INTERNATIONAL MULTI DISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT
eISSN 2394-6334 Impact factor: 8.854 Volume 13, issue 04 (2026)

STRATEGIES FOR ENHANCING ENERGY EFFICIENCY IN BUILDINGS AND FACILITIES

Khafizov Islom Ikramovich,

Ph.D., dotsent, Asia International University

Abstract: This article examines the current state of energy consumption at an industrial enterprise, including electricity, heat, gas, fuels and lubricants, as well as ventilation and compressed air systems, buildings and structures, technological equipment, and auxiliary systems. It identifies existing technical and commercial losses, develops energy balance sheets, evaluates the efficiency of resource utilization, and proposes economically justified technical solutions for energy conservation.

In addition, the study provides a systematic analysis of the enterprise's energy profile, highlighting key technical indicators, sources of energy losses, potential reserves, and optimization pathways for major energy consumers. It also outlines a set of technical and organizational measures aimed at improving energy efficiency, along with their economic feasibility and implementation timelines.

Keywords: Selnickel steam boilers, CO and nCO emissions, combustion process, thermal efficiency, air consumption, gas consumption, fan frequency, valve opening angle, burner, compressor.

Introduction

To ensure the rational and efficient use of energy resources at industrial enterprises, identify energy losses, and determine technical measures for their reduction, a scheduled energy audit is conducted in accordance with the requirements of the Law of the Republic of Uzbekistan "On Energy Saving, Rational Use and Enhancement of Energy Efficiency," as well as Resolution of the Cabinet of Ministers No. 690 dated October 19, 2024, and the Joint Resolution of May 8, 2025.

To evaluate technical losses within the enterprise's power supply system, an analysis was carried out based on measurements reflecting the actual load conditions of transformers, 0.4 kV cable lines, and distribution equipment. The assessment considered key factors such as transformer overloading, voltage imbalance, harmonic distortion, power factor, and load distribution uniformity.

The installed transformers, each rated at 1600 kVA, were operating at load levels ranging from 30% to 40% during the measurement period, which coincided with a phase of production recovery. This level of loading indicates that the transformers are functioning within safe and optimal limits relative to their nominal capacity, with no significant risk of thermal stress or insulation degradation.

Technical losses in transformers are divided into two: no-load losses (P_0) and no-load losses (P_k). According to the passport data of the MAKSAN 1600 kVA transformer, no-load losses are 2.26 kW, and no-load losses are 17.6 kW. Since the load level during the measurement was 0.3–0.4 pu, the no-load losses are formed in the range of 1.6–2.8 kW. The total technical losses for each transformer are around 4–5 kW, which confirms that the transformers operate with minimal energy losses in real operating mode. Since the territory of the enterprise is 9.7 hectares, the length of the 0.4 kV distribution cables is technically estimated to be in the range of 2.5–3.5 km. The cables used in the distribution lines are power cables with aluminum wires with a cross section of 35–70 mm², and their resistance values correspond to the range of 0.443–0.268 Ohm·km. During the measurement, phase currents were recorded in the range of 140–195 A, due to uneven loading, there is current asymmetry in some lines. Technical losses in cable lines, calculated according to the I^2R formula, are around 3–6 kW, and 35–40 percent of the total losses at the enterprise level fall on cable networks.

According to the network quality indicators, voltage harmonics were in the range of 1.1–1.6 percent at all transformer points. These values are significantly lower than the current UzDSt 13109 and IEEE-519 standards, indicating that there are no factors that degrade voltage quality. Current harmonics increased to 35–43 percent at some points. This indicator is a specific feature arising from inverter drives, pulse loads and welding units. However, due to the low three-phase voltage harmonics, high current harmonics do not have a significant negative impact on the overall system stability.

According to the general analysis, the total technical losses in the enterprise's electrical networks are formed from losses in transformers, I^2R losses in cable lines and reactive power currents, and were estimated at around 7–11 kW per TP under current load conditions. Total technical losses at the enterprise are in the range of 60–80 kW, which is considered normal for the period of resuming production. According to the analysis results, no overheating, excessive asymmetry, voltage dips, and dangerous harmonics were detected in the electrical network. The technical condition of the transformer and cable infrastructure is satisfactory, and energy losses are kept to a minimum under the current load conditions.

