21st Intersociety Energy Conversion Engineering Conference

ADVANCING TOWARD TECHNOLOGY BREAKOUT IN ENERGY CONVERSION

Vol. 1

Volume One of Three

21st Intersociety Energy Conversion Engineering Conference

ADVANCING TOWARD TECHNOLOGY BREAKOUT IN ENERGY CONVERSION

San Diego, California
August 25–29, 1986

iecec '86

Sponsoring Societies:

American Chemical Society
(1986 Conference, San Diego, CA)

Society of Automotive Engineers
(1985 Conference, Miami Beach, FL)

American Nuclear Society
(1984 Conference, San Francisco, CA)

American Institute of Chemical Engineers
(1983 Conference, Orlando, FL)

Institute of Electrical and Electronic Engineers
(1982 Conference, Los Angeles, CA)

American Society of Mechanical Engineers
(1981 Conference, Atlanta, GA)

American Institute of Aeronautics and Astronautics
(1980 Conference, Seattle, WA)

ISBN 0-8412-0986-3
Library of Congress Catalog Number 86-071520

Printed in USA

Proceedings of the 21st Intersociety Energy Conversion Engineering Conference

Published by the
American Chemical Society
1155 Sixteenth Street, N.W.
Washington, D.C. 20036

Message from the General Chairman

This is the second time that I have been responsible for organizing the IECEC Conference. The first time—the 14th IECEC—was in 1979 at the height of the oil price hysteria. Those were exciting times for the Conference...everyone wanted to be involved and expectations were high. This year we find ourselves at the other end of the cycle, we hope. Expectations are a lot more realistic but important progress is being made.

The theme for the 21st IECEC—"Advancing Toward Technology Breakout in Energy Conversion"—sums up pretty well where we are today. Seven years ago when Hamid and I worked to organize the 14th IECEC, we were almost overrun with people interested in the terrestrial applications of advanced energy conversion. This year's meeting will be very different. The large fossil energy programs have been shut down, but many of the important energy conversion technologies are making more quiet progress in laboratories and development centers. We see graphic evidence of that progress in the technical papers and demonstrations during the week. The Conference gives us a chance to talk about our progress and to gauge it against our own understanding of the technical and economic requirements.

The Program Committee has assembled a very impressive program. Approximately 450 presentations have been accepted for the Conference. As in past years, we need several parallel sessions to accommodate these papers in a week long meeting. The program addresses both the specialist who wishes to spend most of his time on one or two areas and the generalist who wishes to sample the papers from a number of fields.

This is the third time the American Chemical Society has sponsored the Conference. What a pleasure it is to work with this organization. The staff of the Society makes the job of the General Chairman much easier because of their enthusiasm, competence and willingness to contribute. My special thanks to Nancy Hadlock and Shirley Massman for many hours dedicated and creative effort. Finally, my congratulations to Hamid Arastoopour and his Program Committee for a first rate job and to the authors who are responsible for the Conference's good standing and importance.

Returning to our opening theme, the response of the energy supply industries to recent events is one of caution and retrenchment. As technologists, our own response does not need to be so cautious. We are making progress in energy conversion technology. This Conference gives us the opportunity to discuss our accomplishments and to consider future directions.

James E. Mitchell
ARCO Resources Technology

Message from the Program Chairman

The 21st Intersociety Energy Conversion Engineering Conference is taking place at a time when the public is thinking about the energy situation and its future outlook because of the low price of gasoline and expressing concern about nuclear safety as a result of the Chernobyl accident. Generally not recognized immediately by the public is the impact of advanced technology on improvements in energy research and development. Today, advances in drilling and reservoir engineering research make extraction of gas from geological structures previously thought to be beyond reach feasible. The use of computers in energy research experiments and the use of supercomputers in analysis and design of sophisticated energy conversion systems advance the engineering application aspects of energy conversion toward technology breakout.

This Conference focuses on the impact of advanced technology on energy research, recent engineering research accomplishments, environmental issues, and energy management and policy. The 21st IECEC features sessions on conventional and unconventional methods of energy conversion. Aerospace power, energy storage, and Stirling engines are again strongly represented, and several new subjects such as cogeneration have been added.

