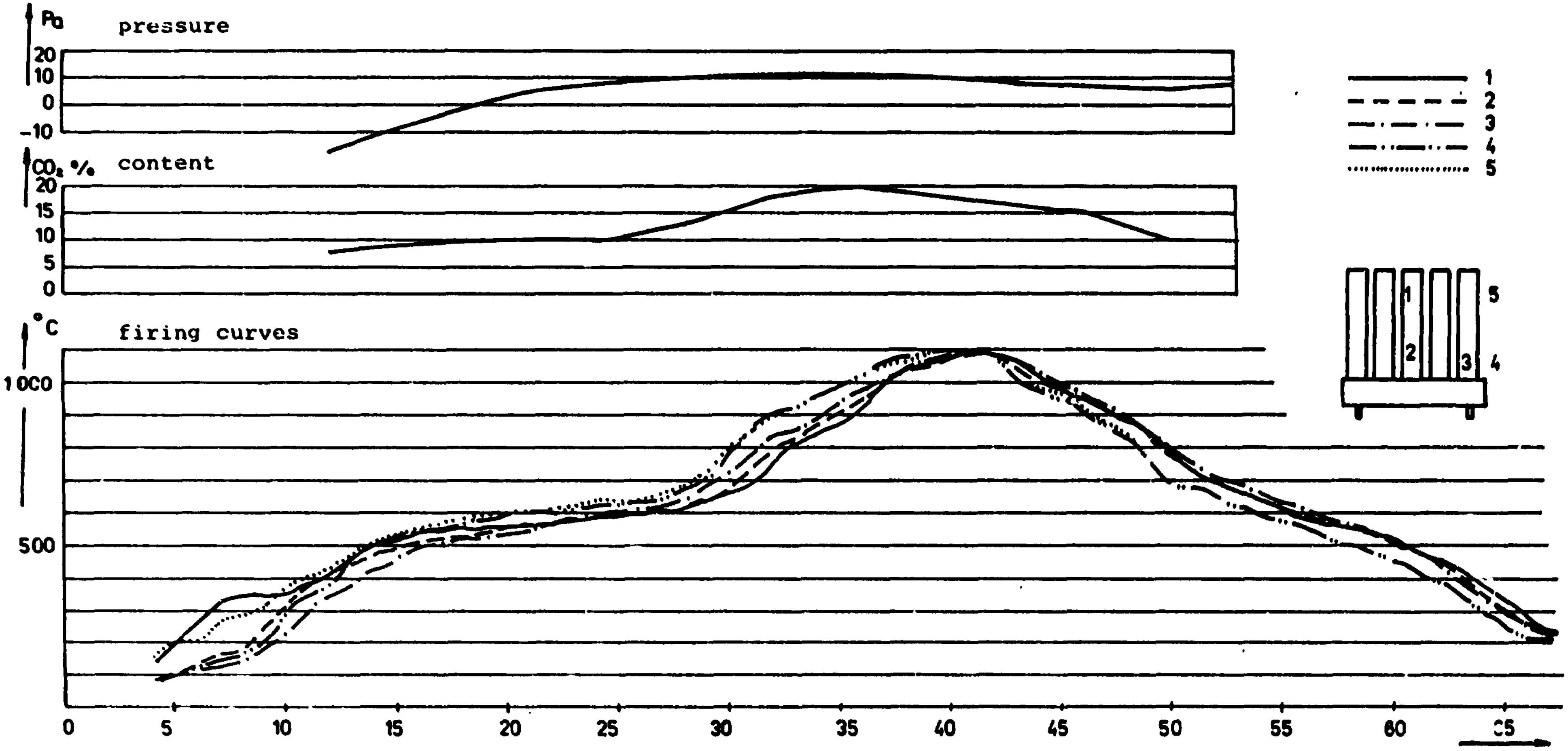


Figure 31 Firing Curves, Combustion Gases Analyses and Pressure of the Kiln Atmosphere

Gas composition, consumption and quality fluctuation:

The consumption of town gas in respective days of measurement and the average consumption per one hour presents Fig. 32. The composition of gas shows Fig. 33. The gas quality fluctuation, expressed by the percentage of the average value of Wobbe's number can be seen in Fig. 34.

Accumulated heat:

The loss by heat accumulated in ware and in kiln cars was calculated from average temperature, specific heat and material flow of respective material. The temperature was measured in the upper, central and lower part of the setting on the circumference as well as in the centre of the setting. The temperature of kiln car lining and the temperature of iron boggie was measured in three different points. This way three cars per day were measured, i. e. during four days of diagnostic measurement 12 cars. The average temperatures of individual materials were used for calculations.

Fig. 32 Gas Consumption

Day of measurement	Consumption (m^3)	Average ($m^3 . h^{-1}$)	% of average
1.	10 995	458	97.9
2.	11 091	462	98.7
3.	11 324	472	100.9
4.	11 514	480	102.6

Average consumption during the measurement: 468 $m^3 . h^{-1}$.

Fig. 33 Average Composition of Gas

Component	Portion (%)
H_2	50.90
CO	15.39
CH_4	19.76
C_nH_m	0,80
CO_2	10.60
N_2	2.55

Calorific value of this gas: 13 754 kJ m^{-3}.

Fig. 34 Gas Wobbe's Number Fluctuation

Day	Time	% from average
1.	6.00	101.3
	12.00	101.7
	18.00	100.5
	24.00	101.8
2.	6.00	100.9
	12.00	101.2
	18.00	100.7
	24.00	99.8
3.	6.00	100.3
	12.00	98.7
	18.00	99.4
	24.00	99.6
4.	6.00	95.7
	12.00	98.6
	18.00	99.1
	24.00	97.9

Heat flow by the heat, accumulated in setting:

$\dot{Q}_{as} = \dot{m}_s . c_s . (t_s - 20) = 0{,}406 \; . \; 0{,}795 \; . \; 130{,}0 = 42.0$ kW

$\dot{m}_s$ .... material flow of setting (kg.s^{-1})

c_s .... specific heat of setting (kJ.kg^{-1}.K^{-1})

t_s .... average temperature of setting (°C)

Heat flow by the heat, accumulated in kiln car lining:

$\dot{Q}_{al} = \dot{m}_1 . c_1 . (t_1 - 20) = 0{,}301 \; . \; 0{,}897 \; . \; 103{,}0 = 26.3$ kW

$\dot{m}_1$ .... material flow of kiln car lining (kg.s^{-1})

c_1 .... specific heat of kiln car lining (kJ.kg^{-1}.K^{-1})

t_1 .... average temperature of kiln car lining (°C)

Heat flow by the heat, accumulated in iron boggie:

$\dot{Q}_{ab} = \dot{m}_b . c_b . (t_b - 20) = 0{,}95 \; . \; 0{,}477 \; . \; 78{,}0 = 3.5$ kW

$\dot{m}_b$ .... material flow of iron boggie (kg.s^{-1})

c_b .... specific heat of iron (kJ.kg^{-1}.K^{-1})

t_b .... average temperature of iron boggie (°C)

Firing conditions:

Gas composition, theoretical need of oxygen and the amount of combustion products presents Fig. 34..

Fig. 35. Theoretical Need of Oxygen, Amount of Combustion Products

Component	Volume (m^3) in m^3	Need of O_2 (m^3)	Comb. products (m^3)		
			CO_2	H_2O	N_2
H_2	0.509	0.2545	-	0.509	-
CO	0.154	0.0770	0.1540	-	-
CH_4	0.198	0.3960	0.1980	0.396	-
C_nH_m	0.008	0.0240	0.0160	0.016	-
CO_2	0.106	-	0.1060	-	-
N_2	0.025	-	-	-	0.025
Σ	1.000	0.7515	0.4740	0.921	0.025

Theoretical need of oxygen for firing 1 m^3 gas is 0.7515 m^3. This amount of oxygen brings about nitrogen:

$$0.7515 \cdot \frac{79}{21} = 2.8271\ m^3$$

Theoretical need of firing air for firing 1 m^3 gas:

$$V_{at} = 0.7515 + 2.8271 = 3.5786\ m^3$$

Theoretical volume of dry combustion products formed by firing 1 m^3 gas:

$$V_{dt} = 2.8271 + 0.0250 + 0.4740 = 3.3261\ m^3$$

Theoretical volume of wet combustion products:

$$V_{wc} = 3.261 + 0.9210 = 4.2471\ m^3$$

Real volume of combustion products

This value could not be measured directly. Therefore it was determined from the concentration of CO_2 in stack draught. Except the CO_2 volume formed by firing gas also the CO_2 volume formed by the decomposition of calcium carbonate contained in fired material had to be taken into account. By this decomposition 58.44 m^3 per hour was formed, i. e. 0.1249 m^3 per 1 m^3 of fired gas.

The average CO_2 concentration in the stack draught during the time of measurement was 2.5%.

The real amount of dry combustion products can be determined from theoretical content of CO_2, devided by real percentage of CO_2 content:

$$\dot{V}_{dr} = \frac{0.474 + 0.1249}{2.5} \cdot 100 = 23.956\ m^3 \text{ per 1 } m^3 \text{ of gas, i. e. } 3.234\ m^3 \cdot s^{-1}$$

The real amount of wet combustion products:

$$\dot{V}_{wr} = \dot{V}_{dr} + \dot{V}_{H_2O} = 23.956 + 0.921 = 24.877\ m^3 \text{ per 1 } m^3 \text{ of gas, i. e. } 3.234\ m^3 \cdot s^{-1}$$

The air excess coefficient for this amount of combustion products:

$$n = 6.76$$

Loss by air from cooling zone

The warm air was draught from cooling zone by the piping of rectangular cross-section 0.6 x 1.2 m. The air flow velocity was calculated from the dynamic pressure, measured by Pitot´s tube and precise manometer in six lines, devided regularly along the cross-section of piping. The average air flow velocity calculated:

$$v_a = 3.92\ m.s^{-1}$$

Static pressure of air:	20 Pa
Temperature	109°C
Specific density	0.899 $kg.m^{-3}$

The amount of warm air, draught from cooling zone:

$$\dot{V}_{ac} = 1.96\ m^3.s^{-1}$$

This air was used for drying of pressed pieces.

Heat Balance of the Kiln

Heat input by fired gas:

$$\dot{Q}_g = \dot{V}_g.H_g = \frac{468}{3600}.\ 13\ 754 = 1788\ kW$$

$\dot{V}_g$ .... amount of fired gas $(m^3.s^{-1})$

H_g .... calorific value of gas $(kJ.m^{-3})$

Heat loss by calcium carbonate decomposition:

Heat loss by decomposition of 1 kg:	11 280 $kJ.kg^{-1}$
Average calcium carbonate content:	9.73%
Output of the kiln:	1 462 $kg.h^{-1}$

Heat loss by $CaCO_3$ decomposition (technological loss):

$$\dot{Q}_r = 0.0973\ .\ \frac{1462}{3600}\ .\ 11\ 280 = 446\ kW$$

Heat loss by the air from cooling zone:

$$\dot{Q}_{ac} = \dot{V}_{ac} \cdot c_{ac} \cdot (t_{ac} - 20) = 1,96 \cdot 1,302 \cdot 89 = 227 \text{ kW}$$

$\dot{V}_{ac}$ .... amount of warm air $(m^3 \cdot s^{-1})$

c_{ac} .... specific heat of air $(kJ \cdot m^{-3} \cdot K^{-1})$

t_{ac} .... temperature of air (°C)

Flue loss:

$$\dot{Q}_f = \dot{V}_{wr} \cdot c_{cp} \cdot (t_{cp} - 20) = 3,234 \cdot 1,319 \cdot 128 = 546 \text{ kW}$$

c_{cp} .... specific heat of comb. products $(kJ \cdot m^{-3} \cdot K^{-1})$

t_{cp} .... temperature of comb. products (°C)

Loss by accumulated heat:

$$\dot{Q}_{at} = \dot{Q}_{as} + \dot{Q}_{al} + \dot{Q}_{ab} = 42,0 + 26,3 + 3,5 = 71,8 \text{ kW}$$

Heat Balance - Review of Items

	kW	%
Heat input	1 788	100.00
Loss by calcium carbonate decomposition	446	24.94
Loss by the air from cooling zone	227	12.70
Flue loss	546	30.54
Loss by accumulated heat	72	4.03
Other losses (by conduction of brickwork, by leakage, to foundations, etc.)	497	27.79

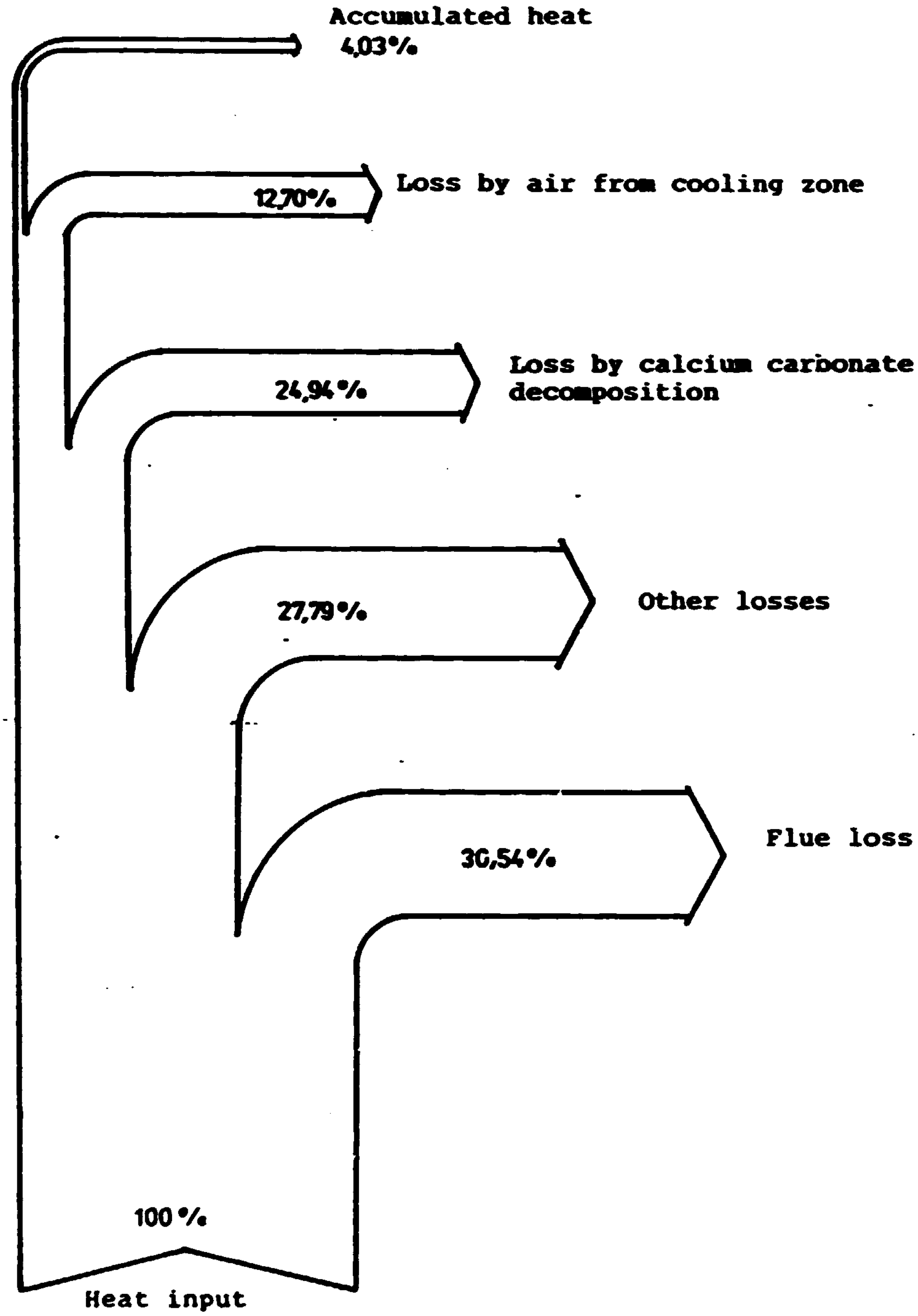


Fig. 36 Heat Balance - Sankey's Diagram

Graphically is the heat balance expressed in Fig. 35 ·

Specific Consumption o. the Kiln:

