IMPLEMENTATION OF ENERGY AUDIT IN THE CHINESE STEEL INDUSTRY - CASE STUDIES OF INTEGRATED STEEL PLANTS

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Abstract

Steel production is one of the energy intensive industries in the world. Energy saving measures are of increasing interest to Chinese steel industry in recent years. One of the technical instruments of energy saving is energy audit. This paper presents the energy audit analysis of integrate steel plants in China as a case study. The analysis is useful to determine the actual consumption, reveal the anomalies and suggest corrective measures. These will provide clear indication on the pattern of energy losses and will aid in decision support for evolution of energy saving measures. The paper will show the achievements of Chinese steel plants during these years of energy saving activities proposed by government and the potential for energy efficient renovation. Some suggestion has been made in order to widely use this analytical diagnostic tool in Chinese steel industry.

Keywords: steel production; energy audit; energy saving
Introduction

China’s economy has been steadily developed since its adoption of “open policy” in 1978. However, compared to developed countries, the production and energy technology in China are still in a low level. The previous economy development can be characterized as high investment, high materials consumption and high pollutions with a low productivity. Therefore, serious problems, such as shortage of energy and raw materials, environmental pollutions, have occurred during the first period. These problems will become more prominent and will be bottlenecks for the economy development in the new period.

The steel industry is the basis for the national economy, representing economy status and national power for a country. Chinese steel industry has been rapidly developed during the last decades, especially since the new century. China has been the biggest steel producer and consumer since 1996. In 2006, the steel production and consumption were 420 million and 384 million tonnes, respectively. The competence of the steel industry has been improved quickly, and product structures have been optimized as well. The steel industry has played an important role for national economy’s steady development. At the same time, it should be pointed out that the steel industry is a high-energy consumption with high pollution industry. Steel industry is the main energy and water consumer, accounts for 15% and 14% of total energy and water use respectively; at the same time, SO$_2$ emission from the steel industry is around 6.6% of the total emission in China. The strategic tasks faced by the steel industry are to facilitate structure adjustment and optimization, and to improve steel industry’s quality and benefit.

A complete audit for input-output of energy sources will evaluate the state of art of energy use, monitor and manage energy consumption in the enterprise. Hence, from national resources point of view, it can help allocate energy sources effectively, improve energy efficiency. In addition, it will be good for environmental protection and economy’s continuous development.

Energy audit is a complete monitoring process to energy consumers during their energy use, conversion and consumption [1-2]. This whole process is based State energy conservation law, regulation and standards. Energy audit is a macro statistic analysis method. It will make a throughout analysis on energy consumption and energy saving at different levels in the enterprise. The energy consumption index from the energy audit will be helpful for the enterprise to evaluate and monitor the energy use. The enterprises can improve their energy management and economic benefits by implementing some energy saving measures. Therefore, the energy audit is an effective measure to realize the energy saving for the steel industry. At the same time, it will create a platform so that Chinese steel plants can compare with foreign steel companies, for further performance improvement.

Recently, some representative steel plants in China, e.g. Bao Steel, have conducted energy audit by assistance from some international third-party certification bodies, e.g. DNV*. This paper will describe the energy audit system applied to the Chinese steel industry by showing an implementation case study.

Description of Energy Audit System

The energy audit system consists of three parts, i.e. audit procedure, preparation of energy audit report and methodology of energy audit.

*Det Norske Veritas (DNV) is an independent foundation with the objective of safeguarding life, property, and the environment.
Audit Procedure

The audit procedure includes the following steps:

- The energy audit monitoring department shall draw up the detailed task scheme and timeline, and clearly define the target for the audit and the detailed items to be audited in accordance with the criteria and methodology of energy audit, and give a prior notice to the enterprise to be audited (10 days in advance as a rule).

- The enterprise being audited shall faithfully provide the relevant information, especially the information on the output of production of the enterprise.