The technical session organizers selected more than 450 abstracts for further consideration and comprehensive review. These were listed in the preliminary program. The organizers, who are among the top scientists and engineers involved in energy research and development, were responsible for the content, quality, and approval of the papers. They have accepted this challenge and its responsibilities aggressively and developed a first-rate program comprising about 84 technical sessions. The Wednesday Luncheon is followed by a plenary session with invited panelists who are among the Nation's leaders in energy research and development.

I would like to thank the authors, organizers, technical advisors, session chairpersons, and the ACS Department of Meetings and Divisional Activities staff members whose hard work made this Conference successful. I also would like to extend my thanks to Dr. William Staats of Gas Research Institute and Jonathan W. Hurwitch of Battelle Pacific Northwest Laboratories for assisting me in the organization of the technical program.

Hamid Arastoopour
Department of Chemical Engineering
Illinois Institute of Technology

GENERAL COMMITTEE

General Chairman—*Dr. James E. Mitchell,* ARCO Resources Technology

Program Chairman—*Dr. Hamid Arastoopour,* Illinois Institute of Technology

Assistant Program Chairman—*Dr. Jonathan W. Hurwitch,* Battelle Pacific Northwest Laboratories

TECHNICAL ADVISORS

Dr. William J. Billerbeck—MRJ
Dr. Ryszard Gajewski—U.S. Department of Energy
Dr. William Staats—Gas Research Institute
Prof. S. A. Weil—Institute of Gas Technology

1986 IECEC STEERING COMMITTEE

American Chemical Society (ACS)
Dr. Hamid Arastoopour, Illinois Institute of Technology
Dr. James E. Mitchell, ARCO Resources Technology

American Institute of Aeronautics & Astronautics (AIAA)
Dr. Robert Barthelemy, Wright Patterson AFB
Mr. A. Warren Adam, Sundstrand Corporation

American Society of Mechanical Engineers (ASME)
Dr. Ozer Arnas, California State University
Dr. Robert J. Copeland, Solar Energy Research Institute

Institute of Electric and Electronics Engineers (IEEE)
Dr. Arthur Schoenfeld, TRW

American Institute of Chemical Engineers (AIChE)
Dr. Elton J. Cairns, Lawrence Berkeley Laboratory
Dr. Paul A. Nelson, Argonne National Laboratory

American Nuclear Society (ANS)
Dr. Patrick Bailey, Lockheed Research & Development
Dr. David L. Black, Westinghouse Electric Corporation

Society of Automotive Engineers (SAE)
Dr. Buryl L. McFadden, Wright Patterson AFB
Dr. Floyd A. Wyczalek, General Motors Corporation

COOPERATING SOCIETIES

American Power Conference (APC)
Dr. Edward S. Pierson, Purdue University

Electro-Chemical Society (ECS)
Dr. Ernest Littauer, Lockheed Palo Alto Research Laboratory

International Solar Energy Society (ISES)
Gershon Meckler, Meckler Associates, PC

Japan Society of Mechanical Engineers (JSME)
Naotsugu Isshiki, Japan Society of Mechanical Engineers

8964738

IECEC '87

22nd Intersociety Energy Conversion Engineering Conference

"ENERGY-NEW FRONTIERS"

Call for Papers

Wyndham Franklin Plaza
Philadelphia, Pennsylvania
August 10-14, 1987

General Chairman
Robert R. Barthelemy
Air Force Wright Aeronautical Labs
AFWAL/CT
Wright-Patterson AFB, Ohio 45433
(513) 255-9400

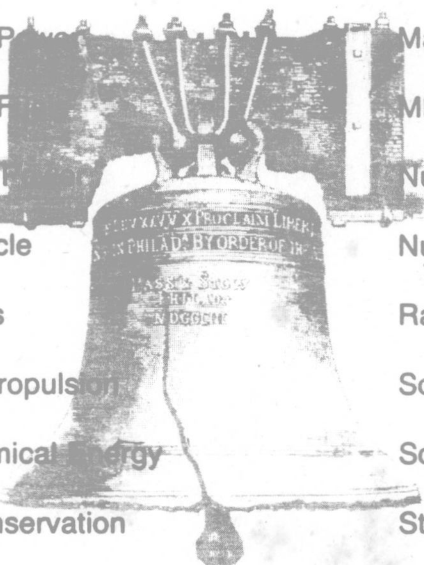
Assistant Chairman
Charles E. Jobe
Air Force Wright Aeronautical Labs
AFWAL/GLXRI
Wright-Patterson AFB, Ohio 45433
(513) 255-5953