Production of the kiln	0.406	$kg.s^{-1}$
Heat input	1 788	kW
Specific consumption of heat for firing 1 kg of product	4 403	$kJ.kg^{-1}$

7.e Evaluation

Firing curves

The temperature distribution in the cross-section of the kiln can be considered satisfactory one (see Fig. 30). The temperature differences between the lower and upper part of the setting in preheating zone are acceptable for bisque firing and considerably lower than that in kilns of traditional construction. The rise of temperature in temperature interval from 500°C to 600°C slows down. The dilatation curve of fired material shows maximum in this interval, caused by physico-chemical changes in material. Therefore the reduction of temperature rise is advantageous in this interval.

Some imperfections can be seen in the course of cooling. Fired material shows high thermal shock resistance in temperature interval from 1060 to 800°C and therefore the cooling should be more rapid here. It would enable to slow down temperature decline in the interval from 600°C to 500°C. Problems of the cooling are partly caused by comparatively short cooling zone of the kiln. To improve the situation the owner of the kiln lengthened the cooling zone by putting last three pairs of burners of firing zone out of operation. On the other side this measure brought about deterioration of temperature equalization in firing zone.

The cooling rapidity is higher in the end of the kiln. The outlet temperature of about 150°C is obvious for this type of kiln.

Pressure conditions

The normal pressure (equal to atmospheric pressure) exists in the kiln between the 19th and 20th section. The rest of the kiln from this part is in overpressure with maximum from 32nd to 36th section (10.6 Pa). It is the upper admissible limit in considerably long part of the kiln. It causes the penetration of kiln atmosphere to the inspection tunnel and increases losses by leakage.

Kiln atmosphere

The composition of kiln atmosphere is influenced significantly by the decomposition of calcium carbonates which is most intensive in temperatures from 700 to 950°C. The CO_2 content reaches 20% in the part of kiln with this temperature. The CO_2 content falls down in preheating zone due to air excess in burners. The CO_2 content is 7.9% in the 12th section and 2.5% in stack draught (air excess coefficient n = 6.76). The combustion products penetrate deep to the cooling zone. The CO_2 content amounts 8.3% in 55th section of the kiln.

Gas quality

The differences of Wobbe's number did not exceed $\mp$ 2% from average. The duration of the change being shorter than several hours, it was compensated by thermal inertia of kiln brickwork and no changes could be registered. The change longer than one day caused the intention of the kiln to change firing curve. In such case the input had to be regulated by the attendance. Such a long change occured during the measurement. The quality of gas declined in first two days. It was reflected by increased consumption of gas.

Heat balance

The greatest deal (30.54%) of the input (1788 kW) represents the flue loss. It is caused by great volume of combustion products, necessary for temperature equalization in the cross-section of the kiln.

The uncommon item of heat balance is the loss by decomposition of calcium carbonate. It represents almost 25% of the input. The use of calcium carbonate for body composition brings on one side energy conservation by lowered firing temperatures, on the other side a part of conserved energy is spent for the decomposition of calcium carbonate.

The loss by hot air from cooling zone is relatively low (12.7%). It is caused by the construction of brickwork of cooling zone. The brickwork is intensively cooled here by vertical channels. Thus the low surface temperature of relatively thin lining is reached, but the heated air from channels escapes to the space above the kiln without any use.

The loss by accumulated heat in fired material and in kiln cars forms about 4% of the input. This item is on the level of these of similar kilns and can be partly reduced (as it can be seen in the following).

The rest of the input - almost 28% - is spent for the losses through lining, by leakage (penetration of kiln atmosphere to inspection tunnel due to relatively high pressure of kiln atmosphere in firing zone), by losses through foundations etc.

The specific consumption 4 403 $kJ.kg^{-1}$ exceeded projected value 3 770 $kJ.kg^{-1}$ by 16.8%. It was caused partly by lower actual output than projected, partly by the loss by the decomposition of calcium carbonate which had not been taken into account in the project.

Suggestions and Recommendations

Firing curve

Thermal treatment of material can be considered ideal in preheating zone. Temperature differences in the cross-section are also acceptable in preheating zone. Most of the reject occur in cooling zone. This fact is confirmed by the character of the cracks. Therefore the shape of cooling curve must be changed to reduce the reject occurence (6.3%).

Principles, which should be observed:

A) To cool the material as quickly as possible to the surface temperature 650°C.

   It can be managed by:

   - blasting-in the air to the three last pairs of burners which are out of operation
   - adjustment of cooling fans in the corresponding part of the kiln at maximal output.

B) To deccelerate the cooling in the temperature interval from 650°C to 450°C by:

   - complete closing of cooling system in corresponding part of the kiln.

C) To accelerate the cooling in the last part of the kiln (with temperature below 450°C) as much as possible by:
   - opening the direct cooling at maximum.

Heat balance

To lower the specific consumption of heat it is necessary:

A) To use the heated air from cooling zone in the entrance air lock

B) To increase the output of exit air lock for the purpose of better cooling of material in last sections of the kiln.

The main principle, which must be strictly observed during the adjustment of the kiln: changes must be realized one after another. Only after the response and when the new stabilized operation is reached, a new change can be accomplished. Thus the effect of each change can be registered.

7.f Contributions

As mentioned above, diagnostic measurements represent a very important part of energy management in ceramic industries. Contributions of realized recommendations can be classified as direct and indirect ones.

Direct contributions

energy conservation is realized by:

- adjustment of burning conditions
  (adjustment of optimal air excess, adjustment of the outlet temperature of burners, etc.)
- adjustment of pressure conditions
  (reduction of too high pressure in firing zone brings about reduced penetration of kiln atmosphere to inspection tunnel)
- adjustment of firing curve
  (if temperature in some parts of the kiln is higher than necessary, its reduction brings about lower losses by conduction of brickwork)
- adjustment of entrance and exit air locks, etc.

quality improvement and reject decreasing is accomplished usually by:

- firing curve optimization
- temperature equalization in the cross-section
  (by the use of mixing fans, by pressure curve adjustment, by setting optimization etc.)

output increase can be realized by:

- optimization of setting
  (with optimal heat transfer to and from fired material)
- temperature equalization in the cross-section of the unit, firing curve optimization
  (it enables in some cases to shorten firing cycle and thus increase the output)

Substitution of fuel used

Detailed knowledge of material thermal treatment gained by diagnostic measurement enables successful substitution of the fuel, together with the second measurement, serving for optimal adjustment of the unit, firing a new fuel.

Indirect contributions

Besides direct contributions an indirect profit can be gained by diagnostic measurements. Detailed technical information about heat consuming unit serves as the basis for:

- constructional improvements
- decision about the stage of modenization
- recommendations on waste heat utilization
  (utilization of heat escaping from cooling zone, by combustion products, etc.)

Contributions, gained by realized recommendations:

a) optimization of firing curve

Firing curve being changed as recommended, the reject occurence was reduced from 6.8% to 4.1% and thus the daily output increased from 3834 m^2 to 3945 m^2.

b) energy conservation

The surplus of heated air from cooling zone was used in the entrance air lock. Increased output of the exit air lock improved the cooling of fired material at the end of the kiln.

These two changes brought about energy conservation 122 kW which represents gas conservation 729 m^3 per day, i. e. about 250 000 m^3 annually.

Financially expressed, the daily reject reduction 111 m^2 represents about 550 US dollars, i. e. about 200 000 dollars annually. Energy conservation 250 000 m^3 of gas represents about 75 000 US dollars annually.

7.8 Portable energy kit

The portable energy kit is a special form of auditing means. It is designed to measure all necessary variables for energy audits with minimum requirements on the transport of instruments. The complete set is easily transportable by air, weighing 60-70 kg brutto and being packed in 3-4 separate cases. The idea of a portable energy auditing kit resulted mainly from the need of energy audits in developing countries where some (especially small-scale) industries are not equipped with sufficient instrumentation. An ordinary pick-up or even a car can be used for local transport of the kit from plant to plant.

The portable energy auditing kit was designed by the UNIDO-Czechoslovakia Joint Programme for International Co-operation, Non-metallic Industries in Pilsen, exploiting also the experience of the Research Institute for Ceramics, Refractories and Non-metallic Raw Materials in Pilsen. It is described in the following paragraphs.

Possible composition of energy kit instrumentation and suppliers

A. Temperature measurements	Supplier (producer)
- Flexible thermocouples NiCr-Ni (8 pcs)	Oesterr. Philips Industrie Ges mbH, Triester Str. 64 Postfach 217 A - 1101 Vienna, Austria

- Recorder Philips Transocomp. with accessories	Same
- Thermocouples PtRh 10-Pt (length 1,600 mm - 4 pcs)[b]	Same
- Compensating lead wires NiCr-Ni (4 x 150 m)[b]	W.C. Heraeus GmbH Herausstr. 12-14 D - 6450 Hanau Federal Republic of Germany
- Compensating lead wires PtRh 10-Pt (4 x 150 m)[b]	

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a) The specification of equipment in this annex is only mentioned by way of illustration and does not constitute an endorsement of specific suppliers or equipment

b) These items of equipment should be supplied by the counterpart after negotiations on the measurement conditions. They are not very portable.

- Digital pocket thermometer Therm 2220 - 3 and 2 probes	Ahlborn Mess und Regelungstechnik Eichenfeldstr. 1-3 Postfach 1260 D - 8150 Holzkirchen Federal Republic of Germany
- Digital pocket thermometer Therm 2222 - 2 incl. probes	
- Infrared thermometer "Thermopoint"	AGA Infrared Systems S - 18211 Danderyd Sweden

B. Pressure and volume flow measurements

- Electronic micromanometer EDM 2,500 M with accessories	AIRFLOW Lufttechnik GmbH Postfach 1208 D - 5308 Rheinbach Federal Republic of Germany
- Pitot´s tube (D = 10 mm, l=1,500 mm)	

- Anemometer Testovent 4000 incl. 2 probes	Same
C. Moisture measurements	Supplier (producer)
- Digital hygrometer TESTO 6400 with 2 probes (for gases and solids)	TESTOTERM GmbH Gebler gasse 94 A - 1170 Vienna Austria
D. Chemical analyses of gases	
- Electronic analyzer for CO_2 with set of filters and ceramic tubes	VEB Junkalor Altener Str. 43 45 Dessau German Democratic Republic
- Fuel Efficiency Monitor	Neotronics Ltd. Parsonage Road Takeley Bishop´s Stortford Herts CM 226 PU United Kingdom
E. Computing technique	
- Programmable calculator Sharp PC 1401 - Printer Sharp CE-126 P - Casette recorder Sharp CE-152	REMA Commerz Handelsges. m.b.H Computer Organization Mölkergasse 4 A - 1080 Vienna Austria
F. Auxiliary material	
- Special literature - Set of tools - Protective aids	

Total cost of above instruments is about $ US 35,000.

8. ENERGY BUS OF THE FACULTY OF ELECTRICAL ENGINEERING OF THE UNIVERSITY OF ZAGREB (CASE STUDY II)

8.1 General Description

The energy bus program was started at the Faculty of Electrical Engineering as part of a complex energy conservation program for the Department of Energy of Croatia, in the year 1985. The goals of the program were:

- to develop and equip an energy bus capable of supporting energy auditing in any industry,
- to form an energy team - a team of interdisciplinary specialists (electrical, mechanical, civil engineers, economists, designers) - who should offer technical and financial consultancy services to the industry, and work with the energy bus,
- to promote public awareness, research and training and efficient energy use.

The concept of the energy bus reflects the above-mentioned goals. The energy bus is equipped for doing energy auditing in thermal and electrical industrial energy systems. The main idea during the design phase was to provide all necessary instrumentation for the measurement of the main flows and preparation of global energy balance. Special attention was also paid to energy monitoring and control systems which are an important link in the energy supply - demand chain in a factory. All the equipment is portable, and the current composition of the energy bus equipment is adjusted to the type of industry being visited.

The role of the energy bus was not just to carry around the instrumentation and the crew, but to promote efficient energy use as well. That was the reason why the vehicle itself was chosen to be an attractive one, and the special logo was designed (Fig. 37).

The promotion of the energy bus was organized through a one day seminar in a hotel and the energy bus was in operation measuring the energy consumption of that hotel. Newspapers and TV also made notices of the energy bus, its purposes and possibilities. All this was organized to promote the energy bus itself, and generally the energy efficiency, too.

Another role of the Energy bus was to serve as a mobile training center. For that purpose it is equipped with portable TV, video recorder, camcoder, set of video cassettes and other teaching tools. The video cassettes cover all aspects of energy use in factories and they are particularly suitable for training the operating personnel for efficient energy use in various parts of the energetical and technological processes. This role of the energy bus is also very important since it makes the people aware of possible ways for energy savings, and prepares them to work with and operate improved and new equipment and processes.

8.2 Instrumentation

The instrumentation of the energy bus is generally similar to that described in Chapter 7, so it will not be repeated here. Some differences only occur at the instrumentation for energy auditing of electricity consumption and data acquisition system. That will be mentioned here.

Fig. 37 Energy Bus of the Faculty of Electrical Engineering of the University of Zagreb.

