The Chinese Motor System Optimization Experience:

Developing a Template for a National Program

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Abstract

Industrial electric motor systems account for more than 50% of China's electricity use. If optimized, their efficiency could be improved by 20%. In response to this opportunity, China established a Motor Systems Energy Conservation Program in cooperation with the UN Industrial Development Organization, the US Department of Energy, and the Energy Foundation. A previous paper described progress at the mid-point of this pilot program. This paper presents the final results documented in case studies, and training activities and through a final independent program evaluation. The focus is on the efficacy of transferring complex system optimization techniques across languages and cultures using classroom instruction and hands-on measurement and assessment training in factories. Details are provided on lessons learned, including the strengths and weaknesses of the training model in preparing Chinese engineers to conduct plant assessments, develop projects, and train factory personnel.

1 Background and Introduction

This paper describes the *China Motor Systems Energy Conservation Program*, a technical cooperation project financed by Chinese government and industry, the United Nations Foundation (UNF), the United States Department of Energy (USDOE), and the Energy Foundation. The project was implemented over the period 2001 to 2004 by the Vienna-based, United Nations Industrial Development Organization (UNIDO) in cooperation with Lawrence Berkeley National Laboratories (LBNL), and the American Council for an Energy Efficient Economy (ACEEE).

UNIDO's government counterpart in China was the State Development and Planning Commission (SDPC), subsequently reorganized as the National Development and Resource Commission (NRDC). UNIDO contracted with the China Energy Conservation Investment Corporation (CECIC) to supervise in-country activities. In turn, CECIC subcontracted with the Jiangsu and Shanghai Energy Conservation Centers who made local hosting arrangements for training, execution of plant assessments, systems optimization projects and case studies. Staff from both centers were among the participants in the training courses.

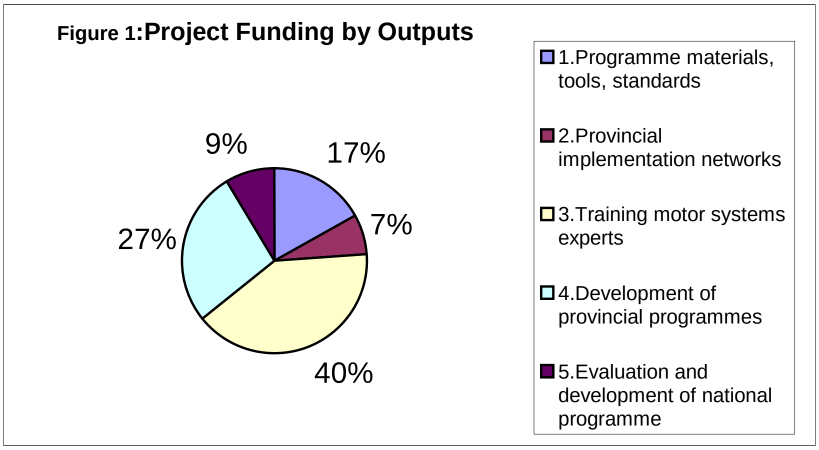
Equipment manufacturers have improved the performance of individual energy-consuming components such as motors, pumps, compressors and steam boilers, but these components only provide a service to the production process when operating as part of a system. Improvements to the efficiencies of motor systems often yield, in addition to energy savings, increases in productivity and reliability.

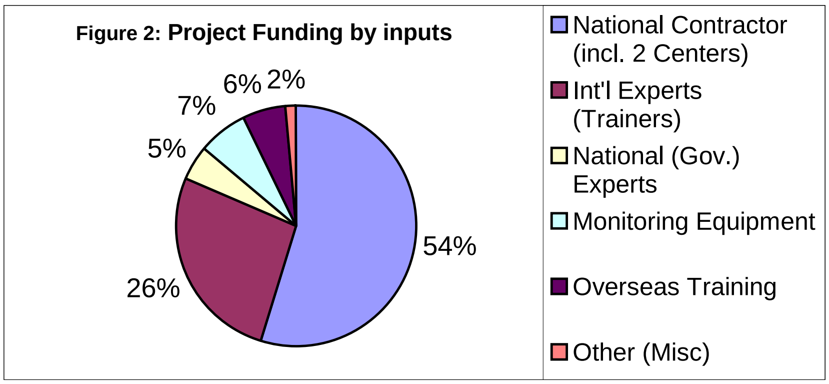
The program was as a pilot effort, which focused on Jiangsu and Shanghai provinces. It was designed to achieve significant energy savings in each province and also to provide a laboratory to test concepts for a nation-wide effort. The ultimate goal - *the program's development objective* - is to control the growth of greenhouse gas emissions by establishing a national mechanism to promote motor system efficiency in industries throughout China. The program expects to achieve at least a 10% reduction in energy usage for each targeted motor-driven system.