Technical Program Chairman
A. Warren Adam
Sundstrand ATG
4747 Harrison Avenue
Box 7002
Rockford, IL 61125
(815) 226-6419

Assistant Chairman
Anthony L. Russo
Franklin Research Center
20th and Race Streets
Philadelphia, PA 19103
(215) 448-1080

The Intersociety Energy Conversion Engineering Conference provides a forum to present and discuss engineering aspects of advanced technology or nonconventional energy conversion systems and devices. The conference is supported by seven participating societies and three cooperating societies. The American Institute of Aeronautics and Astronautics will serve as host society for the 1987 IECEC. The conference will cover recent accomplishments in energy conversion research, development, and engineering requirements for energy conversion progress and application; disclosure of concepts with potential for future advancements; and results of research and engineering studies.

1987 IECEC Topical Areas



- Aerospace Power
- Alternative F[illegible]
- Biomedical T[illegible]
- Brayton Cycle
- Fossil Fuels
- Electrical Propulsion
- Electrochemical Energy
- Energy Conservation
- Energy Power and Planning
- Energy Storage Systems
- Geothermal Power
- Hydrogen Energy Systems
- Marine/Terrestrial Energy Systems
- MHD & Other Topping Cycles
- Nuclear Fission
- Nuclear Fusion
- Rankine Cycle
- Solar Energy Conversion
- Solar Heating & Cooling
- Stirling Cycle
- Thermoelectric Power
- Thermionic Power
- Unique Power Systems
- Wind Power

Four copies of abstracts of papers should be submitted to the Technical Program Chairman by **December 1, 1986** for review by the Program Organizers. Summaries should contain about 500 words presenting facts that are new and significant and should indicate the results achieved. The abstract should include an introductory statement indicating the purpose of the work and a closing statement summarizing the significant new results. Authors will be notified of abstract acceptance and will receive instruction for paper preparation on or about **March 2, 1987**. Accepted papers are to be presented orally and authors will be required to provide a complete camera ready manuscript by **May 15, 1987** for publishing in the proceedings of the 1987 IECEC meeting.

SAE

Unless otherwise specified, reply to:
American Institute of Aeronautics and Astronautics, 1633 Broadway, New York, N.Y. 10019 (212) 581-4300

Volume 2

Seasonal Thermal Storage
Low Temperature Thermal Storage
High Temperature Thermal Storage I: Solar Dynamic
High Temperature Thermal Storage II: Terrestrial Solar Thermal
High Temperature Thermal Storage III: Non-Solar Specific
Innovative Energy Storage
Transport of Thermal Energy
Batteries I & II: Stationary Energy Storage
Batteries III: Electric Vehicles
Batteries IV
Fuel Cells
Solar Conversion
Solar Conversion/Solar Heating/Cooling
Technical Application Consideration in Evaporative Cooling
Wind Energy
Photovoltaic Programs and Prospects
Photovoltaic Power System Application
Photovoltaic Innovative Devices and Concepts
Space Thermionic Power
Thermoelectric and Dynamic Power Systems: Terrestrial

Volume 3

Space Power Requirements and Issues
Space Solar Cells
Space Solar Arrays
Space Nickel-Cadmium Batteries
Space Nickel-Hydrogen Batteries
Space Lithium Batteries
Cell Design/Component Improvements & Evaluation
Space Fuel Cells
Spacecraft Power Distribution
Computer Analysis of Spacecraft Electronics
Aircraft Power Systems
Spacecraft Power Electronics
Space Power Systems Automation
Inertial Energy Storage for Space Applications
Advanced Space Power Concepts
Thermal Aspects of Space Power
Manned Space Station Power Systems
SP-100 Space Reactor Technology
Thermoelectrics for Space Reactors
Space Reactor Technology Development
Radioisotope Fueled Space Power Systems
Multi-Megawatt Nuclear Power Technology for Space
Space Solar Dynamic Power Systems
Space Steady-State High Power