8.2.1 Measurements of electricity consumption

A brief description of efficient electricity use is given in Appendix I. The main quantities are active and reactive power. If the measurements are made continuously, then a load diagram can also be constructed. The load diagram is important if the peak load saving and reactive power compensation are the conversion measures to be taken. In such a case, besides the total load diagram, it is also important to obtain the data about the pattern of electricity consumption of various equipment and devices, e.g. motors, furnaces, lighting. etc.

This requires a simultaneous measurement of electricity consumption of selected single consumers as well as the total electricity demand. Another requirement is not to interrupt the operation of the equipment because of connections or disconnections of the measurements.

Bearing that in mind, a special measuring and data acquisition system has been developed (Fig. 38), which meets the following requirements:

1. it does not interfere with the regular operation of the facility under consideration,
2. it provides simultaneous measurement of active and reactive power,
3. it provides simultaneous measurement of total electricity demand, and consumption of selected single consumers,
4. through a standard serial communication channel (RS 232) it can be connected to a computer for storing the data.

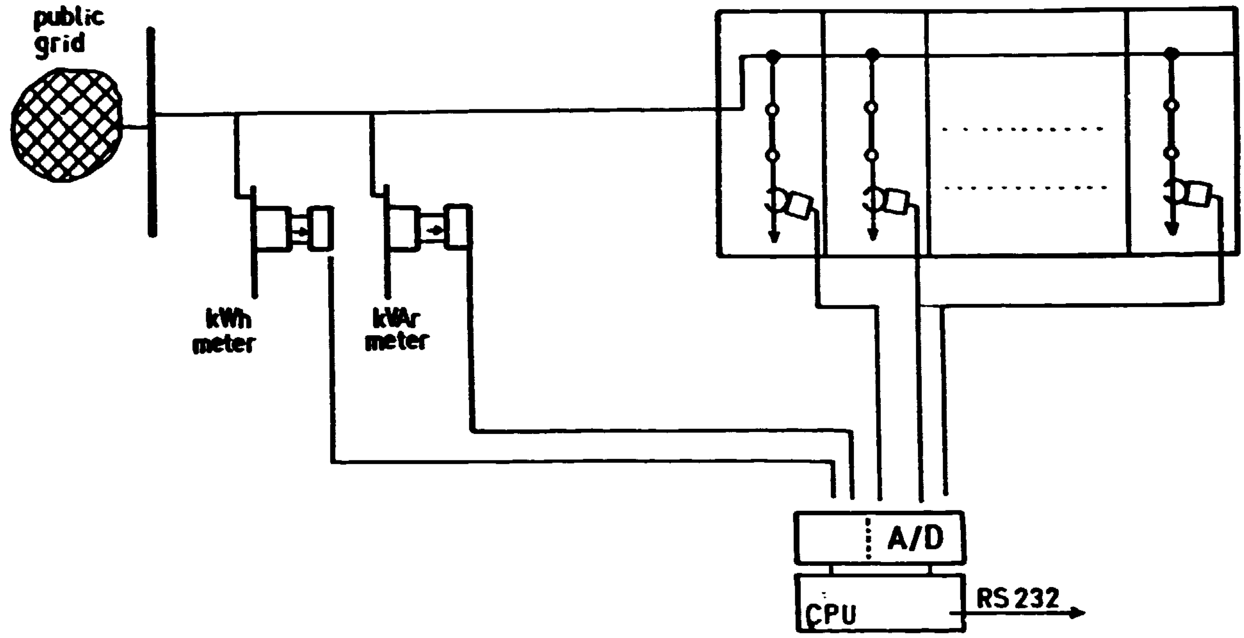


Fig. 38 A scheme of the electricity consumption measurement in an industrial facility.

The total active and reactive energy consumption is by the existing kWh and kVAr meters which are always installed in any factory. If the meters are of electronic type, then the read-out is made by the fotocell based device and if the meters are of impulse type, then adequate counters are attached.

The measurement of the consumption of a single user is made by the means of a clip transformer with the appropriate output signal which is fed together with voltage data to the microprocessor - based device. Voltage and current signals are compared there, and the angle between them is calculated. All that information is sent to the computer through a serial channel (RS 232). Once the data on voltage, current and angle are available in the computer, calculation of active and reactive power can be done easily.

8.2.2 Data acquisition system

The data acquisition system is of modular and distributed processing design.

Modularity means that it consists of various modules which can be combined according to the needs for energy auditing. One module represents an 8 channel system for electricity consumption measurement as shows in Fig. 38. If it is necessary to measure more than 8 channels, two or more modules can be applied. The other module is for standard 0-20 mA signals which are the usual outputs from the transducers. The next module is suitable for signals from thermocouples, etc.

A microprocessor unit can be attached to any module and it takes care of data conversion from all the inputs, and data transmission to the main computer. Because of the modular and distributed design it is possible to do very complex measurements in large industries with a lot of measuring points. The practical limit of the system is 1024 simultaneous measuring points.

An example of the data acquisition system configuration is given in Fig. 39.

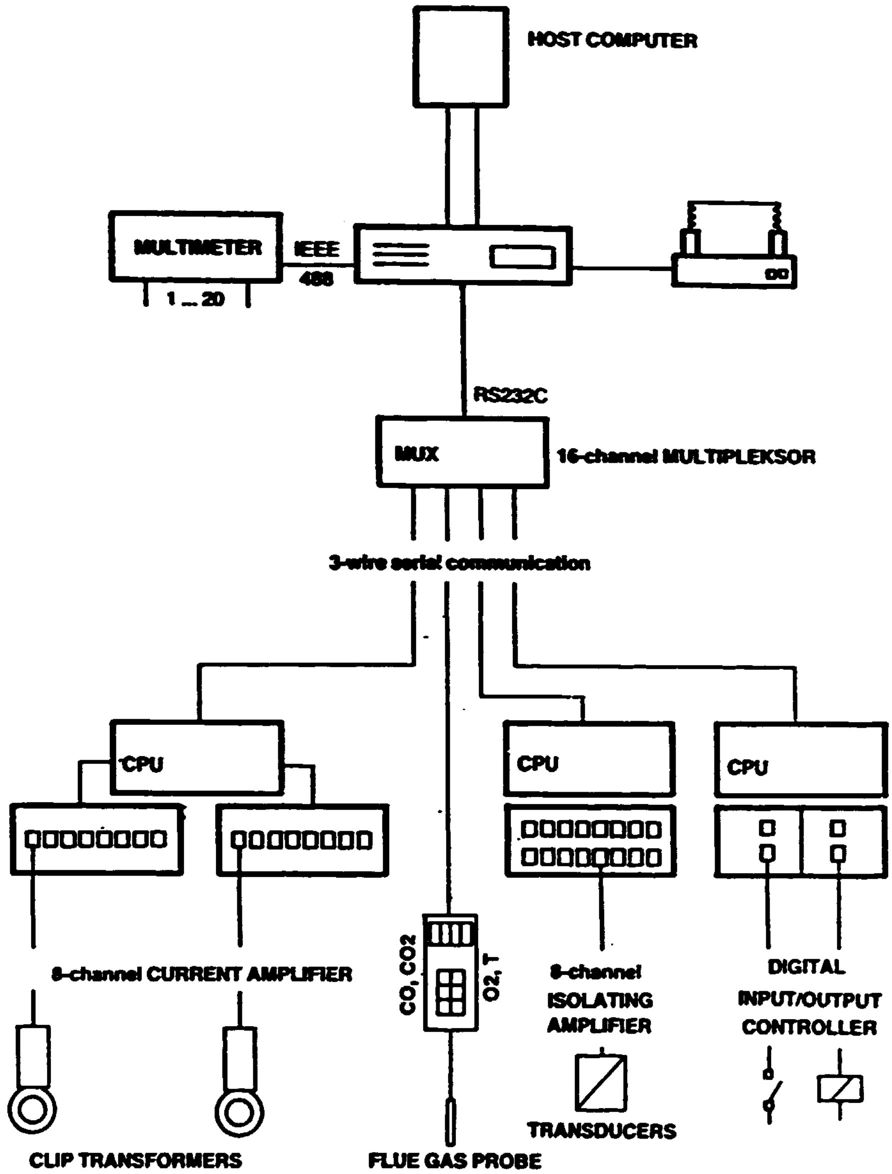


Fig. 39 An example of data acquisition system configuration

The host computer is an IBM AT with the following characteristics:

- 80286 INTEL processor
- 80287 math coprocessor
- EGA graphics card
- 640 kB RAM
- 1,5 MB extended RAM
- 40 MB hard disk
- 1,2 MB floppy disk
- 360 kB floppy disk
- colour monitor and mouse
- EPSON FX-100 printer
- 4 communication channels RS 232
- 2 parallel communication channels
- 1 IEEE communication channels

There is also a software package for initialization of the data acquisition system. The initialization means telling the computer how many modules there are, what are the measuring quantities and corresponding constant factors, what are the time intervals between successive measurements, how many quantities will be measured and stored.

8.3 Energy auditing in buildings - a practical example

Modern public and commercial buildings are important energy consumers. All year long they consume great amounts of thermal and electrical energy for heating or cooling, ventilation, lighting, etc. (Fig. 40).

In such a variety of energy needs a lot of opportunities exist for more efficient energy use. There are data (OECD sources) that the energy consumption in the commercial building was 600-800 kWs/m_2 before applying energy conservation measures, and 250-330 kWh/m_2, after. It means that energy saving up to 60% is possible. That is the reason why energy auditing in buildings was chosen as a case study.

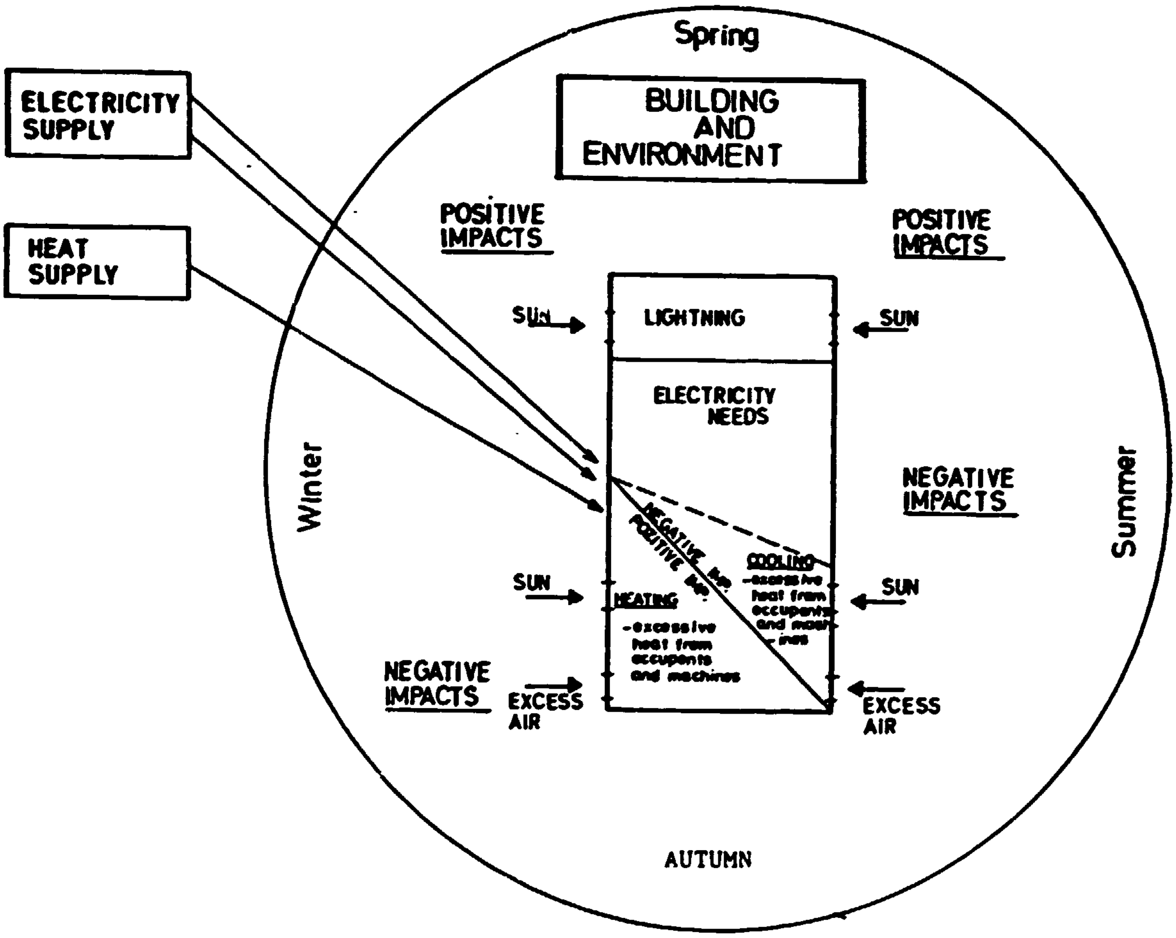


Fig. 40 Building energy needs during a year.

In this case study a practical example of energy auditing in the buildings of the Faculty of Electrical Engineering is shown. The buildings' profile is as shown in Fig. 41. Offices and small laboratories are in building "C", heavy laboratories and large lecture halls are in building "B", and small lecture rooms are in building "A".

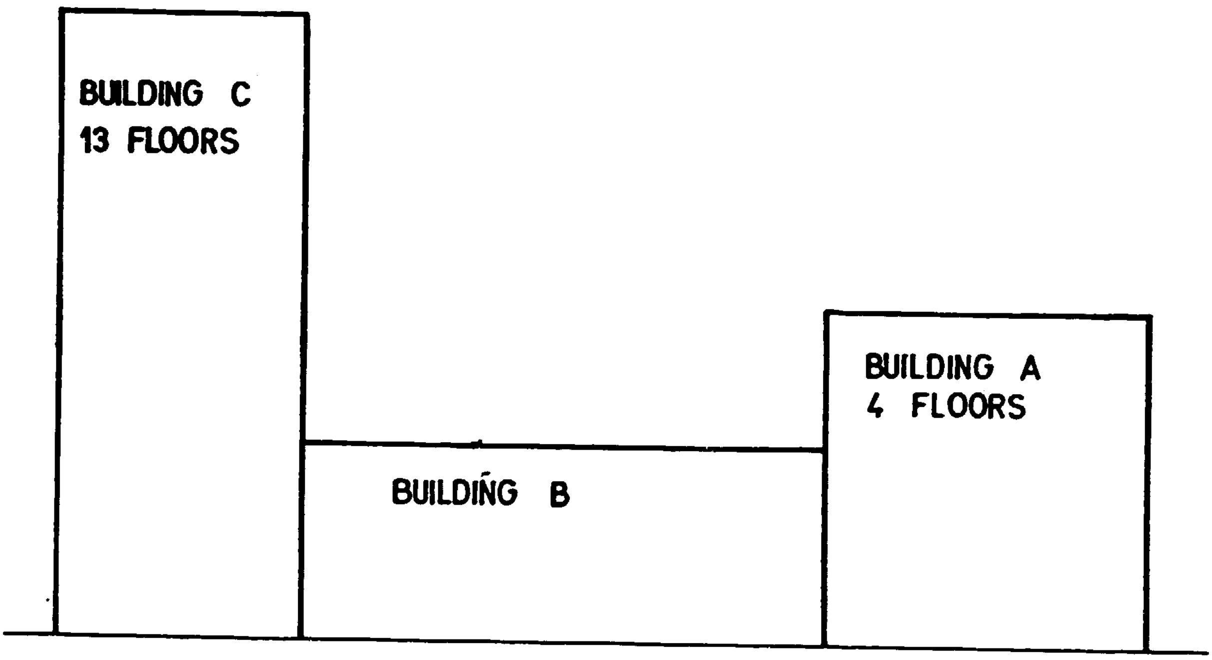


Fig. 41 The profile of the audited buildings

The electricity supply is from the own 10 kV substation, and the heat supply from the district heating system.