- The energy-related testing is carried out; the various data on the consumption of energy and raw materials of the enterprise are calculated and processed; the systematical calculation and analysis are made based on the conversion efficiency and technological process of the enterprise's equipment under energy control by reference to the relevant State energy conservation regulations, the State energy-related standards, the domestic and international advanced levels, the status quo of the trade; the categorized search for different troubles and the causes of energy wastage is done; and the recommendations for rectification and improvement are put forth.

Preparation of Energy Audit Report

The energy audit report of the enterprise shall include: 1) Description of related items of the energy audit; 2) General situation of the enterprise: the conditions of the main energy-consuming systems and installations, and the status quo of the energy control system and energy consumption; 3) The findings of the energy (resources) audit of the enterprise, including the calculations and analysis of the various energy consumption quotas, and the evaluation on the energy cost and utilization effects; 4) The test results of the main energy-consuming equipment of the enterprise, including the operating efficiency and the energy consumption quotas of the main energy-consuming systems and installations; 5) Analysis on the existing problems and energy conservation potentials; 6) The economic and technical analysis and evaluation of the enterprise's technical updating projects for energy conservation; 7) The conclusion of the energy audit of the enterprise and the relevant recommendations on rectification.

Methodology of Energy Audit

The methods adopted for energy audit are based on the principles of energy conservation and of mass conservation, the theory of system engineering is used for the comprehensive closed audit of the input and output in the process of the production operation of the enterprise, each factor or link that effects the levels of energy consumption and material consumption of the enterprise is analyzed quantitatively, thereby finding out the problems of energy wastage and the energy conservation potentials, analyzing the causes, and putting forth the relevant recommendations for measures of rectification for the definite purpose of energy conservation. The overall structural framework of energy audit is shown in Figure 1. This audit system is an integrated system of quality, environmental and energy [3-7].
Case Studies of Energy Audit of China's Iron and Steel Industry

In the course of an on-site investigation at an iron and steel company, the statistics and analysis of the relevant data for the energy consumption of its special steel branch were made, the energy balance sheet (both including energy-consuming working media and excluding energy-consuming working media), the energy balance chart (both including energy-consuming working media and excluding energy-consuming working media), the water balance sheet and the water balance chart for the years 2005 and 2006 were prepared, and the preliminary comparison was made between the data on the status quo of the energy consumption of the special steel branch and the relevant quotas listed in Industrial standard of the People's Republic of China for Environmental Protection (HJ/T189-2006) [8], Clean Production Standard for Iron and Steel Industry [9], based on which the interim report on the energy audit of the enterprise was given.

The absence of scientific, consistent, systematic principles and methods in the investigation, assessment and analysis of the energy consumption of enterprises tends to result in the misinterpretation and misunderstanding of the massive data on energy consumption, for example, which organizations' relevant activities and processes to be included in the examination of energy consumption, how to define the organizational boundary and
operational boundary for energy control; how to deal with the purchase of renewable energy sources, how to deal with the energy consumption and control of outsourcing activities, how to deal with the change in the data on energy consumption resulting from the change in the activities of organizations during different years, how to create the quota system of energy consumption for organizations based on the data from proper investigation of energy consumption. The detailed solutions to all these issues have been given in Guide to Energy Accounting [10]. The data listed in the report based on Guide to Energy Accounting shall be integrated with the financial information provided by the enterprise and aligned with the international accounting method. The correlation, integrity, consistency, transparency and accuracy of the energy audit case shall be ensured. The following shall be included:

**Setting of Organizational Boundary**

The operation of an enterprise varies with the change in its legal and organizational framework, including all of its own operations, and its corporate and non-corporate joint venture companies and subsidiaries. For accounting purposes, these operations shall be dealt with in accordance with the rules which are set on the basis of the organizational framework and the relationship between the members concerned. As a first step, the company shall, on the organizational boundary set for the energy investigation, select one of the methods for unified summarization of the information on energy consumption, and then consistently apply the selected method to define the operating bodies of the company and their operations, thereby accomplishing the purpose of energy consumption accounting and reporting.