Table of Contents

Volume 1

Unique Power Systems

Optimization Technique for Large Cogeneration Systems

Commercial/Light Industrial Cogeneration, An Approach

Coal Conversion

Biomass Energy

Rock Fluid Interactions with Respect of Enhanced Oil Recovery

Hydrogen Energy

Nuclear Energy

Heat Engines

Small-Capacity Heat Pumps: Advanced Concepts

Industrial Heat Pumps

Stirling Engines: Program Overview and Summaries

Stirling Engines: Engine Test Results

Stirling Engines: Analysis (Heat Exchange and Flow)

Stirling Engines: Modeling and Optimization

Stirling Engines: Components

Stirling Engines: Concepts and Applications

Magnetohydrodynamics

SEASONAL EFFICIENCY SIMULATION AND ENERGY QUALITY OF GAS-BOILERS

Lorenzo Rosa and Renzo Tosato
Ist. di Macchine - Università di Padova
Padova, Italy

ABSTRACT

Performances of gas-fired ideal boiler, condensing boilers and conventional ones are simulated by computer.

A numerical model estimates the seasonal efficiency of boiler, as a function of:
- external mean temperatures,
- boiler performances at full load,
- boiler stand-by losses (at null load),
- heating management mode (heating night interruption or temperature lowering during night hours).

Simple equations permit to foresee reliable seasonal efficiency of boilers and their energetic quality, as the capacity of using the heat value of natural gas during heating season, in comparison with ideal boiler

BOTH CONVENTIONAL AND CONDENSING BOILERS can be simulated by a single numerical model. A full load performance simulation of condensing boiler has been described in a paper presented at the IECEC '84 (1)*. Steady-state and cyclic tests have been carried out in our laboratory, with continuous measurements of quantity of generated condensate, fuel consumption and temperatures. A simulation of cyclic operation both of conventional and condensing boilers is described in another paper presented at the IECEC '85 (2).

In residential heating plants, a definitely interesting item is the seasonal fuel consumption estimate. Normally, the user wants a constant temperature in every room (about 20C) with the possibility of lowering it during the nights and week-ends. In Europe, a night interruption of firing is required by law to reduce fuel consumption, therefore, a reliable forecast of seasonal efficiency must also simulate the boiler working during restart period. This working mode is different from a cyclic one, because the boiler operates at full load, but its return water temperatures are continuously rising.

The energetic quality of a boiler can be defined as its capacity of using the heat value of fuel during the heating season, in comparison with ideal boiler. The ideal boiler is defined as a boiler where the return water temperature is the same as the temperature of flue-gases; besides, this ideal boiler has no excess air of combustion and shows no heat losses towards the surroundings, nor stand-by losses (fig. 1).

* Numbers in parentheses designate references at the end of paper.

At the present time, the performances of boilers and losses at null load are being evaluated in laboratory without the possibility of comparing the laboratory performances with the performances of boiler working in the plant (3).

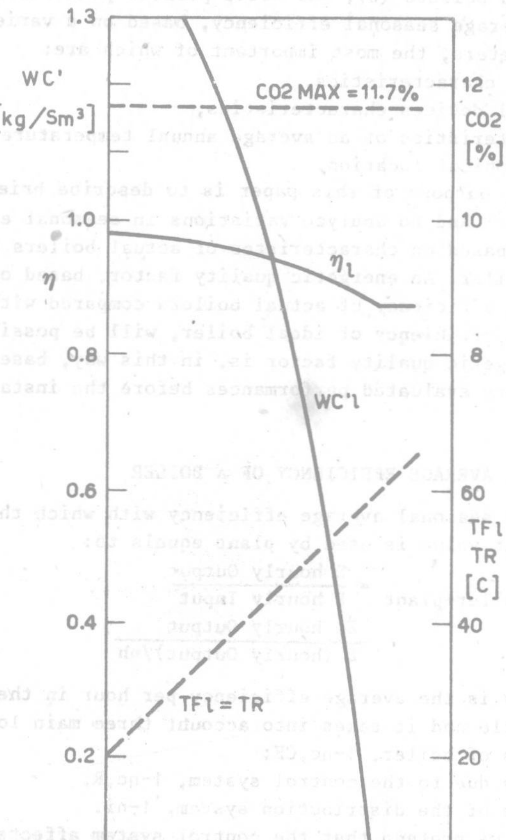


Fig. 1. - Performances ηl, CO2%, WC'l and TFl of ideal boiler, as function of return water temperature TR.