The energy bill was comparatively high against the other expenses, so the Faculty management decided to start an energy conservation project. A very detailed measurement and an analysis of energy consumption were undertaken in order to get a clear picture of the buildings energy behaviour . Some of the results will be described in the following text.

8.3.1 Energy auditing of electricity consumption

Firstly, a brief survey of electricity bills was done. It was found that the average yearly consumption was around 350.000 kWh, and that the monthly peak load was varying between 120-190 kW. The charge of the peak load was more than 65% of the total electricity bill. That was the first indication that it might be worth to do a closer examination of the electricity consumption and to consider a kind of peak load control. It was also found that the reactive energy consumption was very high. That caused unnecessary high addition to the electricity bill.

Secondly, a survey of the main electric loads was undertaken. They consist of:

- electric motors for heating and ventilation systems, (installed power P_1 = 45 KW)
- lighting
- elevators
- laboratory equipment being used for teaching

After that a measurement plan was prepared. In the preparation of the measurement plan, the following guidelines were taken into account:

- purpose of measurement
- foreseeable retrofitting actions
- constraints for implementation.

The above-mentioned items are explained below:

Purpose of measurement. Before starting a measurement it is always necessary to know what is expected to be found out by the measurement. The intention was to find out what is the load diagram for active and reactive energy, what is the pattern of the peak load, and what is the contribution of some load categories to the peak load.

Foreseeable retrofitting actions. Such a purpose of measurement as described may require unnecessary complex measurements as a consequence. That is the reason why it is advisable to have in mind possible retrofitting actions prior to starting the measurement, then one can concentrate on measuring those details which will or will not justify the predictions. In this case study, it was foreseen that the peak load control might be feasible, and that the reactive power compensation had to be done.

Constraints for implementation. After recognizing the possible retrofitting actions, the constraints of facility under consideration have to be taken into account. Namely, any kind of energy conservation measure must not disturb regular activities or production. If the peak load control is considered, it means that such electrical loads have to be identified, the interruptible operation of which will not disturb regular activities. In this study case it meant that elevators, laboratory equipment, lighting, etc., could not be included into the peak load control scheme. So, there was no reason to include them into the measurement plan either.

After such consideration, the following characteristics were measured:

- total active energy consumption
- total reactive energy consumption
- peak load
- load diagram of electric motor for heating and ventilation .

For research purposes these measurements were done all year long, but otherwise it is not necessary. What will be sufficient in most cases is several days of measurement in the heating season and several out of it.

The following diagrams show the results.

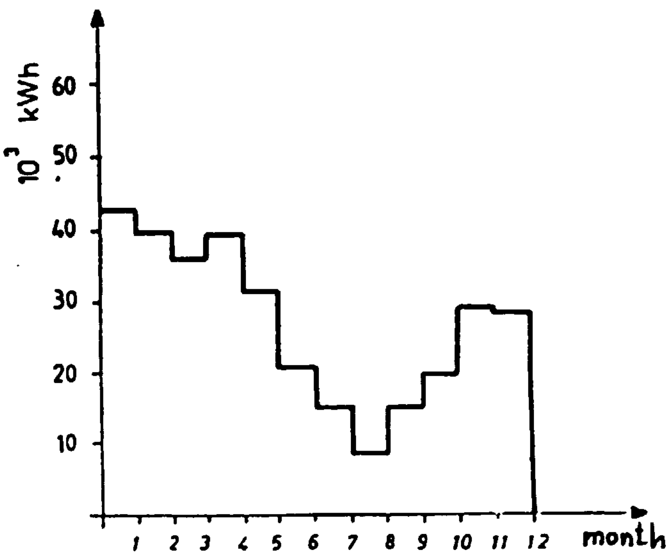


Fig. 42 Yearly active energy consumption

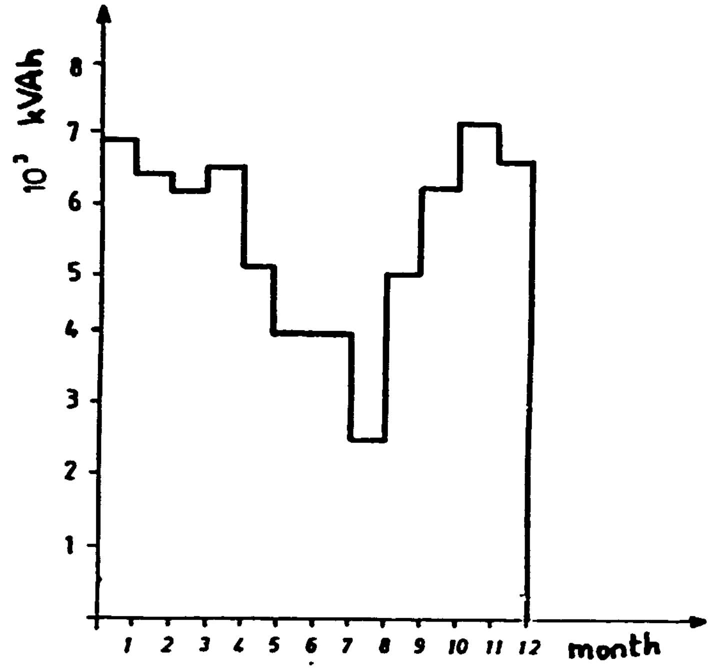


Fig. 43 Yearly reactive energy consumption

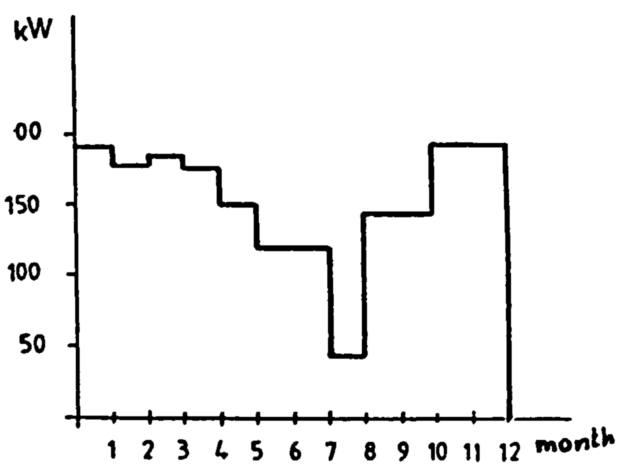
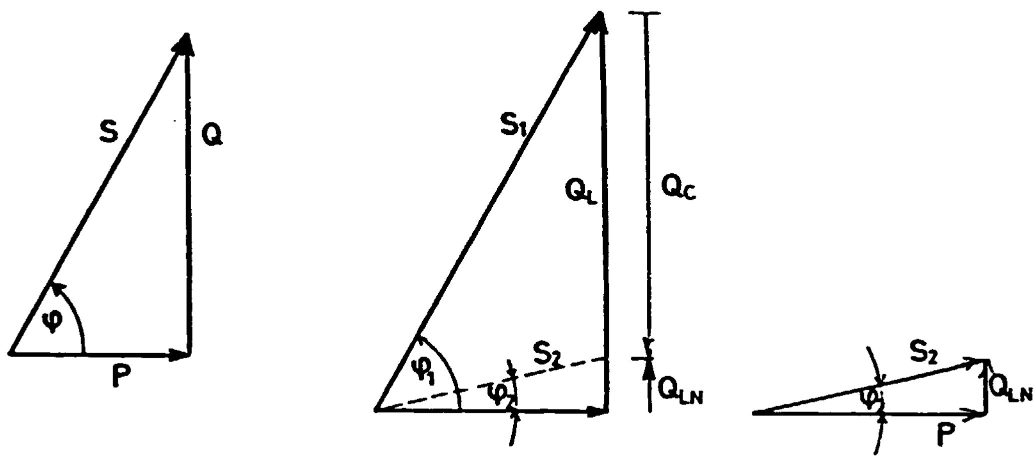


Fig. 44 Yearly peak load diagram

It is obvious from Fig. 43 that the reactive power consumption is too high. The reason for that is a large number of electric motors and flu lamps which have a low power factor ($\cos\varphi$). The flu lamps have $\cos\varphi = 0,5$ and the motors $\cos\varphi = 0,7 - 0,9$.

To lower the cost for reactive power, it is necessary to compensate excessive inductive power consumption by introducing capacitors. The relationship between active and reactive power is shown on Fig. 45.



Q_L = inductive power prior compensation

Q_C = necessary capacitive power for compensation

φ_1 = power angle prior to compensation

φ_2 = power angle after compensation

Fig. 45 The triangle of active (P), reactive (Q) and apparent (S) power

Q_c can be calculated as follows:

$$Q_c = P\,(tg\,\varphi_1 - tg\,\varphi_2) =$$
$$P\,(tg\,(arc\cos\varphi_1) - tg\,(arc\cos\varphi_2))$$

But for a proper sizing of the compensating capacitors it is also necessary to take into account operating time T:

$$Q_c = \frac{Wq - W\,tg\,(arc\cos\varphi_2)}{T}$$

W_q and W are, respectively, reactive and active power consumed in a given period.

After the installation of the compensating devices, the yearly reactive energy consumption become as shown on Fig. 46. The payback period of that investment was less than 7 months.

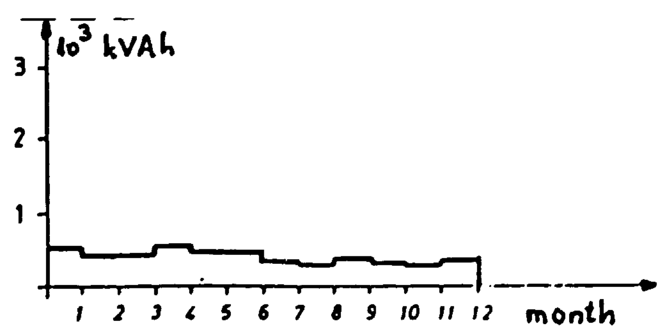


Fig. 46 Yearly reactive energy consumption after the retrofit measure

From the peak load measurement it was found that the average peak load in the interval 8 AM - 6 PM was 103 kW with standard deviation σ = 12 kW. The maximum peak load appeared only several times per month and it lasted less than half an hour per day.

The maximum allowable peak load was calculated as

$$P_{ma} = P_{RV} + 3\sigma = 103 + 36 = 140 \text{ kW}$$

To keep the peak load on that level, it was necessary to introduce a kind of peak load control scheme and to select the electrical loads which could be controlled.

In that case the only candidates available were electric motors from heating and ventilating systems.

But, the peak load control requirements must not disturb the regular function of the system being controlled. It means that the heating and ventilating system must maintain appropriate environmental conditions in the lecture rooms even though the peak load control is applied.

The additional measurements were done in order to check the influence of the heating system's interruptible operation on the environmental condition. It was found out that the building characteristics enable such an operation of heating system without serious changes in environmental conditions.

So, it was decided to apply the peak load control by the control of electric motors from the heating and ventilating system. Since the motor's switching equipment was already suitable for remote control, it did not require too much work to connect them to the control system (Fig. 47), so the investment was moderate. They pay back period for that measure was less than one year.

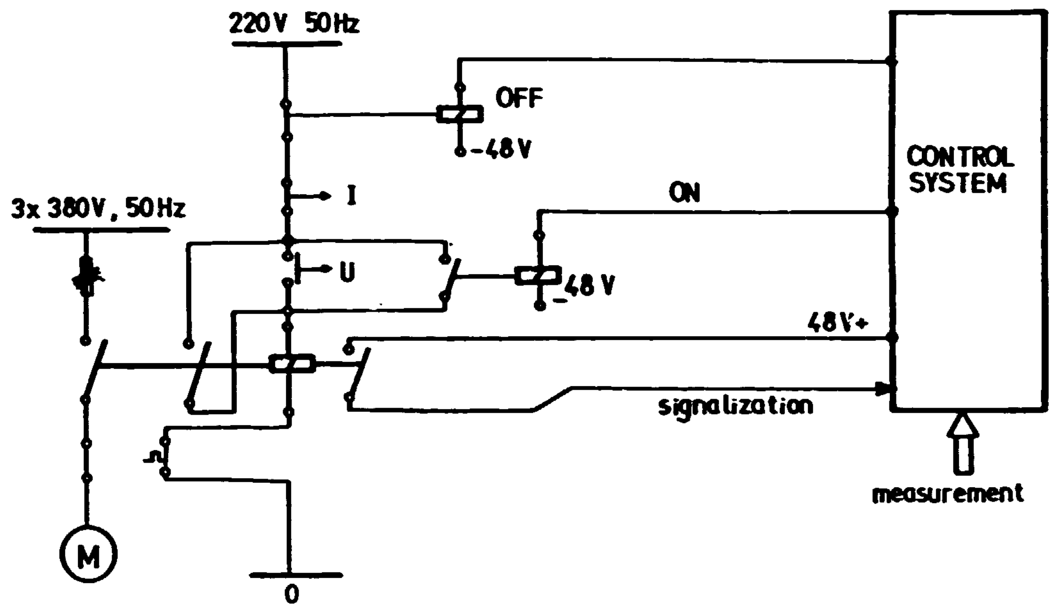


Fig. 47 Connecting an electric motor to the peak load control system

8.3.2 Energy auditing of heating system

The Faculty buildings are supplied by heat (hot water) from the district heating system. The monthly bill consists of the cost of heat power and the cost for heat energy. The heat power is calculated according to the buildings' shell characteristics as a single maximum heat demand, which can appear during the heating season - in this case 2.59 MW. The heat energy was estimated, not measured, to be around 46000 MWh/year. The contract with the heat supplier was also made that way , so the payment was made according to the estimated consumption. The buildings, together with the heating system are more than 25 years old. They were made in the time of cheap oil when nobody paid too much attention to the energy consumption and energy cost.