Standard practice in the design of UNIDO technical cooperation projects requires the elaboration of measurable *outputs* which together contribute to achieving the desired program objective or goal. The *China Motor Systems Energy Conservation Program* was designed to deliver the following five outputs:

1. Training materials, motor system analysis tools, and systems standards developed, codified and available in Chinese and English languages.
2. Implementation networks established in each of the two pilot provinces in China.
3. A core group of national experts from each province trained in motor systems optimization.
4. Two provincial programs implemented, including specific goals for training programs delivered, systems assessments provided and projects/case studies completed.
5. Completion of an evaluation and elaboration of the national program.

Figures 1 and 2 show the approximate distribution of the budgetary resources - provided by UNF - between each of the foregoing outputs and between the major groups of program inputs directly managed by UNIDO. Additional in-kind funding provided by USDOE, the Energy Foundation and Chinese sources brought the total program budget to about euro 2.32 million.





The planned independent program evaluation specified in output 5 was undertaken during and on completion of implementation. This paper benefits from this evaluation (2).

2 Effectiveness

2.1 Prerequisites for success

Several aspects of the program facilitated its successful implementation:

Firstly, it responds to promulgated government policy on energy efficiency and consequently enjoys the continuous support of both national and local government authorities. High level, local commitment facilitated the work of UNIDO's subcontractors (the two Energy Centers) in establishing networks and delivering the municipal and provincial programs as required by outputs 2 and 4. Since the program was part of a broader scheme involving complementary inputs from US and China, it benefited from additional (non-budgetary) inputs in the form of knowledge and expertise from a wide range of sources. UNIDO's prime contractor for the program (CECIC) is the most prominent Chinese agency in energy efficiency investment.

Significant UNF resources (57%) were dedicated to preparation for, and delivery of, training as defined in outputs 1 and 3 (fig.1). Twenty six percent of the UNF funds were used to field the international training staff (fig. 2). However, additional USDOE in-kind co-funding (€348,000) was made available to augment the budget for international expertise. Adequate funding of the training components assured the availability of high quality trainers who were both technically experienced and excellent communicators. One initial impact of high quality training was to secure the full commitment of senior officials from the two Centers. These senior officials participated actively in several of the training modules, which in turn served as an inspiration and motivation to Center staff. It also facilitated marketing system optimization services to the Centers' clients. Participants also included several factory-based energy engineers who became instrumental in developing system optimization projects in their own facilities, frequently in cooperation with Energy Center staff.

Both Centers view energy systems optimization as a new business opportunity and their sense of ownership for the program resulted in commitment beyond their duties as UNIDO subcontractors. Knowledge and skills acquired through the UNIDO program enable them to offer improved services to their clients. In turn, commitment from clients (who are concerned about competitiveness), led to increased commitment of all the trainees.

2.2 Effective Delivery

The program initially developed and translated training materials on motor system optimization. This was followed by in-country training by international experts in motor system optimization. Along with the training, the international experts conducted factory visits in each province to demonstrate application of the principles taught in the training sessions and to instruct the experts in the use of measurement equipment purchased for each Center as part of the China Motor Systems program. Training focused on pumps, fans, and compressed air systems. The program was designed to accommodate *learning by doing* through practical, on-site training. The importance attached to industrial plant evaluations and to the development of projects and completion of case studies based on real investments helped trainees to recognize the importance of obtaining results.