The energetic quality of appliances whose operation depends on the user (such as washers, water heaters, etc.) is evaluated by full load tests (4). Boilers function at reduced loads most of the time and energetic quality can be evaluated only through the seasonal average efficiency.

Tests taken during the functioning of similar plants, at the same climatic conditions, offered the

8412-0986-3/86/0869-002/$06.00/0

possibility of comparing condensing boilers with conventional ones, while cyclic laboratory tests indicated the boiler characteristics at reduced loads (2,5).

So far, there is no record that the goal of attributing an absolute energetic parameter to a boiler to define its saving quality has been achieved.

Furthermore, the existance of different types of boilers (condensing, high efficiency and conventional) seems to complicate the technical analysis which should valid results of a single model in all cases.

It is therefore a matter of establishing an energetic priority list based on both full and null load tests: such tests are being conducted in some countries, based on specific standards.

The authors have developed a numerical model of the functioning of both conventional and condensing gas-fired boilers (6); the model permits prediction of their average seasonal efficiency, based on a variety of parameters, the most important of which are:
- boiler characteristics,
- control devices characteristics,
- characteristics of an average annual temperature and geographical location.

The purpose of this paper is to describe briefly this model and to analyze variations in seasonal efficiency, based on characteristcs of actual boilers and ideal boiler. An energetic quality factor, based on seasonal efficiency of actual boilers compared with seasonal efficiency of ideal boiler, will be possible. The energetic quality factor is, in this way, based on laboratory evaluated performances before the installation.

SEASONAL AVERAGE EFFICIENCY OF A BOILER

The seasonal average efficiency with which the high heat value is used by plant equals to:

$$\eta_{boiler+plant} = \frac{\Sigma \text{ hourly Output}}{\Sigma \text{ hourly Input}} = \frac{\Sigma \text{ hourly Output}}{\Sigma \text{ (hourly Output)}/\eta h} \quad (1)$$

where ηh is the average efficiency per hour in the working cycle and it takes into account three main losses:
- losses of boiler, $1-\eta c,CF$;
- losses due to the control system, $1-\eta c,R$;
- losses of the distribution system, $1-\eta i$.

If we pretend that the control system affects only the cyclic efficiency of the boiler ηc, then we can say that ηc is product of the boiler efficiency $\eta c,CF$ if it is directly connected to plant (the most efficient connection) by the value of influence of the control system $\eta c,R$ (2).

Then the efficiency ηh of the boiler and plant will be equal to:

$$\eta h = \eta c,CF \cdot \eta c,R \cdot \eta i = \eta c \cdot \eta i \quad (2)$$

If we want to examine the energetic quality of the boilers only, we will have consider that:
- because the control system efficiency $\eta c,R$ is not generally constant, we will consider only the best set-up of boiler to plant, the direct connection ($\eta c,R = 1$);
- distribution system without heat losses ($\eta i = 1$);

therefore the values obtained with eq. (1) for the seasonal efficiency η:

$$\eta_{boiler} = (\text{energetic quality factor}) \cdot \eta_{\text{ideal boiler}} \quad (3)$$

are valid only if:

$$\eta h = \eta c,CF \quad (4)$$

It is clear that any conclusion drawn in this paper on energetic quality of boilers only to the boiler directly connected to the plant and that more general conclusions on average seasonal efficiency of boiler and plant may be drawn after examination of different types of control systems and distribution ones.

FULL LOAD, NULL LOAD AND CYCLIC EFFICIENCIES

The working of a boiler in an actual heating plant can be simulated if we can predict the boiler efficiency at partial loads. A model of boiler working with an ON-OFF cyclic mode can be based on the assumptions (2):
- during the ON time, the efficiency is the same as during full load operation. The efficiency depends on the return water temperature;
- during the OFF time, the efficiency is null and energy losses are a function of the average temperature of the boiler.

This model permits prediction of the cyclic efficiency with an equation rather simple, valid for loads between 0 and 1 and presented as follows:

$$\eta c,CF = \eta o/(1 + (\eta o-\eta^* \cdot CI) \cdot PR/CI/PC^*) \quad (5)$$

where:

ηo is the full load efficiency of the boiler, which varies with the return water temperature, especially for condensing boilers;

η^* is the full load efficiency when the return water temperature TR is 60C and outlet water temperature TM is 80C;

CI is the capacity factor, the ratio between the useful power required from boiler at the nominal output PC*;

PR is the power lost at null load to keep the boiler at the same boiler temperature as during the ON-OFF cycle and with the direct connection.