As a consequence one had:

- high cost for heating energy
- poor environmental conditions during winter, particularly cold windy days.

So, the purpose of auditing was:

- to find out if it is profitable to change the contract with the heat supplier, e.g. to install the heat meter and pay according to the real, not estimated, consumption;
- to find out the reason for poor environmental conditions.

Heat demand depends on building shell characteristics, weather conditions and environmental requirements.

Firstly, the heat losses through the elements of the building shell were calculated as well as the heat gains according to the average climate conditions in the heating season, and it was learned that the heat power was 2.4 MW (2.59 MW was mentioned in the contract).

Secondly, it was decided to measure the environmental conditions in the buildings during the whole heating season. Thermometers were installed on each floor of building "C" (13 floors) and in the representative rooms in buildings "A" and "B". The temperature of the supplied hot water from the district heating system was also measured and the temperature of the cold return water as well, (Fig. 48).

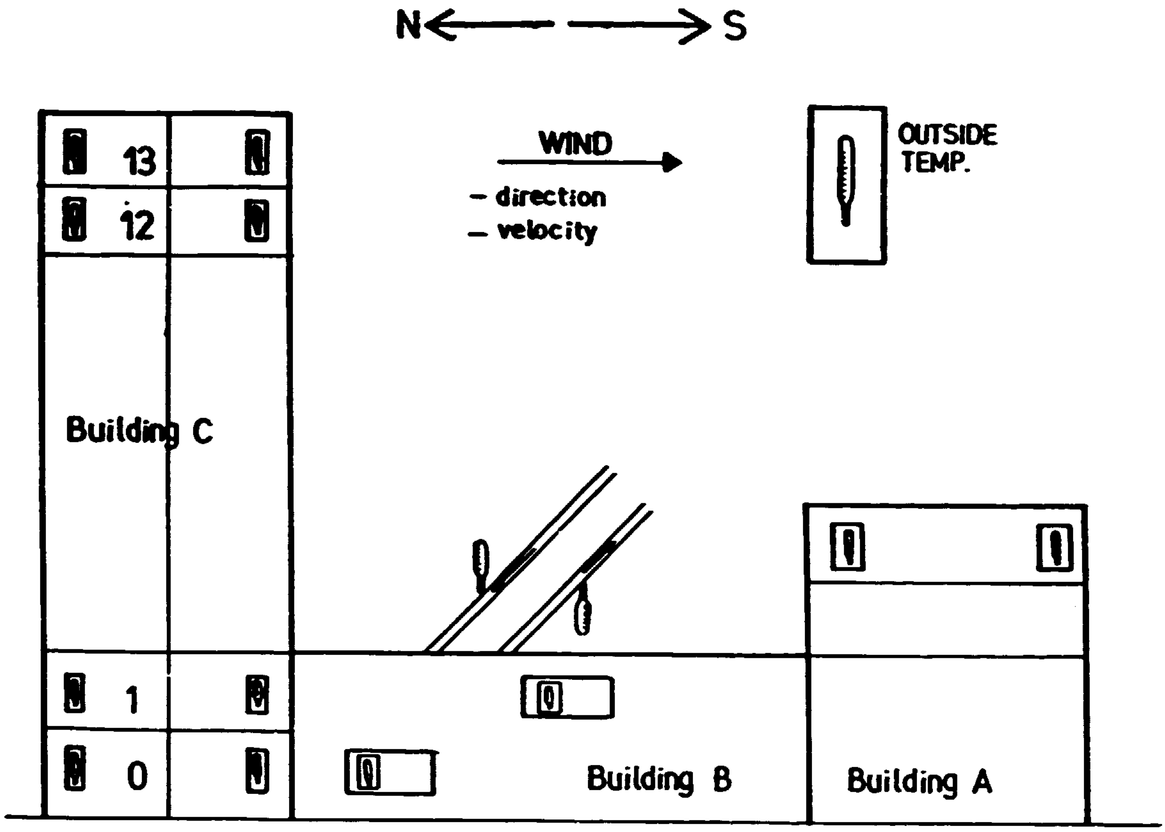


Fig. 48 The scheme of temperature measurement

The wind direction and velocity, and the outside temperature were registered, too. All these measurements were recorded each day during the whole heating season, four times a day.

Here are the findings:

- in the cold and cloudy weather, no wind, the average temperature was as required, and more or less the same in all the measured parts of the buildings,
- in the cold and sunny weather, the temperature was considerably higher in the rooms facing south due to passive solar heat gain,
- in the sudden rise of outside temperature the heating system did not respond properly, so the inside temperature became too high,
- the start and stop of the heating system operation was not adjusted to the working schedule in the buildings,
- in the windy days, the temperature in all the rooms was below the acceptable limits, the deviations being more severe with the rising wind velocity. The temperature fall was even more drastic in the rooms facing north (below 15° C). At the same time, the temperature of the supplied hot water was in the required range.

It was suspected that the main causes for the bad environmental conditions in the windy days were the windows. Therefore, additional measurements in one room facing north was made in order to find the heat loss due to infiltration and natural ventilation.

A special divice was installed on the room door to make an underpressure of 50 Pa in the room (Fig. 49).

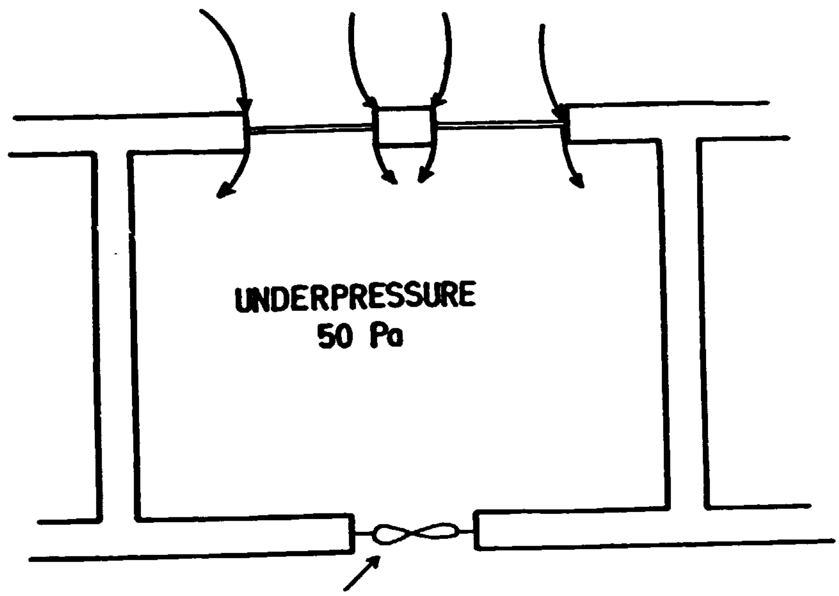


Fig. 49 Measurement of infiltration losses in a room

The room volume was V = 70 m^3 and the air flow rate Q = 600 m^3/h. It gives an 8,6 air exchange per hour, while the upper allowable limit according to standard is 2.

Due to such excessive infiltration losses, the heat losses were 120 W/m^3.

After that one window, and then both were sealed on the spot. That gave 5,03 and 3.4 air exchange per hour, respectively.

The gained results proved the initial suspicion that the main cause for the bad environmental conditions in the cold and windy days were the poor windows.

The recommendations were to seal and fix every second window, since a change of the windows would cost too much. It was also recommended to change the contract with the heat supplier, to install a heat meter, and to introduce more sophisticated control of the heating system.

The recommendations were accepted and they resulted in a 50% reduced heat energy bill in the next heating season. The payback period was less than six months.

III. Energy Management in Industrial Plants

Energy management in industrial plants is characterized by some or all of the following activities:

1. Industrial Energy Management
2. Non-traditional and simplified technologies and raw materials with lowered energy demand
3. Thermal process optimization, limitting firing conditions and optimum unit outputs
4. Energy audits of industrial plants
5. Thermal equipment modernization including insulation
6. Waste heat utilization
7. Motivation of kiln service, standardization
8. Climate conditions

1. Industrial Energy Management

As it has been already mentioned the world energy situation calls for an efficient solution that will extend the life of energy sources in the future, enable the development of new types of energy and ensure further development of industrialization in various countries.

The problem of energy may be classified into three areas

- natural energy sources
- energy producing industry
- consumption areas

Ensuring the energy sources either from country's own deposits or by importing them it is the subject of activity of a government control and planning authorities and it is a part of an entire energy policy of each country. The capacities and construction of the energy producing industry securing the generation of consumption types of energy are the principal part of the national economy control and planning both from the capacity and development point of view.

The entire consumption area of fuels and energy can be divided between the industry and the other sections (transport, agriculture, population etc.) approximately in similar shares. The consumption of energy by other sections is given by the living standard and after it reaches an optimum stage it does not change substantially anymore.

The industry keeps a foremost position in the energy consumption. The present energy consumption is derived from its capacities, technical level of the equipment and its control proper; the prospective one then from its further development, rationalization and application of the scientific and research results in the entire production cycle.

Therefore, the industrial sphere is the main field of activity that should reach an optimum stage in the energy consumption through the complex control system of energy consumption whereby the entire all-country balance in energy should be improved or, to enable further expansion of the industry, by energy economization, as the case may be.

The principle of management

The complex control system of fuel and energy consumption in the industry aims at reaching optimization of production capacities and thermal processes under the condition of minimum energy consumption. Each industrial branch is of a different nature given by the technological process. Therefore, the consumption control system can be most properly applied within the individual industrial branches so that it should act effectively and completely. Despite that the principle of this system is common for all branches.

Establishment of a team organization is the basis of an energy consumption control system (Fig 49). Such a team organization should ensure all the research and technical activity in the principal areas aimed at the energy consuming equipment and should elaborate finally a complex rationalization programme based on the research results, analyses of the consuming equipment and on the optimation considerations.

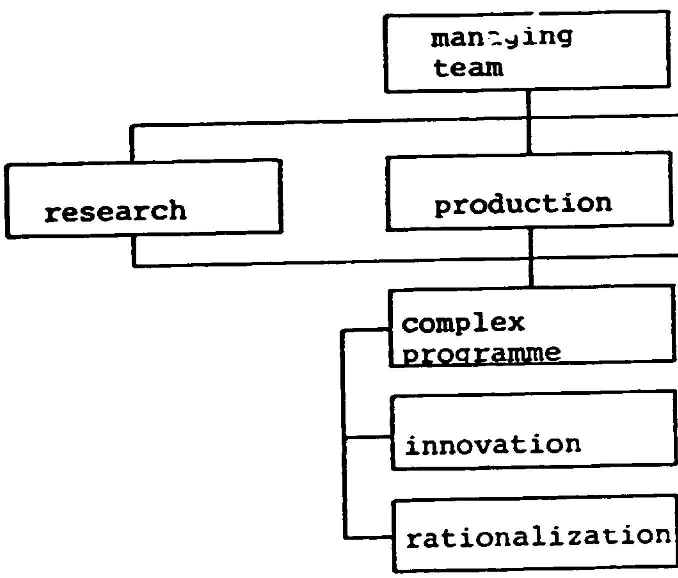


Fig. 50. Team Organization

<u>Managing team</u>

It consists of organization workers and specialists shown hereinafter (Fig. 51). The main activity of the specialized groups is first of all to elaborate a programme of research and diagnostic work in the individual areas, gathering of the results and processing all the s marized materials and giving proposals for solution.

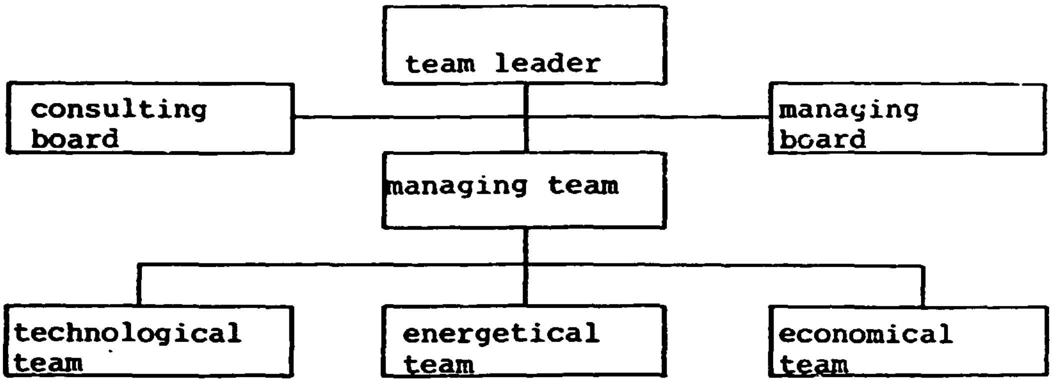


Fig. 51. Managing Team

The results of the individual sectional works should be compiled into the proposals for solution, consulted in the consulting board and submitted to the managing board. The managing board then takes into consideration the results obtained from the technological, energy and economical teams, summarizes the appropriate proposal and takes a decision on incorporating the proposal into the complex programme including the determination of time and extent.