Information about systems optimization is, to some extent, available in the public domain but its successful application requires a rigorous campaign of training for specialists and awareness building for a wide range of stakeholders, particularly plant managers and equipment suppliers. To overcome company level barriers, industry managers must be convinced that energy efficiency investments, including system optimization and plant assessments, save enough money to make them worth doing. Benefits that resonate with managers include greater reliability and avoidance of expensive production interruptions caused by equipment failure as well as greater production capacity through more effective use of existing equipment. Management support is required to link the capital cost of equipment with operating costs in order to implement a life cycle cost approach to system upgrades,

In the China Motor Systems program training was delivered to two groups of recipients:

- Training to prepare Chinese experts (Center staff and key plant energy engineers) to conduct plant assessments for industrial energy system optimization.
- Training for factory personnel so that they understand the benefits of undertaking system optimization investment projects.

In the first case, training materials (course content, software tools and delivery methods) were developed with the long-term goal of transitioning responsibility for delivering the training from the international team to Chinese experts.

The second type of training materials was designed for the use by the Chinese experts in delivering an "awareness level" system optimization training for factory personnel. These training materials provide an overview of a topic, such as pumping system optimization, in a one-day seminar

The intensive experts' training took care to avoid ""ready-made"" solutions Variable speed drives, for example, although a useful means of avoiding the energy losses created by throttling valves, do not fit all circumstances. Trainees were taught how to identify problems, develop a measurement plan, collect and analyze data, and make recommendations to address identified problems.

Considerable emphasis was attached to problem solving through team-based challenges. Close interaction between the Chinese trainees and the international team of trainers was central to the program's success. Building on cultural norms, senior participants were engaged as co-trainers. Training went beyond the traditional pedagogic approach of formal lectures. Exercises were designed to gain class participation. For example, opportunities were created for the Chinese trainees to present their findings from factory-based system optimization exercises to their colleagues and to the foreign experts and then to discuss their observations as a group.

2.3 Lessons learned

- Adequate preparation for each in-country training module is critical. Sufficient time must be made available in advance of each module to mobilize industrial plants to host practical training sessions. The process used for the UNIDO pilot included identifying two-three potential in-plant training sites and sending some preliminary information about the sites to the instructors in advance. The international team arrived one week in advance of the actual training to visit the proposed sites with Center staff, walk the system, meet with and interview the plant managers and engineers, discuss training logistics, prepare systems for taking measurements (e.g.- line taps) and take preliminary measurements. Final selection of training sites was made in cooperation with the Center staff. Factors considered included whether the system was suited for illustrating optimization techniques, the physical logistics of working with a group of students around the system, and management support.

- The China Motor Systems program modules consisted of one-week blocks of time dedicated to intensive training on the optimization of one system. The need to compress in-country training into one-week blocks and deliver sufficient information for system optimization is a major challenge. Modules must be carefully planned to maximize learning during each one-week period.
- Adequate training on project financing should be given equal priority with technical training. Trainees can find it difficult to translate engineering results into business financials.
- Training to adequately prepare an individual to conduct system optimization assessments is resource-intensive and best suited to developing a small cadre of skilled professionals to work with plant personnel. At key organizations, several people should be trained, since some trainees will move to other jobs.
- Follow up between trainees and trainers is critical including follow-up visits, supplemental training, and regular email contact. With limited resources and over long distances this can be a challenge.

2.4 Results (Plant Assessments and Case Studies)

The first 38 industrial plant assessments completed by Chinese engineers, who received system optimization training identified nearly 40 million kWh in annual energy savings for an average per system savings of 23%.

Table 1 shows the specific goals and the status of the two centers in December 2004.

Table 1 Achievements of Centers

Goals	Jiangsu Status	Shanghai Status
Train 10 Motor System Optimization Experts (5 per Center)	> 10	> 10
Complete Plant Assessments for 34 Factory Enterprises (17 per Center)	18	23
Implement 8 Demonstration Projects with Case Studies (4 per Center)	4 completed, 8 underway or planned	4 completed, 3 planned
Train 200 Factory Enterprise Personnel per Center	>700	>200

Additionally, as a direct result of a study tour to the USA, the Shanghai Energy Center developed an internship program for senior year university engineering students

A pump system optimization project, undertaken by the Shanghai Center in cooperation with the New Asiatic Pharmaceuticals Co., offers an illustration of a typical case study. This company, established in 1926, manufactured a total production value of 3 billion RMB (€280,500,000) in 2001. It uses 16.98 million kWh annually in a cooling water system with 4 parallel pumps each of 160 kW capacity. Three pumps operate continuously, one provides backup.