We can reasonably assume that the efficiency of present boilers at full load ηo takes into consideration two types of losses only:
- Losses due to radiation, convection and conduction towards the surroundings, in any case rather limited (2 to 4%); losses depend on the average temperature of the water in the boiler and must not be confused with stand-by ones, which are to be charged to the air circulation during the OFF time only; as a consequence, η^* and ηo take into account these losses too.
- Losses due to latent and sensible energy of flue-gases. Thermal energy of flue-gases varies with the return water TR, related to the heat exchange efficiency. The return water temperature TIC, for which the condensation is beginning and the mass of the condensate WC'20 at the return water temperature of 20C are to be experimentally determined. Based on expermental tests conducted on a few boilers, we can believe that, for temperatures of return water TR ranging between

TIC and the reference temperature of 20C, the mass of condensate per standard cubic meter of natural gas is:

$$WC' = WC'20 \cdot (1 - ((TR-20)/(TIC-20))^2) \quad (6)$$

In this way, efficiency at full load ηo is:

$$\eta o = \eta^* + R/HV \cdot WC' + cpFS/HV \cdot (TF^*-TF) \cdot VFS + cpW/HV \cdot (TF^*-TF) \cdot VW \quad (7)$$

$$\eta o \cong \eta^* + R/HV \cdot WC' + cp/HV \cdot (TR^*-TR) \cdot (VFS+(1.612-WC')/0.806) \quad (8)$$

and therefore it is a function of η^*, TIC, TR and WC'20 only.

Conventional boilers and high-efficiency boilers show a low TIC (20-40C) and WC'20 ($\sim$0.1kg/Sm^3) values, so that ηo remains practically constant for the whole range of TR. The value of TIC for condensing boilers is roughly around 50÷55C, while WC'20 has a value of 0.9÷1.2kg/Sm^3. The ideal boiler efficiency is shown in fig. 1 with the following equation:

$$\eta 1 = 1 - ((cpFT \cdot VFT + cpW \cdot (VW-WC'/0.806)) \cdot TR + R \cdot (VW \cdot 0.806-WC'))/HV \quad (9)$$

The null load of actual boilers can be expressed as a function of the boiler average temperature TC, of input of permanent pilot PP and of the temperature TP at which the pilot can keep the boiler at stand-by:

$$PR = PP/(TP^2-20^2) \cdot (TC^2-20^2) \quad (10)$$

In home boilers, the power of permanent pilot is normally 0.01·PC* (the pilot power is in fact PP=230W, while the boiler output is PC*=23kW). It is convenient to refer PR to the average temperature TP reached at stand-by by the boiler when only the permanent pilot is functioning, since a laboratory test is rather simple and does not require a complicated rig.

When the permanent pilot power PP1 is different from PP, if we accept that the loss be a parabolic curve, TP1 follows the equation:

$$PR = PP1/(TP1^2-20^2) \cdot (TC^2-20^2) = PP/(TP^2-20^2) \cdot (TC^2-20^2) \quad (11)$$

It is rather easy to figure that the TP temperature would be if the pilot power was 0.01·PC*. We believe TP as typical value of the losses and it will be as:

$$TP = (20 + 0.01 \cdot PC^*/PP1 \cdot (TP1^2-20^2))^{0.5} \quad (12)$$

For the direct connection, the capacity factor CI results in proportion with the return water temperature TR:

$$CI = (TR-20)/(TR^*-20) \quad (13)$$

and also, in proportion, with the boiler average temperature TC:

$$CI = (TC-20)/(TC^*-20) \quad (14)$$

and:

$$TC^* = TR^* + 10K \qquad TM^* = TR^* + 20K \quad (15)$$

In conclusion, the cyclic efficiency $\eta c,CF$ is a function of η^*, TIC, WC'20 and TP, as far as the boiler is concerned and of temperature TR as far as the plant is concerned.

During the heating season, the temperature TR depends on the surroundings temperature, which varies depending on the reference year.