Research area

Research and development form a very important area which, when aimed at reducing the energy consumption, plays a vital role in the development of a particular branch. The programmes of the tasks specified by the managing team and solved by the research are classified into two parts - the technological and thermal ones cover the following principal problems: (Fig. 38)

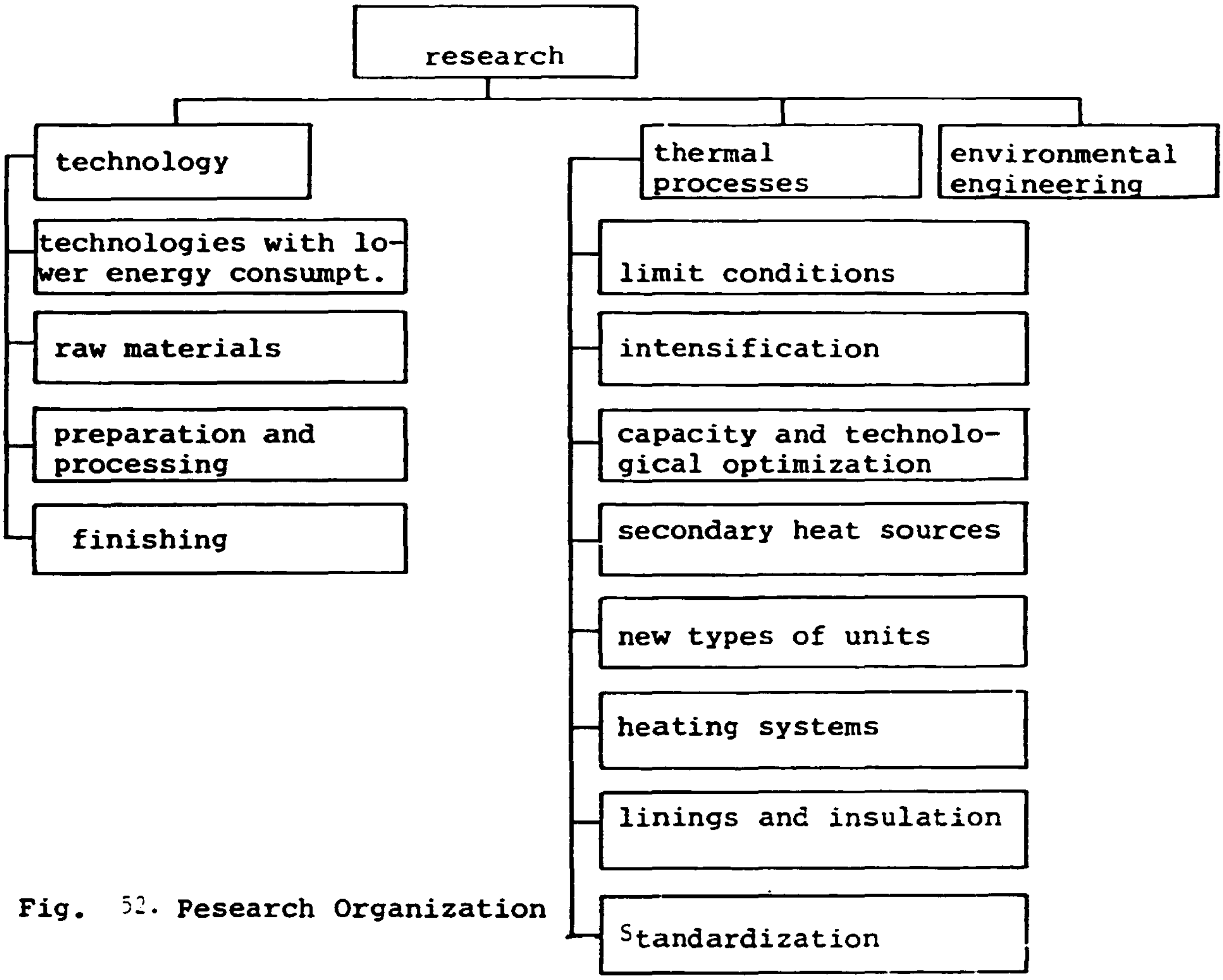


Fig. 52. Pesearch Organization

The research tasks may be, as partial ones, aimed at the solution of some contemporary problem in the production to reach more effective production by means of a reconstruction, changes in technology or by an optimation of the process. Mostly, however, they are aimed at a future innovation programme through which more distinct energy effects should be achieved.

Production area

The energy in the production sphere is first of all focused to a complex diagnostics of the present condition to a detail determination of production conditions and corresponding energy consumption. The specialized teams then work out the initial documents based on the data having been so found out i. e. types of energy, specific consumption and the existing energy standards for each unit. They serve as a basis for the elaboration of a plan and materialization of all types of rationalization actions. For the scheme of the activities see Fig.52 .:

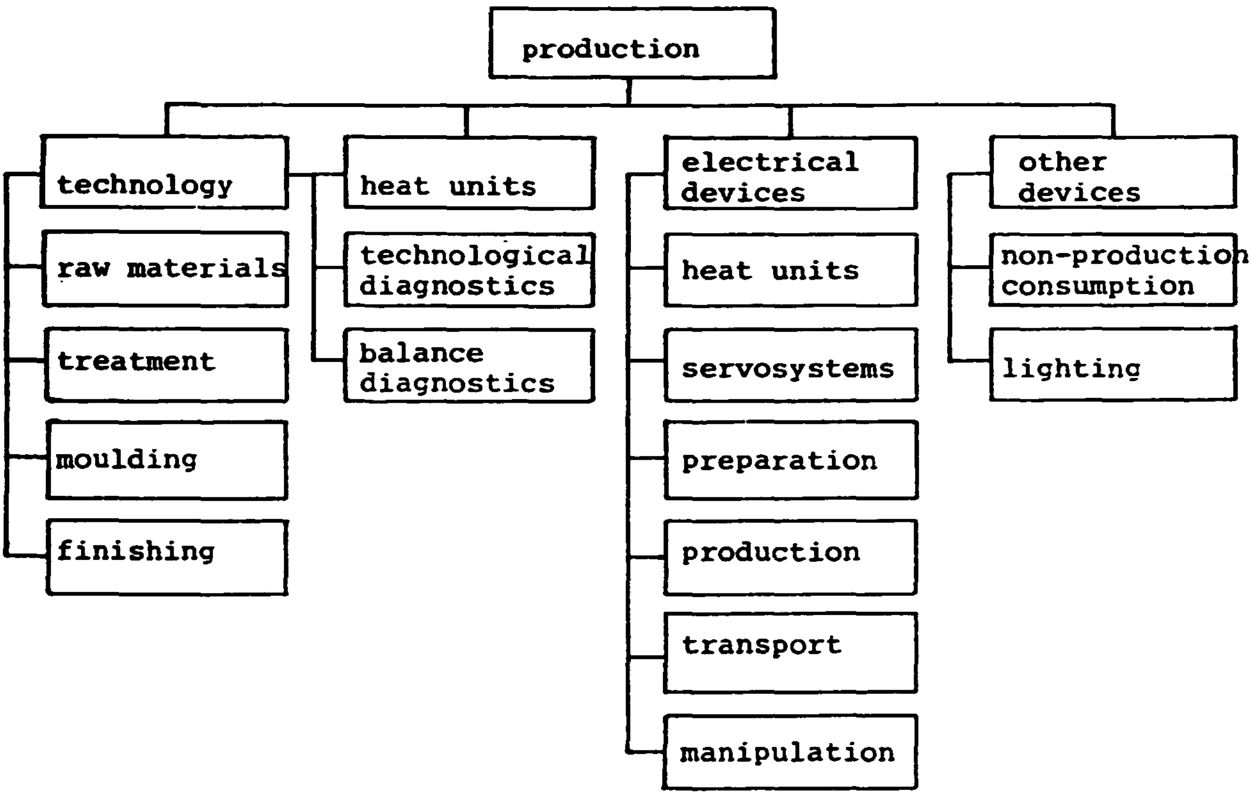


Fig. 53. Production Area Activities

Investment area

Plans of the investment developemnt in every branch are derived from the needs of inner market as well as from the export possibility. They secure an innovation programme both for individual pieces of production equipment and by a construction of new workshops or factories. The activity of the energy consumption managing team has a double form in the investment stage. Knowing the existing condition of he production equipment and the results of the research and development the managing team is capable of passing a judgement on any intended investment from the energy requirements point of view whether the energy consumption will comply with the intentions determined by the complex rationalization programme. It is also possible to judge the progressivity of every new technological process in comparison with the existing degree of the world technics.

The scheme of the activities within the investment area is shown in Fig. 54:

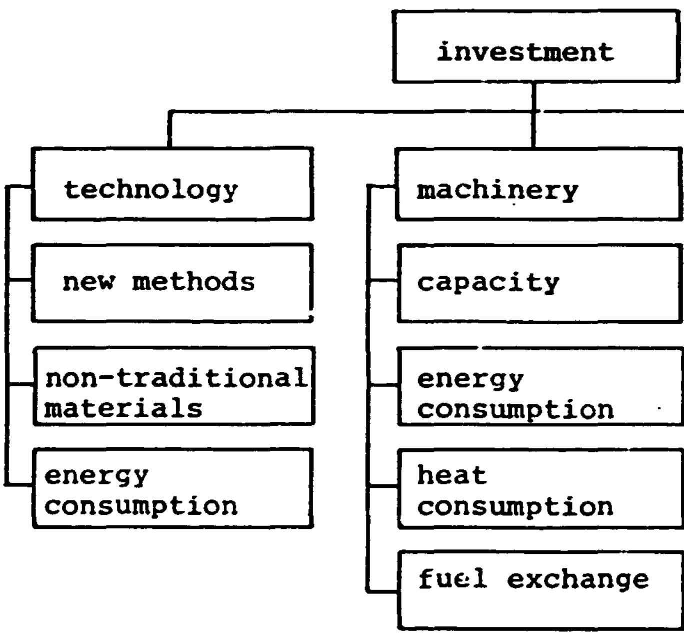


Fig. 54. Investment Area Activities

<u>Complex rationalization programme</u>

Research, technical and production basic documents from the foregoing stages are coming to the managing team where they are processed carefully.

The diagnostics of the production sphere of a branch enables to get an overall picture of the existing state and how the energy consumption is distributed factory wise, production lines wise down to the individual machines and equipment wise. It also gives data on capacities and technology.

The research and development render the basic information of the present development in the world. The research and development activity in its tasks is to solve new technologies and thermal units applicable in the innovation actions or in the construction of new production lines and plants.

Investment plans and intentions enable to judge further expansion of a branch from the point of view of new technology, sales and, first of all, of the required energy sources and their efficient exploitation.

The managing team elaborates all alternatives of the technical and economical solutions based on these expensive bases and evaluates them economically. The result of it are completely realistic ways of modernization that should secure lower demands for energy. Several solutions on different levels are made for a certain problem. The following alternatives e. g. are elaborated to reduce energy consumption in the firing process of bricks in a tunnel kiln: change in the raw material composition, change in the positioning of bricks on the tunnel cars, optimization of the thermal curve and of the heating system, intensification of the heating, even reconstruction of the unit if necessary, utilization of waste heat and even replacement by a completely new equipment as the case may be. It is a matter of course that several ways may be materialized simultaneously. It is upon the economists and the managing team to decide the time schedule and extent of the whole rationalization action.

The individual stages of these actions may be classified into:

optimization of 1^{st} grade
optimization of 2^{nd} grade
and innovation

The optimization of the 1^{st} grade covers all technological and thermal changes in the existing state that, according to the diagnosis results, contribute to achieving an optimum process without any substantial modifications.

The optimization of the 2^{nd} grade covers new technology of lower energy demands, reconstruction of heating systems, utilization of waste heat, intensification of processes etc.

The innovation represents the highest grade and is connected with the implementation of new technologies, change in fuel types, construction of new equipment etc.

Final complex rationalization programme for fuels and energy within a specified branch represents then a set of individual actions being documented technically in details, supported economically and compiled into an accurate time schedule of materialization. It results then in a conclusive programme of progressive reduction of fuel and energy consumption which begins after the diagnosis of the existing conditions and their optimization and ends by the innovation actions. The character of this principle of consumption control is a general one and when worked out for the conditions prevailing in a certain branch it may include specific changes. Nevertheless, it is the only way how to solve progressive reduction of energy consumption in the industry completely starting from the present conditions up to realistic prospects.

2. Non-traditional and simplified technologies and raw materials with lowered energy demand

The most important technologies, in connection with energy and material conservation, are those with lowered energy demands. The energy and material conservation in the production can be achieved by a complex of measures the most significant of which are as follows:

2.1 Non-traditional technologies and raw materials applied in the composition which not only lower the energy requirements but also the material costs. The heat consumption can be lowered by up to 35% depending on industrial sectors.

2.2 Simplification of production technology characterized by single firing processes, the heat energy savings reach up to 60%. The simplification can also be reached by the connection of several operations in a continuous flow, such as the iron and steel industry as well as glass industry.

2.3 Production and application of non-fired products with different ceramic, hydraulic, organic or chemical bonds. The energy savings up to 65% can be reached. These products can be shaped or unshaped. The cold hardening methods are becoming very useful in different industries.

2.4 Minimization of heat treated ingredients in different body compositions of products enabling the energy savings of about 15% of the total.

2.5 Use of proper insulations in the kilns and driers

Application of ceramic fibres in the periodical kilns brings the heat energy savings up to 35% while in the tunnel kilns of about 5% to 10% of the total consumption. Properly insulated driers, specially those which operate continuously, lower energy consumption in all industries.

2.6 Lowering material requirements

a) substitution of available and cheaper raw materials for the deficite ones

b) application of opaque or partly opaque glazes on tile products to balance the influence of cheap raw materials in the body

c) lowering of rejects by proper technological development and strict technological process control

d) product dimensions and mass kept in minus tolerances

e) mass reduction of products according to their functional requirements

f) optimization of kiln output according to the minimum specific energy consumption

g) reduction or elimination of auxiliary material consumption during the whole production process. The most important material for heat savings is the kiln f rniture which can even more than double the heat specific consumption for the ceramic product if no care is kept.

h) application of green and fired rejects as the secondary raw material into the manufacturing processes leads to the low-waste technologies.

2.7 Application of progressive production operations

a) pressure casting into non-gypsum molds saves up to 70% from the costs of molds and their drying, up to 50% of the roof-up area and 10-20% of manufacturing costs per 1 piece.

b) Dry pressing of dinnerware by isostatic pressing saves the electric energy by about 35% and the heat energy by about 5% of the total.

c) shaping of refractories chemically bonded by vibration.

2.8 Increasing of the useful technical and aesthetic parameters of materials and the choice of optimal product type for the respective application.