A plant assessment by the Shanghai Center determined that the pumps were oversized and also unable to respond to seasonal variations in load. The assessment also identified improper pipe configuration at pump inlet and outlet and inadequate performance of the heat exchangers. The center installed 2 new pumps with proper head and flow rate, redesigned inlet and outlet configurations, installed a variable speed drive and automatic control system and introduced cooling water treatment to clean pipes and heat exchangers.

The Shanghai Center invested 1.2 million RMB in project cost under a shared savings arrangement-80/20 over 3 years (80% to ESCO, 20% to end-user). Energy savings were 1.05 million kWh or 49% of system energy usage. Cost savings were 660,000 RMB (€62,000) annually with a 1.8 year payback.

A project undertaken by the Jiangsu Center in cooperation with SINOPEC Yangtze Petrochemical Company offers another example of the benefits of a system optimization approach. The company has 34 production areas with a total production capacity of 8 million tones per year crude oil refining, 6.5 million t/a ethylene, 300 thousand t/a Ethylene Glycol, 7.70 thousand t/a plastic, 8.5 thousand t/a aromatic hydrocarbons. In 2003 the Energy Center and the company conducted a system assessment which determined that the material supply and consumption in the production chains were not in balance. As a result, the pumps were oversized and throttle valves were frequently used to regulate fluid flow and pressure, thus wasting electricity.

The project included the installation of 34 VSD on 34 motors for the material pumping system. On project completion, the specific energy consumption was reduced from 8.016 kWh/t to 5.766 kWh/t crude oil refined, with estimated annual electricity savings of 14.08 million kWh, and 11270 tons of CO2 emission reduction. The simple payback period is 0.48 years. The plant has experienced additional cost savings from reduced maintenance and prolonged equipment life, as well as improved working conditions due to lower noise levels.

3 Sustainability

Outputs 2, 4 and 5 were designed to provide for continuation of efforts to optimize industrial motor systems in China beyond project completion. About 43% of the total budget was dedicated to this task, (figure 1).

3.1 Developing the Market

Shanghai and Jiangsu Centers have been in existence since the mid-1980s as part of the Chinese government response to a need for energy conservation and regulations established at that time, which the Centers help industry comply with. The Jiangsu Center serves industrial enterprises throughout the entire province of Jiangsu—102,600 square kilometers. The Jiangsu Center identified thirteen cities in Jiangsu province in which to conduct workshops, plant assessments and undertake projects. The Shanghai center, in contrast, serves a smaller geographical area, 6,200 square kilometers including the Pudong development area and the metropolitan area of Shanghai. The provinces are located adjacent to each other but it takes about four hours by express train and about 6 hours by car to travel between the Centers.

Jiangsu province has a population roughly four times the size of the municipality of Shanghai. The types of industrial enterprises operating in the two areas are quite different. Shanghai is a major port and has attracted a significant amount of western investment capital. Two industries targeted by the Shanghai Center are pharmaceuticals and automobiles. Jiangsu has many large industrial enterprises, yet they are scattered across the province and represent a diversity of industries leaving no obvious industry group on which to focus. However, the Jiangsu Center used its expertise and contacts to somewhat target heat and power plants that provide electricity and district heating to industrial enterprises in their communities.

As a consequence of these pronounced differences in clientele served by each Center, they developed different business models to deliver system optimization services. These models also reflect the organizational strengths and business goals of each center.

Shanghai has established an Energy Services Company (ESCO)-type business model and intends to become the source of expertise that is currently lacking in local manufacturing plants. Shanghai manufacturers, that are not state-owned, run a western style, lean operation. Plant personnel are focused more on production than the operating energy sub-systems of the factory. The Shanghai Center wants to offer energy sub-system expertise and wants to share the energy savings achieved by implementing projects based on their analysis and recommendations. For Shanghai, offering factory training is a “means to an end” attracting new prospects for the Energy Center’s services, including project financing.