If the iron and steel company carries out the overall investigation of energy consumption, it shall decide whether the method of shareholding proportion or the control method (financial control and operational control) shall be used for define the organizational boundary for the investigation. At the planning stage of the investigation of energy consumption, discussions shall be conducted on the respective coverage, merits and shortcomings of the two methods in order to select the better one for defining the organizational boundary. As the subject of the case is the special steel branch, which is a wholly-funded subsidiary of the iron and steel company, all of the energy consumption of the special steel branch shall be included in the list of the investigation, in terms of the organizational boundary of the energy audit of the special steel branch, whether the shareholding proportion method or the control method is to be used. For this reason, when defining the organizational boundary for the energy audit of the special steel branch, the energy of different kinds and the energy consumption at different levels shall be included. In the case of energy audits of other companies, their commercial activities, energy accounting and reporting requirements shall be taken into consideration when deciding whether to use shareholding proportion method or control method (financial control or operational control) for defining the organizational boundary for the energy investigation.

If the energy accounting investigation is done with the special steel branch as a independent entity, besides its own production activities and auxiliary activities, which have been included in the scope of the energy audit, the shareholding proportion method and the control method shall be used for the comparison of the definition of the organizational boundary in order to use the best method to decide which specific processes and activities of the special steel branch shall be defined within the organizational boundary of the subject of the investigation.

**Setting of Operational Boundary**

After the company defines the organizational boundary with all the operating bodies owned or controlled by it, the operational boundary shall be redefined. The setting of operational boundary includes identifying and operating the related consumption, which shall be
classified as direct energy consumption or indirect energy consumption, and then the category of the accounting and reporting of indirect energy consumption shall be determined.

In order to manage energy effectively and innovatively, the setting of a comprehensive operational boundary which includes both direct consumption and indirect consumption will help the company manage more successfully all types of energy risks and opportunities existing in the value chain.

In order to help to describe the direct and indirect consumption sources, enhance the transparency and provide a common tool for different organizations, different types of energy policies and different commercial purposes, the energy accounting and reporting have defined three categories of energy consumption: category 1 (consumption of direct energy sources), category 2 (consumption of electric power as an indirect energy source) and category 3 (consumption of the other indirect energy sources).

In selecting the operational boundary for the energy audit of the special steel branch of the iron and steel company, as a first step, the first category of energy consumption is identified. It covers the consumption of the energy consuming sources owned or controlled by the company, including steam production, gas production, production of various energy-consuming working media, the energy consumption of every step of production process, other auxiliary productions, and energy consumption of communications and transportation. Then category 2 is identified to be from the energy consumption which occurs when the outsourced electric power is consumed. It is calculated by converting the electric power consumption into standard coal consumption. From this calculation, the indirect consumption of coal resource by the company can be found. At the current stage of energy control, category 3 has not been taken into consideration. It is recommended that category 3 be taken into consideration in due course as soon as it becomes possible. For example, the transportation of outsourced raw materials or goods, the employees' business trips and commuting trips, the transportation of products sold, and relevant activities.