2.9 Dimensional accuracy which eliminates additional repairs of dimensions according to the market requirements

3. Thermal Process Optimization

To reach the optimum heat conumption during the firing process, two factors are to be analyzed:

a) Limiting firing conditions of the products, which depend on different structural changes of the blend during their heat treatment, such as loss of chemical water, decomposition of kaolinite, crystallographic changes of silica modification, changes of alumina structure, etc. Many of those changes must be respected during drying and firing to avoid any damage to the products. (See the following diagrams 1 and 2). The other products require controlled cooling in order to regulate the speed of growing and size of crystals. The shortest heat treatment which respects all technological requirements is called the limitting treatment with the lowest possible heat consumption. Each drier´s or kiln´s output shows an optimum of energy consumption since overloading of the kilns will waste the energy as well as the partly loaded driers and kilns increase the specific heat consumption very much. (Fig. 41)

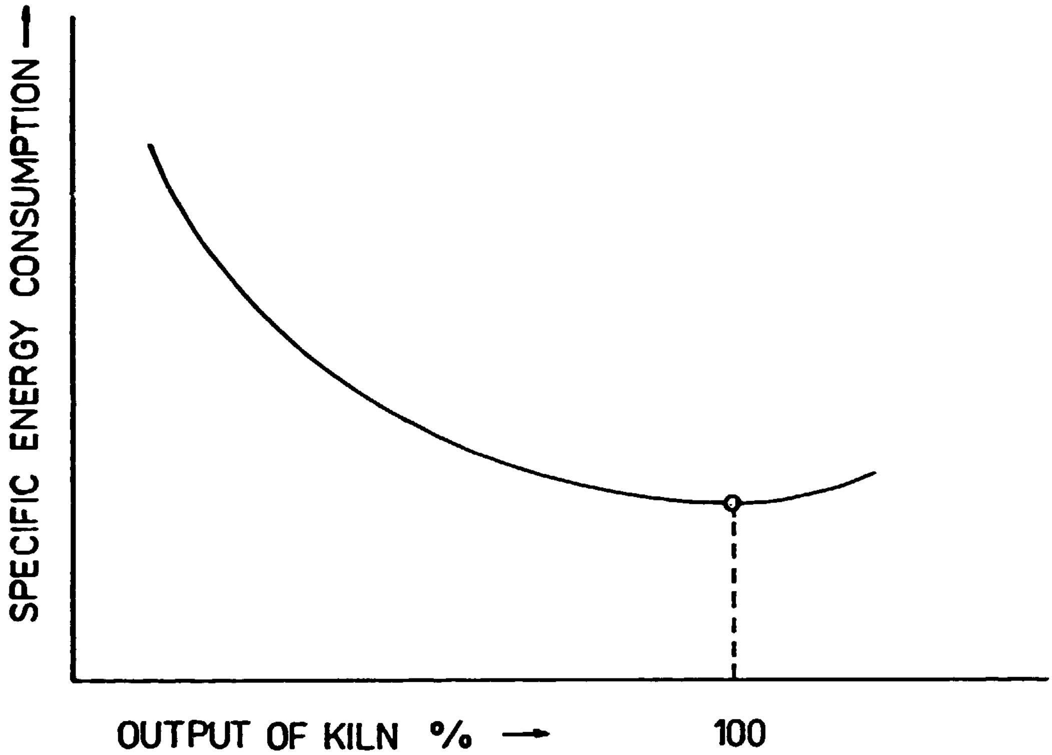


Fig. 55.

4. Energy Audits of Industrial Plants

The diagnostic measurement provides the team of experts with objective and detailed data about thermal unit operation. The sets of values obtained under common working conditions being completed with the information about technological parameters of the production unit and fuel consumed are evaluated in energy conservation study. This study agrees with the user of the heat consuming unit as an indispensable basis for his further technical, operational and organizational measures and steps to reach advisable energy savings, production intensification, improvement in the quality of products and reduction of rejects occurence. These contributions can be ensured either by the improvement of product thermal treatment or by reduction of energy losses.

There are two types of diagnostic measurements, either focused to the technological process optimization or to the energy conservation. Nevertheless the complex measurements, e. g. combination of technological and energetical types of measurement are most advisable for the purpose of energy management. The complex measurement provide the team of experts with complete information about the unit. Thus they can prepare to the user of the heat consuming unit the objective and complex statement and draft all suitable and recommendable adjustments and changes which are to be realized for perfect and effective service of the unit.

Regardless of the type of measurement (energetical or technological) the activities performed during the measurement comprise the three fundamental stages:

- statement of thermal unit operation conditions, performance of objective tests and functional measurements
- evaluation of tests and measurements
- working out proposals for technical, energetical and operational and organizational arrangements or recommendation on heat balance or reconstruction purposes.

Put into practice the arrangements may lead to one (or more) of four main contributions:

- energy conservation
- quality improvement and reject decreasing of product manufactured through the improvement of thermal technological conditions
- output increase of the heat consuming unit
- substitution of fuel used by another one

5. Thermal equipment modernization including insulation

Thermal equipment modernization means a step in which a capital input is already necessary. Therefore, the modernization is to be considered in two different levels:

a) Partial modernization which is usually realized according to a feasibility study. It covers, for example, the change of burners, increasing the cooling capacity, installation of mixing fans to the preheating zone, etc. The increased efficiency of the kiln will cover the costs spent on the partial modernization.

b) Complex innovation of the unit which requires high investments and, therefore, this step is applied when the increased output is requested and it must be based on a feasibility study. The traditional lining is replaced by new insulating materials; the kiln can be extended, the atomated regulation applied, etc.

6. Waste heat utilization

Waste heat is the heat rejected from the thermal process at the temperature high enough above the ambient temperature to permit the extraction and utilization of additional value from it. Usual sources of waste heat are combustion gases, air from the cooling zones of kilns and driers outlet. Such heat is utilized either directly or indirectly, tranferred in a heat exchanger.

The attempts to exploit waste heat quantitatively leads to the cases that outlets from different driers, boilers and kilns with lower enthalpy is being exploited. It is therefore that low temperature heat exchangers are developed which enable the service to operate with combustion gases of relatively low temperatures. Many such cases occur in the food, chemical and building materials industries. Since these temperatures are usually already below the dew point, attention is to be paid to different problems of corrosion.

However, different feasibility studies made show that period of the return of total capital invested is usually not higher than one to the three years.

7. <u>Motivation of the kiln service, standardization</u>

Economic motivation of the persons, who can affect the energy consumption of any energy consuming unit, is a very important issue. These people are influencing the energy consumption as they directly manage the operation of the unit, they apply their services non-stop, they release immediate decisions on the regulation and operation and, finally, they are responsible for the outputs and quality produced. Therefore, they are the first who can play the role in energy conservation, if properly motivated.

To be able to apply economic motivation on energy unit servicing people, it is necessary to know the standardized conditions of the unit, i. e. the standard energy consumption in the connection with the output. The standard energy consumption is derived from energy auditings, analysis of results achieved and established consuming and manufacturing standards for the unit.

If the servicing people prove that they take care on the operation, if they apply positive measures for energy conservation by keeping jointly the products quality for their attempts, they receive bonnusses which are only fragments for the total benefit of an industrial plant. If the servicing people do not care on the operation of the energy unit, they are punished gradually according to the weakness of their discipline.

Practical examples show that any industrial activity and energy conservation depends on the economic stimulation of the servicing persons and on the introduction of proper standards of energy consumption. In such a way considerable energy saving can be achieved up to 10% from total depending on the type of industrial activities.

8. Climate conditions

Climate conditions which differ according to the geographical location influence the energy consumption of an industrial plant in both ways, in the technological energy consumption as well as in the overheads energy consumption.

The manufacturing technology must respect the temperature, pressure and relative moisture content of the air additionally, those countries with intensive sun radiation exploit the solar energy either directly for drying or preheating different raw materials and semiproducts or indirectly by converting the solar energy into the increased enthalpy of different liquids and gases, which is then exploited in the manufacturing process.

Overhead energy is called that energy which must be spent in order to enable the operation of an industrial plant during all the year. Overhead energy is the energy which is spent for heating, illumination and air conditioning. Meanwhile some of the Middle European industrial plants show the overhead energy to be between 10 to 16% from total energy consumption, it can be expected that plants located in more northern altitude will need higher proportions meanwhile southern location will lower the consumption of the overhead energy needed.

IV. Final Note

Presented paper "Energy Auditing of Industrial Plants" brings the introduction into the problems of energy management from the view of the energy auditing, which is one of the most important measures for energy conservation. After the general introduction, the theory and practice of energy auditing is discussed. As the energy auditing of industrial plants always is associated with the technology, main energy management steps are analyzed as the guidance for energy conservation in the industrial plants.

All foregoing chapters, however, are related to the energy auditing as the Volume I, which is associated mostly to the general purposes, measuring tecnniques and theoretical aspects as well as to the general guidelines for factories energy equipment. Volume II will analyze the problems of energy auditing of selected industrial plants and Volume III will present several practical case studies, which will comprehensively describe positive results from energy auditing already reached in the different industrial plants.

The extent of this paper, exceeding the original programme, is necessary in order to show to the reader the more important possibilities for energy conservation as the guidance for its technological application.

APPENDIX I

ELECTRIC ENERGY SUPPLY SYSTEMS

I. EFFICIENT ELECTRICITY USE

About 30% of all conventional energy resources in the world are today transformed into electric energy (hydropower plants are not comprised here). With such a trend, that percentage is estimated to increase to 40-50% in 2000. The improvement of the performance level in conventional plants (thermal and nuclear) plants) has a significant impact on the whole power supply industry. The efficiency factor in those plants is expected to increase from today's 30-35% to 40-45%, not counting the production in combined production. Nevertheless, the total efficiency, if forecast participation of electric energy is realized, will decline from the present 78% to about 70% in 2000, which increases the importance of electric energy consumption rationalization.

Apart from the production losses in the electric energy travelling from the source to the consumer, there are also losses in transmission and distribution. The efficiency factor in those plants ranges today from 90 to 92%. Due to economic and ecological reasons, a significant efficiency increase is not expected in future.

However, in addition to already mentioned losses, there are losses with the consumers themselves as well. An electromotive drive and lighting with standard bulbs are taken as an example. If we consider the relation between useful work and the primary source energetic value, we can see that the saved amount of kWh saved fuel in the power plant (electromotive drive) to 20 kWh (light source).

While we cannot individually influence the production and transmission significantly, we can do that for sure in the domaine of consumption. As industry consumes 60 - 70 % of the total electric energy production and has relatively great load density, it should be the first candidate for testing the possibilities of savings. The fields in which we should reach for the possibilities for more efficient electric energy use will be indicated in continuation.

1. TERM DEFINITIONS

This chapter will be used to define the most common general terms in the analysis of efficiency, as either technical or economic parameters.

EFFICIENCY - the term efficiency can be defined in two senses. In the sense of the first law of thermodynamics, the efficiency is defined as:

eta = energy out / energy in

while in the sense of the second law of thermodynamics it is defined as:

epsilon = exergy out / exergy in

The efficiency of the sense of the second law presents system or equipment performances compared to the optimal (ideal) feasible performance, where epsilon max. = 1 and epsilon > eta.

MAXIMAL DEMAND (peak load) (kW) - is the maximum average loading through 15 minutes in the period of higher day tariff.

TARIFF SYSTEM - represents the policy of energy use. Most commonly there are two seasons (winter or higher and summer or lower) and two daily tariffs (day or higher and night or lower).

ACTIVE ENERGY DEMAND (kWh) - is measured energy demand through a certain period (usually one month).

REACTIVE ENERGY DEMAND (kVArh) - is measured reactive energy demand through a certain period. A part of the demand is free of charge (most commonly representing 1/3 of active energy demand).

SPECIFIC PRICE OF ENERGY - is an economical parameter used for objective evaluation compared with the same or a similar activity or as a test of implemented measures in the efficient energy use, where

c = total cost of energy ($) / total demand (kWh)

SPECIFIC ENERGY CONSUMPTION - is an economical parameter used for compared evaluation, where

s = total energy demand / production output (m3, kg, pcs.)

PAYBACK PERIOD (PBP) - is defined as

PBP = total investment / (total savings : annual operating cost)

PAYBACK RATE - is defined as

PR = (total savings - annual operating cost - amortization) / total investment.

2. CONTROL OF INDUSTRIAL PLANT ELECTRIC POWER SYSTEM

More careful management of an industrial power system can itself lead to considerable savings. The basic and the simplest, though yet too often neglected principle of management is: "if you do not need it, turn it off". Such a measure does not require any investment but only better care of employees.

Related to electric energy management from the perspective of the end-user and tariff system, two techniques are being applied today: peak load control and reactive energy compensation.

2.1 Peak load control

Following the basic tariff system regulations, we should also take account of the load factor. The load factor may be defined as a relation between the consumed energy within an observed period and the energy which would be taken over by a consumer with continuous use of peak load. In other words, the lower peak load, the lower average price of electric energy to be paid by the consumer. Consequently, our aim should be to control production so that the needed energy is consumed with as little power engaged as possible. The modern technology offers a few different solutions for production control, starting from simple time and photoelectric relays, through devices for control and restrictions, to the modern process computer. Each single case should be considered when a decision is to be made for one of those solutions.

Such solutions require certain initial investments, but depending on the electric energy consumption and the load diagram form, the investments return within 1 - 3 years. Where there are extremely big peak loads, a decision could be considered for setting an independent power unit to cover peak load, which can also serve as a spare feed source. Peak load control does not represent any problem generally, especially not in industrial plants where relatively big unit capacities are installed which are not in operation continuously. A delay for a brief period to switch them on does not generally disturb the technological process (Ex. compressors, heating, etc.).

2.2 Reactive energy compensation or power factor correction

The next tariff policy element on the basis of which electric consumption is paid are excessive quantities of reactive energy taken over. Power factor - the active-apparent power ratio - is used as the parameter. Most commonly, the average power factor value within the accounting period should be 0.95 or greater. If the average power factor within the accounting period is less than 0.95 the difference up to 0.95 should be paid. It can be more simply explained with the active-reactive energy ration and it is said that reactive energy is taken over in excess if it exceeds 1/3 of active energy consumption.

An economic analysis can prove that instead of taking over reactive power from power system, it should be produced in one's own plant. Owing to good price performance, the capacitors are used to produce reactive power. The capacitors can be installed either centrally (in the point of taking power) or in dislocation, with the consumers themselves. Capacitor power is calculated on the basis of the expected or measured consumption and the expected time of use, or, if regulation is planned, on the basis of the expected peak reactive power.

With the use of power factor correction transmission losses are reduced, voltage conditions are improved and it is also helpful for the power supplying utilities.

Payback period for the power factor correction investment is 0.7 to 2 years.

II. LOSSES IN ELECTRICAL ENERGY SUPPLY SYSTEMS

Industrial enterprises are faced with a wide variety of energetic problems, some of which are related to the use and conservation of electric energy.

Thus, the electric energy used within an industrial enterprises can be separated in electric energy used directly in the industrial process and electric energy transformed into heat or other forms of energy. In the following we shall deal only with the first category of electric energy usage, the second case being dealt within non-electric energy agents sub-systems.

Within this first consumption category, the main energy loss-generating elements are:

- electrical power transorferms;
- electrical distribution networks;
- electrical driving motors.

1. Electrical Power Transformers

The most important problem concerning the economical operation of power transformers as well as the main source of savings in this field within an existing connection diagram is the accurate selection of operating conditions based upon determination of the load level at which a certain number of transformers (parallel connection) must operate. In this respect, the transfomer power losses are determined as follows:

- active power losses:

$$DPtr = DPfe + DPsc \times \left(\frac{S}{Sn}\right)^2$$

where:

DPtr - transfomer active power losses;

DPfe - no-load running test active power losses (catalogue supplied);

DPsc - rated load short-circuit test active power losses (catalogue supplied);

S - transformer loading apparent power (computed, or measured);

Sn - transformer rated apparent power.

The transformer loading apparent power at a given moment (the moment of measurement) is given by:

$$S = \sqrt{3} \times U \times I$$

where:

U - phase voltage;

I - phase current.