Jiangsu offer training and technical assistance to plant personnel for a fee enabling them to develop and implement their own energy savings projects and programs. In Jiangsu there is a mature manufacturing base (with some newer joint venture projects) whose culture is quite different from Shanghai’s. In Jiangsu, plants have a large staff that includes people dedicated to operating the plant’s energy sub-systems. For the Jiangsu Center, training and assisting factory personnel offers a cost-effective way to generate energy awareness and encourage factories to identify and undertake energy efficiency projects.

Shanghai’s approach to the market will likely produce larger per-plant energy savings, but since the Jiangsu Center should be responsible for generating many smaller projects, the total amount of energy saved may be as large or larger. To effectively realize and document these savings, Jiangsu must institutionalize regular follow-up with factory personnel who have undergone training, perhaps using the possibility of recognition as an incentive for post-training reporting.

Another consideration is that Jiangsu’s approach makes factory personnel responsible for identifying and correcting inefficient energy practices. This may result in an operating culture change that will sustain the initial energy savings. The Shanghai approach involves fewer factory personnel and may not result in an operating culture change. Without a thorough understanding of why system changes were made, Shanghai's customers may revert to old operating practices and negate the energy savings, which could become a major issue for shared savings arrangements. Shanghai will also need to develop a follow-up program, possibly an annual one-day walk through, to ensure that their customers are maintaining their energy savings, sort of an audit maintenance agreement.

3.2 Standards – the Top-Down Component.

Seventeen percent of total UNF funds were used to develop training materials as required by output 1 (fig.1). This also included the substantial revision to a standard for the economic operation of three-phase motors and a separate standard for the economic operation of pumping, fan, and compressed air systems. Both standards are undergoing a public comment period and will be issued in early 2006.

This limited effort reflects the program goals of developing capacity in the two Energy Centers to sell market-based training and/or energy efficiency services to industrial clients rather than seeking to institutionalize sustainability through government intervention. As work on the program proceeded, the importance of a parallel effort to provide government support and recognition through system and energy management standards became evident. Additional support was sought and secured from the Energy Foundation to complete work on revisions to the system standards.

The limitations of relying primarily on the market to carry forward system optimization efforts lies in the fact that most optimized systems lose their initial efficiency gains over time due to personnel and production changes. The system optimization knowledge typically resides with an individual who has received training - detailed operating instructions are not integrated with quality control and production management systems.

Since production is the core function of most industrial facilities, it follows that the most sophisticated management strategies would be applied to these highly complex processes. Successful production processes are consistent, adaptable, resource efficient, and continually improving- the very qualities that would support industrial system optimization. Because production processes have the attention of upper management, the budgetary disconnect between capital and operating budgets is less evident. Unfortunately, efficient use of energy is typically not addressed in these management systems in the same way as other resources such as labor and materials. The answer lies in fully integrating energy efficiency into these *existing management systems.*

The International Organization for Standardization (ISO) has established management systems (ISO 9000 and ISO 14000) that are widely adopted in many countries including China. These standards, are used internationally as a trade facilitation mechanism, are already accepted as a principal source for standards related to the performance of energy-consuming industrial equipment, and have a well-established system of independent auditors to assure compliance and maintain certification[1].

It should be possible to establish a link between ISO 9000/14000 quality and environmental management systems and industrial system optimization based on the creation of a framework. This includes energy efficiency standards, policies, training, and tools that have the net effect of making system optimization for energy efficiency as much a part of typical industrial operating practices as waste reduction and inventory management. This proposal is discussed in another paper (3).

Through the delivery of comprehensive capacity building on systems optimization, the China Motors program has taken a first step in transforming Chinese motor systems industries to a systems orientation. Long-term success will require a permanent change in corporate culture using the structure, language, and accountability of the existing ISO management structure.

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[1] As of December 2003, the latest published data, 500,125 ISO 9001:2000 and 66,070 ISO 14001 certified companies were participating in 149 countries. Extracted from The ISO Survey of ISO 9001:2000 and ISO 14001 Certificates- Thirteenth Cycle: Up to and Including December 2003