**Long-term Tracing of Energy Consumption**

The company has frequently experienced significant structural changes, such as acquisition, divestiture of assets, and merger. These changes have altered the record of energy consumption of the company, and, as a result, made the long-term comparison meaningless. In order to maintain the long-term consistency, or in other words, to maintain the comparison between "similar situations", it is necessary to recalculate the historical data on energy consumption. For the purpose of meaningful and consistent long-term comparison of energy consumption, it is necessary for the company to create a database of performance, i.e., the consumption of baseline years, to be used for comparison with the current consumption. To facilitate long-term consistent tracing of energy consumption, whenever a significant structural change, such as acquisition, divestiture of assets or merger, occurs, it may be necessary to recalculate the consumption of the baseline year. The first step of long-term tracing of energy consumption is to select a baseline year. In this case, the data on the energy consumption for the year 2005 was selected as the data for the baseline year. Considering the fact that during the year 2005 the organizational structure of the special steel branch experienced a series significant changes, including the divestiture of the logistics company, the oxygen station and the installation company from the main body of the company, and the demolition of the gas station, which means that these variation factors no longer existed in the operation of the special steel branch in 2006, since the year 2005 was selected as the baseline year, these factors had to be taken into consideration, and the consumption of the baseline year had to be recalculated, with the energy consumption of the divested facilities and
departments and the demolished gas station reduced from the data on the energy consumption for the year 2005. Only in this way will the comparison of the adjusted results of energy consumption with those of the energy consumption of the year 2006 be meaningful. At present, the necessary recalculation of the energy consumption of the baseline year 2005 is underway. Of course, to make the future comparison ever easier, the year 2006 may be selected as the baseline year of the company. The recalculation of the data on the energy consumption of the year 2005 described here is only as a demonstrative example of the method for determining the baseline year.

**Calculation and Confirmation of Energy Consumption**

With the boundary of the investigation determined, the energy consumption may be calculated by following steps:

**Identifying Energy-consuming Sources** - Based on the production process of the special steel branch of the iron and steel company, the identifiable energy-consuming sources of category 1 include 1) stationary combustion sources such as boilers, gas furnaces, different types of heating furnaces, metal cutting installations, food processing installations, engines and others; and 2) mobile combustion sources such as transport and communication facilities including cars and trucks. Identifiable energy-consuming sources of category 2 include different electricity consuming devices, such as 110-ton ultra high power direct current arc furnaces, 60-ton alternating current arc furnaces, various types of refining furnaces, continuous casting apparatus, various types of rolling mills, hoisting machines, oxygenerators, air compressors, various types of blowers and water pumps, as well as lighting devices.

**Selecting Methods for Calculating Energy Consumption** - In the investigation of energy consumption of the special steel branch, the principle of conservation of energy is used, and the quantity of the energy consumed is determined by comparison of the intrinsic energy of different kinds of energy sources.

**Gathering Operational Data and Selecting Conversion Index** - As a first step of the energy accounting investigation of the special steel branch, large amounts of basic information was gathered on the operational boundary within the current organizational boundary of the special steel branch (at present only limited to the production units directly under the special steel branch, not including those other units to which the shareholding proportion method or the control method may be applicable for definition). The information gathered includes the data for the monthly consumption of the various forms of energy sources of category 1 and category 2 in various production units (steeling making, special metallurgy, steel bars, steel tubes, precise metallurgy, silver steel, air-compression plants boiler houses, gas station and others) and in some auxiliary production links; and the output of different kinds of products.

To facilitate the statistics and calculation of large amounts of statistical data for the energy of different kinds of energy sources measured in different measurement units, when processing the data for special steels, the conversion indices which accords with the reality were used for the conversion between different kinds of energy sources, with the consumption of energy of different kinds converted into equal values and equivalent values of energy. It is shown in Table 1 and 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Coal</th>
<th>Coke</th>
<th>Electricity</th>
<th>Natural gas</th>
<th>Coal gas</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual amount</td>
<td>Ton</td>
<td>Ton</td>
<td>Kwh</td>
<td>M³</td>
<td>M³</td>
<td>ton</td>
</tr>
<tr>
<td>Equal values (tce)</td>
<td>0.9096</td>
<td>0.9289</td>
<td>0.0004040</td>
<td>0.0011117</td>
<td>0.0001963</td>
<td>1.4714</td>
</tr>
<tr>
<td>Equivalent values (tce)</td>
<td>0.9096</td>
<td>0.9289</td>
<td>0.0001229</td>
<td>0.0011117</td>
<td>0.0001963</td>
<td>1.4714</td>
</tr>
</tbody>
</table>
**Table 2 Conversion indices of different energy (Category 2)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Diesel</th>
<th>Heavy oil</th>
<th>Peat</th>
<th>Tar</th>
<th>Stream</th>
<th>Energy-consuming working media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual amount</td>
<td>Ton</td>
<td>Ton</td>
<td>Ton</td>
<td>Ton</td>
<td>M³</td>
<td>Ton</td>
</tr>
<tr>
<td>Equal values (tce)</td>
<td>1.4571</td>
<td>1.4286</td>
<td>0.571</td>
<td>0.808</td>
<td>Statistic value</td>
<td></td>
</tr>
<tr>
<td>Equivalent values (tce)</td>
<td>1.4571</td>
<td>1.4286</td>
<td>0.571</td>
<td>0.808</td>
<td>0.09491 Statistic value</td>
<td></td>
</tr>
</tbody>
</table>