- reactive power losses:

$$DQtr = DQfe + DQsc \times \left(\frac{S}{Sn}\right)^2$$

DQfe - no-load reactive power losses that can be determined with sufficient accuracy as:

$$DQfe = \frac{Io}{100} \times Sn$$

where:

Io - no load current [%] (catalogue supplied)

DQsc - rated load short-circuit test reactive power losses that can be determined with sufficient accuracy as:

$$DQsc = \frac{Usc}{100} \times Sn$$

where:

Usc - rated load short-circuit test voltage (catalogue supplied)

- active energy losses can be obtained by multiplying the active power losses by the operating time:

$$DWtr = DPfe \times t + DPsc \times \left[\left(\frac{S}{Sn}\right)^2 \times tm\right]$$

where:

t - the time interval during which is considered that the transformer operated (with the apparent load S or no-load).

tm - the time interval during which is considered that the transformer operated with the apparent load S.

A practical determination method of transformer losses is one based upon the energy consumption in a characteristic day. It is known that in most enterprises of machine building industry the load is enough stable around a steady value which is typical for a week day. A day during which the load reaches its maximum can be Wednesday or Thursday. Thus, the transformer losses can be expressed depending on a medium load current computed from the energy supplied during a manufacturing shift as:

$$DWz = DPfe \times t + 8 \times \frac{DPsc}{In^2} \times (Im1^2 + Im2^2 + \dots + Imn^2)$$

where:

DWz - active energy daily loss;

In - transformer current at the rated apparent power obtained as:

$$In = \frac{S_n}{\sqrt{3} \times Un}$$

where Sn and Un are catalogue supplied data;

Imi - average current during the manufacture shift i computed as:

$$Imi = \frac{1}{8} \frac{W_i}{\sqrt{3}.\ U.\cos\varphi_i}$$

where:

Wi - supplied active energy during the manufacturing shift i [kWh];

U - load voltage [V];

$\cos\varphi_i$ - average power factor during the manufacturing shift i.

The values of Wi can be easily obtained from existing active energy counters mounted on the load, or from adequate combinations of counter indexes if the counter i is not unique.

The active and reactive power losses and the active and reactive energy losses respectively, vary with related load and in this respect the economical operating conditions must be determined.

In order to cut-down on transformer active energy losses, in principle, in the cases of pair operating transformers, one of them can be disconnected during low-load hours.

Industrial transformation stations generally have one or two operating transformers that supply the departments - technological process. For reason of security, the industrial station transformers operate on low - voltage bars separated by longitudinal coupling devices.

Taking into account the risks determined by frequently operating some low and medium voltage devices, the switching on and off transformers operating in industrial enterprises must be carefully analysed.

Generally speaking, it can be said that for two transformers with rated power varying between 400 - 1600 KVA, the 30% load for a manufacturing shift can determine whether the switching-off of a transformer (in a pair) can be taken into account, with respect to active power losses cut-down.

The cases with more than two transformers are not taken into account here, owing to the structure of the plant network diagrams that do not usually employ such solutions.

2. Electrical Distribution Network

For the large majority of cases, the electrical distribution networks characteristic for the industrial energetic systems arc of a radial type.

The problem of the economical operation at industrial distribution networks consists in selecting a certain configuarion at the level of department - technological process supply, that should lead to low active electric power losses.

The losses within an industrial distribution network for the general case of three-phase a.c. voltage are determined with the following relation:

$$DEe = 3 \times Kf^2 \times Im^2 \times R1 \times \frac{tf}{1000} \text{ [KWh]}$$

where:

DEe - energy losses during time tf;

Kf - shape factor of the line current time variation function;

$$Kf = \frac{Imp}{Im}$$

Im - average value of line measured current [A]:

$$Im = \left(\frac{I_1 + I_2 + I_3 + \dots + In}{n}\right)$$

n - number of equal intervals during which current reading is performed;

Imp - square average value of line measured current [A]:

$$Imp = \frac{I_1^2 + I_2^2 + I_3^2 + \ldots In^2}{n}$$

Ii - current value measured at the half-way of interval 'i' [A];

Rl - line phase-equivalent resistance [ohm] determined as:

$$Rl = Rs \times L$$

where:

Rs - cable specific resistance [ohm/km]

L - cable length [km]

The transformation stations and main panels of the manufacturing departments are customarily supplied by means of two parallel cables. In most cases one of the cables is the reserve and is not loaded.

An important economical step related to network losses consists of setting under load the supply cable reserves. Thus, assuming that the resistance of the reserve cable is equal to that of the main cable (an assumption valid for the large majority of cases) when the cables are set in parallel, the power losses given by:

$$DP = 3 \times R \times I^2$$

when the resistance is reduced to half value, while the same load is maintained become:

$$DP' = 3 \times \frac{R}{2} \times I^2 = \frac{DP}{2}$$

Taking into account the loss values in low and medium voltage industrial networks, this measure is imperative.

Special attention must be given to cutting-down active electric power losses through improvement of reactive power flow in industrial networks.

In an industrial enterprise the main receivers that consume reactive power are: asynchronous motors, electric-arc furnances, welding transformers, induction furnances, synchronous under-excited machines, gas discharge lamps, etc.

When the reactive power is not generated as close as possible (electrically speaking) to the consumer site, a series of negative effects occurs, influencing the entire powergenerating, transporation and distribution chain, namely:

- increase of power and active energy losses as a result of reactive power circulation from power stations to consumers;
- reduced active power loading possibilities for the electric power generating, transport and distribution equipment, therefore the need of eversized it;
- large voltage variation and therefore voltage control difficulties;
- increase of permanent short-circuit current;
- reactive energy payment.

The assurance of a low reactive power input leads to a rational use of all the generating, transportation and distribution equipment.

Power input is characterized by the power factor which in a sine condition is given by the relation:

$$\cos \varphi = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}}$$

where:

P - active power

Q - reactive power

S - apparent power.

As the power is time variable, the above relation is difficult to apply, an average value being used in practice. The average power factor for a T time period is defined through the following expression:

$$\cos \varphi = \frac{Wa}{\sqrt{Wa^2 + Wr^2}}$$

Wa - active energy for period T

Wr - reactive energy for period T

Even if the result is not obtained through actual averaging (integration and averaging on the T interval of the P/S ratio) the value thus obtained is very close to the real one.

In practice, several reactive power input cut-down steps can be taken without resorting to power factor compensation equipment:

- adoption of low reactive power input technological diagrams;
- operation of synchronous motors at the maximum limit of reactive power generating capacity;
- observance of asynchronous motor repair quality level, especially as to what regards air-gap maintenance;
- replacement of asynchronous motors by synchronous ones in case of certain drives (compressors, pumps, fans);
- replacement of low-loaded motors with lower-power motors (in case of motors operating with an under 40% of nominal load are to be replaced without any other technical and economical calculations, those operating between 40 - 70% can be replaced after an adequate technical and economical analysis;
- no-load limiters installation on asynchronous motors, welding transformers and other discontinuous operating devices;
- parallel operation of power transformers according to the minimum loss chart.

Whenever the case requires the adequate reactive power compensation, by means of adequate equipment will be taken into consideration. This will be performed as close as possible to the consumer in order to minimize the active energy losses due to reactive power circulation. A solution that could be taken into consideration is that of individual compensation at certain significant reactive power consumers.

3. Electrical Driving Motors

Electric driving motors have a great importance within power consumption in industrial systems, especially within the engineering machine industry. Thus, a large part of electric energy losses are due to motor losses, consiting of copper and iron losses.

Copper losses can be computed according to the expressions:

active power:

$$DPcu = 3 \times Kf^2 \times Im^2 \times Re$$

energy corresponing to a Tf operating period:

$$DWcu = DPcu \times Tf$$

where:

Kf - shape factor, for the previous relations can be taken Kf = 1.01 with a good approximation;

Im - current measured under normal operating conditions;

Re - the equivalent resistance of the motor, is taken into consideration:

Re = Rind for c.c. motors;

Re = Ri (stator resistance) for synchronous motors;

Re = R1 + R2´ for asynchronous motors with collector rings for which:

R1 = stator resistance;

R2´= stator related rotor resistance determined with the expression:

$$R_2' = R_2 \times (0{,}98 \frac{U_1}{U_2 i})^2$$

where:

R_2 - stator resistance;

U1 - stator line voltage;

U2i - rotor ring line voltage, measured under blocked rotor and open circuit conditions;

Iron losses are determined individually for asynchronous motors with collector rings and for the other electric motors:

- for asynchronous motors with collector rings, iron losses are determined with the use of a wattmeter (wattmetric clamp) or of an active energy counter and an amperemeter (ammetric clamp) mounted in the supply circuit, and are given by the following relation:

$$DPfe = Prd - 3\ Ird^2 \times R1$$

the energy for a Tf interval, respectively:

$$DWfe = DPfe \times Tf,$$

in the above relations:

Prd - power absorbed by the motor with an open rotor circuit;

Ird - stator current with open rotor circuit;

R1 - stator resistance.

- for the other motors, the iron and mechnical losses are determined together, as they are difficult to separate:

$$DP(fe+mec) = 3 \times R1 \times Io^2$$

the energy for a Tf interval, respectively:

$$DW(fe+mec) = DP(fe+mec) \times Tf$$

where:

Po - no-load power;

Io - no-load current;

R1 - equivalent resistance.

For c.c. motors, as the iron losses are very small, the previous relations actually represent mechnical losses.

The mechanical losses into asynchronous motors with collector rings are given by:

$$DPmec = Po - Prd + 3 \times Ird^2 \times R1 - 3 \times Io^2 \times (R1 + R2')$$

the energy losses for a Tf time interval are given by:

$$DWmec = DPmec \times Tf$$

As to what concerns the determination of active energy losses for various types of motors, the difficulty of determining the equivalent resistance must be underlined. This is especially so in the case of asynchronous without collector rings, where their computation relations imply a knowledge of starting input power, a power difficult to observe and measure with the usual equipment.

Taking into account the stated above we tried to replace these calculations with two other computed data:

- the energetic and technological efficiency of an electrical driving;
- the load factor of an electric motor.

The energetic and technological efficiency is a concept which take into account all data about the energy included in a final product during a manufacturing cycle, or during all transforming steps of a raw material into a final product.

Thus, one defines the efficiency of an electric driving as:

$$eta = \frac{Ps \times ts - Po' \times ts \times 100}{Ps \times ts + Po \times to}$$

where:

- Ps - load power;
- Po' - no-load power with the driving mechanism coupled;
- Po - no-load power without the driving mechanism;
- ts - load operating time;
- to - total no-load operating time.

This relation can be extended for the cases of electric drivings that have more than one characteristic load interval (during which the load power is constant) by replacement of:

- Ps - with a sum of Psi (i = 1 ... c, where n is the number of characteristic load intervals);
- ts - with a sum of tsi in the same conditions.

The terms in this relation are easily definable by simple measurements. By using the same measured data it is easy to compute the load factor of the motor as:

$$K = \frac{Po \times to \times Ps \times ts}{Pn \times (to + ts)}$$

Both results are useful in the analysis of electrical drivings dimensions and efficiency as well as in the analysis of the energy use from the technological point of view (intersectoral approach).

4. Measuring Means and Methods

Energy diagnosis of electric power consumers implies a sufficiencly accurate determination of the parameters that, at a given moment, characterize the state and operation of the elements under observation.

It is recommended that the measurement of electric parameters be performed with non-destructive measuring methods that ensure the absence of a limit to a minimum interference with the continuous and/or normal operation of elements under observation. In this respect, it is recommended that current, active and reactive power and power factor measurements be performed with the use of adequate clamp probes and/or measuring equipment. Current reducers should be used only if strictly necessary.

In case such instruments that offer the possibility of convenient, fast and accurate measurements are not availalbe, it is recommended to adopt measuring merhods that fall within the same requirements of non-destructive measurements. Such measurements can also be performed with classical wattmetric kits.

As a general consideration concerning an electric energy auditing session, experience has proven that diagnosis measurements must cover a period of at least three working days, so that operating intervals with different changes can be included and the measurement and data processing results be truly relevant. It has been demonstrated that larger periods improve the accuracy of the determinations, but the difference of error is not important, while for shorter periods statistical error become important.

In order to improve both quality and speed of measured data processing in I.C.P.E. - Bucharest (Romania) it was developed computer programmes package which performs both with electric and non-electric measured data, providing loss computations, In the electric energy area the package ensures computing of transformers as well as load factor for their electric motors.

V. Attachments

1. List of Figures

2. List of symbols

a - temperature conductivity $(m^2.s^{-1})$

A - area (m^2)

c - specific heat $(kJ.kg^{-1}$ or $kJ.m_n^{-3}.K^{-1}$ - for gases)

g - coefficient of gravity $(m.s^{-2})$

i - specific enthalpy $(kJ.kg^{-1})$

I - line current (A)

H - calorific value $(kJ.kg^{-1}$ or $kJ.m^{-3}$ - for gases)

k - heat transfer coefficient $(W.m^{-2}.K^{-1})$

l - length, thickness (m)

L - height (m)

m - mass (kg)

n - air excess coefficient ((1)

p - pressure (Pa)

P - el. power (W)

q - heat flux density $(W.m^{-2}.K^{-1})$

r - specific heat for evaporation $(kJ.kg^{-1})$

R - gas constant $(kJ.kmol^{-1}.K^{-1})$

t - temperature (°C)

T - temperature (K)

U - voltage between two lines (V)

U_o - voltage between line and neutral (V)

v - velocity $(m.s^{-1})$

$\bar{v}$ - mean velocity $(m.s^{-1})$

V - volume (m^3)

w - humidity $(kg.kg^{-1})$

x - moisture content $(kg.kg^{-1})$

Wo, Pr, Nu, Re, Fo, Gr - non-dimensional criteria

tmp - tons of fuel

Greek symbols:

α - heat transfer coefficient $(W.m^{-2}.K^{-1})$

β - volume expansion coefficient (K^{-1})

ε - emissivity coefficient (1)

λ - thermal conductivity coefficient ($W.m^{-1}.K^{-1}$)

η - dynamic viscosity ($kg.m^{-1}.s^{-1}$)

ν - cinematic viscosity ($m^2.s^{-1}$)

ρ - density ($kg.m^{-3}$)

φ, ϕ - phase shift between AC-current and AC-voltage ($\cos\varphi$, $\cos\phi$ - power factor)

σ - Stefan-Boltzmann constant

Subscripts:

a - air

C - combustion products (flue gas)

d - dry

dyn - dynamic

g - gas

G - gross

H_2O - water

in - inlet

n - net

o - normal conditions (0°C, 101, 325 kPa)

out - outlet

p - constant pressure

t - theoretical

T - tar

u - universal

w - surface of a wall

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