CALCULATION OF THE AVERAGE SEASONAL EFFICIENCY

The calculation of the average seasonal efficiency is based on a program which determines step by step for each hour of heating season:

- the boiler load CI (capacity factor),
- the return water temperature TR,
- the average temperature of the water inside the boiler, TC,
- the cyclic efficiency of the boiler at capacity factor CI,
- the hourly output heat and its progressive sum,
- the hourly input heat and its progressive sum, and, finally, the average seasonal efficiency, eq. (1).

Data provided to the program were:

1) the outside temperature, hour by hour, during the heating season, referred to geographical location, which varies too;

2) the parameters of the boiler η^*, TIC, PP, PC*, TP; the variable WC'20 is not indicated because it has been expressed as function of TIC;

3) two models of heating management, to simulate the night reduction of load:

3a) the lowering of the comfort temperature from 20C to 16C during night hours, without considering the inertia of plant and taking for granted that the plant works all night long;

3b) turning off of boiler during night hours as described by italian law with a consequent lowering of the inside temperature; this will require, at restarting, a simulated thermal inertia of plant.

To reduce data combination to a minimum, the authors have simplified the analysis as follows:

1) the outside temperature varies based on a simple law already described in a previous paper presented at IECEC'85 (6), where the only variable is the average yearly temperature TE of the location. TE varies between 10 and 18C;

2) to simulate boilers already installed, new type of boilers (high efficiency and condensing boilers) and ideal boiler, parameters characterizing the model, η^*, TIC, WC'20 and TP, varies as follows:

η^* = 0.70, 0.75, 0.80, 0.85
TIC = 20, 25, 30, ... 59C and WC'20 = 0.1÷1.5
TP = 30, 35, 40, ... 70C

and: η^*1 = 0.876, TIC1 = 59C, TP1= 100C, PP1= 0 for the ideal boiler.

The fuel considered was natural gas (methane).

3) when the yearly average temperature varies between 10 and 18C, the impact on the average seasonal efficiency η of the average yearly temperature TE of the location is very low, less than 2÷3%, and on energy quality factor negligeable. On other hand, η and EQF are much more influenced by the boiler characteristics. For this reason we can reasonably believe that energetic quality factor does not depend on the geographical location and it can be considered as an intrinsic parameter of the boiler.

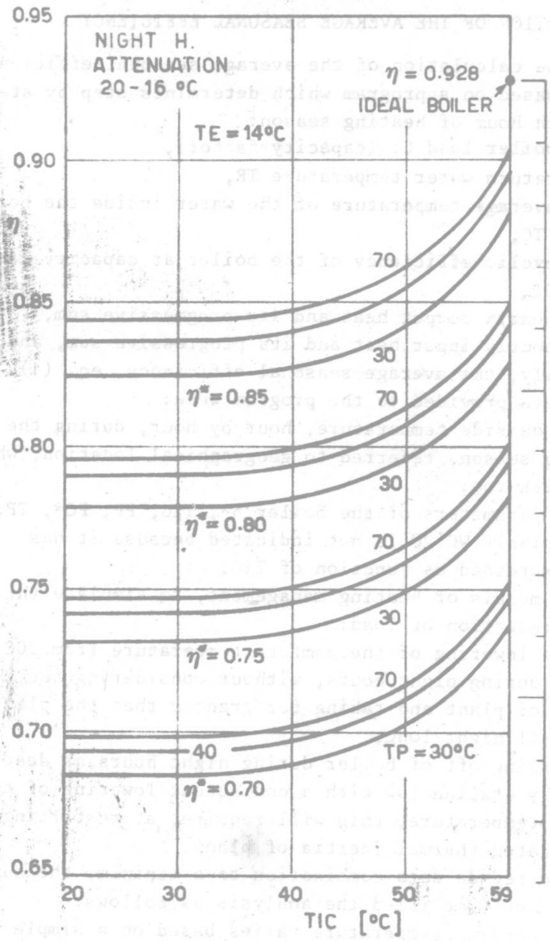


Fig. 2 - Numerical results of average seasonal efficiency as function of parameters of boiler. (TE = 14C, night heating attenuation 20→16C).

SEASONAL EFFICIENCY WITH ATTENUATION OF TEMPERATURE DURING NIGHT HOURS FROM 20 TO 16C

The results of the calculations lead to plots as shown in fig. 2, as the parameters η*, TIC and TP vary. The plots refer to annual average temperature TE of 14C.