Calculation - Through statistics and calculation of the data on energy consumption for each month, the energy balance sheet for the years 2005 and 2006 for the special steel branch was prepared; and the energy balance chart for the years 2005 and 2006 for the special steel branch was drawn. Both the energy balance sheet and the energy balance chart cover the cases including energy-consuming working media and excluding energy-consuming working media. By comparison between the two cases, the effects of energy-consuming working media on the energy balance can be seen. According to the statistical calculation, in 2005, the energy utilization efficiency of the special steel branch was 85.4%, and that of the company was 49.3%. In 2006, the energy utilization efficiency of the special steel branch was 96%, and that of the company was 50%. The water balance sheet and the water balance chart for the special steel branch through the calculation of water balance were also shown in Table 3. It can be seen from the calculation of the water balance that the consumption of new water per ton of special steel was decreased from 13.6 tons per ton of steel in 2005 to 8.5 tons per ton of steel in 2006. Although the water consumption had been decreased remarkably, there was still a gap from the primary standard of Chinese national clean production standard.

**Table 3 The water balance chart for the special steel branch in 2005 (M³)**

<table>
<thead>
<tr>
<th>Items</th>
<th>Self-generated water</th>
<th>Circulating Water</th>
<th>Tap water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase</td>
<td>13140000</td>
<td>11407270</td>
<td>5679020</td>
</tr>
<tr>
<td>Transfer to other localities</td>
<td>1320729</td>
<td></td>
<td>1103122</td>
</tr>
<tr>
<td>Energy consumption of production system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel-making</td>
<td>5176866</td>
<td>5608936</td>
<td>751105</td>
</tr>
<tr>
<td>Particularity residue</td>
<td>398041</td>
<td></td>
<td>128296</td>
</tr>
<tr>
<td>Special cast iron</td>
<td>358304</td>
<td></td>
<td>220640</td>
</tr>
<tr>
<td>Steel rolling</td>
<td>144597</td>
<td></td>
<td>205135</td>
</tr>
<tr>
<td>Bar steel</td>
<td>2830296</td>
<td>5358529</td>
<td>793255</td>
</tr>
<tr>
<td>Steel tube</td>
<td>866709</td>
<td></td>
<td>284125</td>
</tr>
<tr>
<td>Close steel</td>
<td>572758</td>
<td></td>
<td>198342</td>
</tr>
<tr>
<td>Silver steel</td>
<td>349901</td>
<td></td>
<td>67592</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td>59128</td>
</tr>
<tr>
<td>Coal gas</td>
<td></td>
<td></td>
<td>249171</td>
</tr>
<tr>
<td>Boiler</td>
<td></td>
<td></td>
<td>680919</td>
</tr>
<tr>
<td>Others</td>
<td>879513</td>
<td>783202</td>
<td></td>
</tr>
<tr>
<td>Loss</td>
<td>242286</td>
<td>439809</td>
<td>154988</td>
</tr>
</tbody>
</table>

Unified Summarization of Data on Different Levels of the Enterprise - From the status quo of the management of the iron and steel company, it can be seen that for those relatively highly automated branches, including the iron and steel branch and the special steel branch, networked management can be realized, while for those branches just newly merged, such data collection modes as worksheets and even paper sheets, will still have to be continued to be used. After all, the selection of the most efficient mode is restricted by the different conditions of management. The tasks which still remain to be pushed through to completion...
include the setting of the targets for the quality control of the energy accounting investigation and for the reduction of energy consumption.

Experiences and barriers in the energy audit for Chinese steel industry

The energy audit case studies on the large steel industry shows that Chinese government is paying unprecedented attention on energy saving. At the same time, more efforts on greenhouse gases control, especially CO₂, have been paid. China is seeking for international assistances for CO₂ emission reduction by using environmental friendly energy technologies. An example is that China has become the largest CDM† projects host country in the world. It has been accepted by different levels that the economy development should not destroy the natural sources and the environment; instead, a circular economy and a resource-conserving, environment-friendly, efficient society should be created based on Scientific Outlook on Development and Human-Oriented Concept in the technology development. A ‘green’ GDP is more important than the conventional GDP which was pursued by Chinese government before. At the same time, attentions on the energy saving from the industry have been also increasing due to their increasing concerns on high energy prices and their limiting availability. Considering internal and external demands on the energy audit, it can be expected that energy audit will contribute more on energy saving, lower production cost, higher productivity for the industries. It can be also expected that it will further contribute on building up harmonious society which is proposed by the central government.

However, there exist some barriers to implement the energy audit in the steel industry in China, such as:

- The support from the central government is not strong enough, and there is lack of conditionality documentation also;
- Many plants are not familiar with the energy audit, there also exists different understanding on the energy audit;
- Different opinions on how to conduct the energy audit have been shown by some experts, and these are still under discussion;
- A wide market of energy audit has not been formed yet. Currently, it is mainly pushed by the local government;
- It will take a long time to have normative energy audit market since this activity was just started;
- There is lack of legislative authority on implementing energy audit. The Energy Saving Regulation is the only available official documentation;
- The energy audit has double attributes, i.e. carrying out the law and technical service. On the one hand, it is a common sense that law enforcement should be free of charge from the law enforcement agency, and it will become unnecessary to comply with the law if its being charged; on the other hand, technical services for energy saving to industries should be paid. Therefore, it is necessary to establish a market service system, formulate a well-managed market regulation and clarify the list and standard of charges.

† CDM, clean development mechanism. CDM is one of three Kyoto Protocol’s flexible mechanisms. Its intention is to help industrialized countries meet their legally binding commitment under the Kyoto Protocol by offering a low abatement cost. At the same time, it will assist developing countries to achieve sustainable development by implementing eligible emissions reduction projects with investment from industrialized countries. Thus, both developed and developing countries are contributing on climate change mitigation.
Conclusions

Energy audit is an entire audit to the main energy users about their level of energy management, energy use in facilities and during production, energy flows and financial conditions. The purpose of the energy audit is to monitor if the main energy consumers have implemented and fulfilled the national energy policy; and to help energy consumers find out their actual energy use, check waste and weakness existing in the energy use; find out the energy saving potential and give suggestions on energy saving in order to help industries reduce energy consumption and production cost, improve energy efficiency, facilitate a further development of economy and quality for industries. An implementation case study, covering the years 2005 and 2006, has been performed on a large steel plant. The study showed that improvement of some parameters e.g. energy efficiency and water consumption would be value that can reflect the energy utility of enterprise in some extent. On the other hand it was shown that those parameters should be improved and perfected during the time period. Energy audit has become of increasingly important in China, partly because of support from the government. Some barriers to implementation remains. Although the energy audit is in the early stage in China, its implementation is expected widely developed in industries, especially in high energy consuming industries, in the near future.

References

[9] Iron and Steel Industry Association-Clean Production Standard for Iron and Steel Industry