As already stated, the yearly average temperature TE between 10 and 18C has an influence of less than 2÷3% on the seasonal efficiency of the boiler. The average seasonal efficiency of a boiler in a location where the temperature TE equals to 14C may be meaningful also to areas not too different from the location at TE of 14C. However, it is necessary to take for granted that the connection between the boiler and the plant be of direct type and that during the hot season, both the boiler and the pilot be turned off.

Effect of losses at null load is of about 1% when TP varies between 30 and 70C. On the other hand, the effect of the variables TIC and η* is very strong.

The average seasonal efficiency when the inside night temperature is attenuated to 16C, for a geographical location where TE = 14C can be expressed rather correctly as follows:

$$\eta att,14 = (\eta^* + 7.88\cdot(TIC-20)^3/10^7)\cdot(1-(PP/PC^*\cdot\eta^*/(TP^2-20^2)-1.44/10^6)\cdot 3\cdot 10^3/1.58) \quad (16)$$

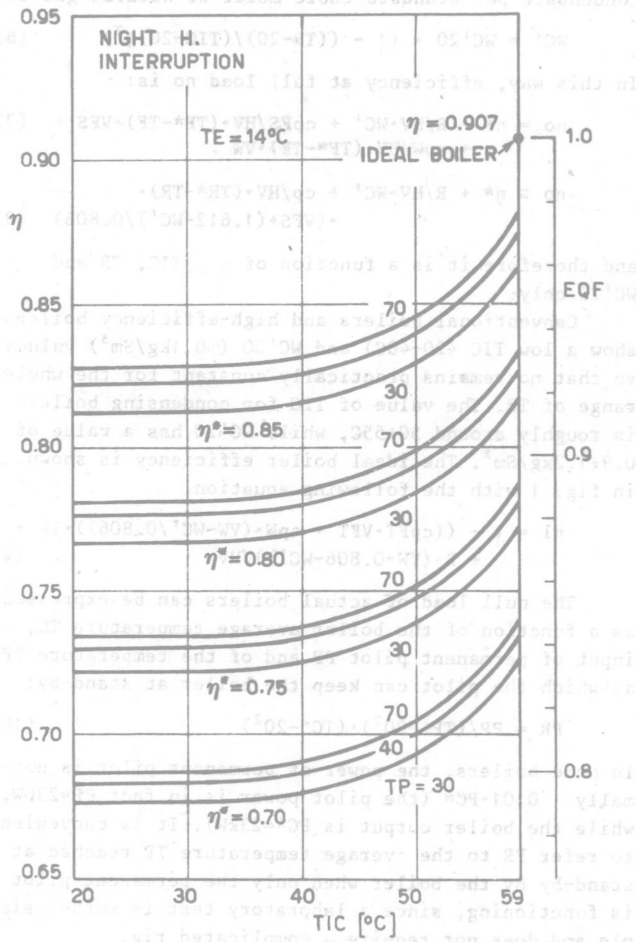


Fig. 3 - Numerical results of average seasonal efficiency as function of parameters of boiler. (TE = 14C, night heating interruption).

As the location varies, the same boiler varies its average seasonal efficiency, in comparison with ηatt,14:

$$\eta att,TE = \eta att,14 - 6\cdot((TE-10)^2/16-1)/10^4/(1-\eta^*)+(TE-14)/500\ (TIC-20)/(59-20) \quad (17)$$

The same fig. 2 shows the energetic quality factor, as function of parameters of boiler, too.

SEASONAL EFFICIENCY WITH NIGHT INTERRUPTION OF HEATING

In comparison with previous case, the boiler is turned off for 10 hours (e.g. from 9pm to 7am) in accordance with italian laws for energy conservation. The inside temperature will spontaneously decrease from 20C of comfort. In this case, it is necessary to consider the thermal inertia of the heating plant. This means that a full load cycle instead of a cyclic one be initiated at 7:00hours. The starting time needed to bring the average water temperature from the initial 20C to the average temperature required by the cyclic functioning of plant, depends on weather conditions at 7:00am hours and on relation between the power of the boiler and the mass of water and material of the plant.

Water, boiler, conduits and radiators are considered as an equivalent water mass of 35kg per kW of boi-