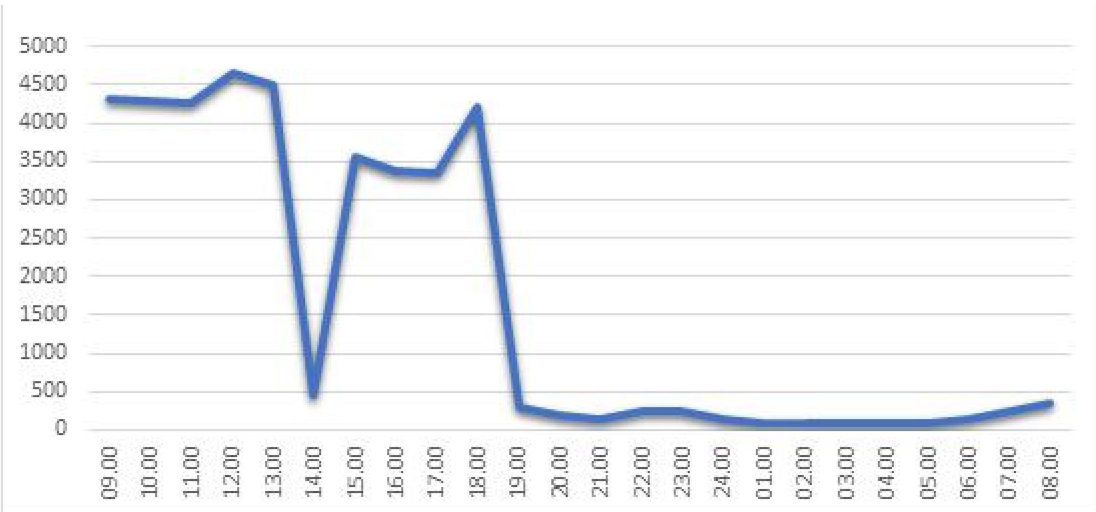
Since the loads at the enterprise are mainly inductive in nature, a certain proportion of reactive power is formed during the use of electricity. In order to reduce reactive power, compensation devices are installed at all transformer points. Each transformer point has compensation panels consisting of capacitor banks with a capacity of 30 kVAr, a total of 34 units. These devices are connected to 0.4 kV distribution panels and are in continuous operation mode.

During the measurements, the power factor was recorded in the range of 0.89–0.99. The PF value of most transformers is higher than 0.95, which indicates the effective operation of the installed compensation devices. The amount of reactive power did not increase sharply during the measurement, the Q value at the transformer points was in the range of 5–30 kVAr. The share of reactive power was also recorded at low values, given the low total load of the transformers.

According to the results of the analysis of the harmonic content, the power.

Graph 1. Electricity consumption 3-14.11.2025

According to the daily consumption schedule, the main load was formed in the period from 09.00 to 18.00. During this period, consumption was in the range of 4300–4650 Wh, and the maximum load was recorded in the period from 12.00 to 13.00. Between 13.00 and 14.00, a short-term decrease was observed due to the lunch break. Starting from 19.00, the load decreased sharply, and between 01.00 and 06.00, the minimum network load was recorded in the range of 100–150 Wh. The total electricity consumption for 24 hours was 35177 Wh. This result confirms that the current production cycle of the enterprise consists only of day shift operations. The monthly analysis examined the consumption dynamics for the period from November 3 to 14. Daily consumption on weekdays ranged from 34,690 to 39,500 Wh. The highest consumption was recorded on November 5, 2025 at 39,500 Wh. Since November 8–9 were weekends, consumption decreased sharply, reaching 200 Wh and 150 Wh, respectively. On November 10–14, against the backdrop of the resumption of production, the electrical load returned to normal levels and was in the range of 35,900–36,800 Wh. These data indicate that the production process at the enterprise operates actively in the usual mode only on weekdays, and on weekends, energy consumption drops to a minimum.



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raph 2. Electricity consumption of the enterprise in 2025

According to the analysis of the monthly consumption graph, it was found that the change in the enterprise load fluctuated in the range of 5–10 percent. This indicates that the loads in the production departments vary depending on the local work schedule and the operation of the technological lines. The enterprise's electricity consumption was stable, and load changes were kept within the regulatory range.

In general, the analysis of electricity consumption regimes confirmed the stability of the energy supply at the enterprise, the operation of the production process on a single shift basis, and the load was minimal on weekends. Based on the measurement results, a daily and monthly consumption graph was formed, which served as the basis for balance calculations at the subsequent stages of energy analysis.

No motion sensors, time relays, or intelligent control modules were installed at the sites. Therefore, in large production areas (for example, in the tukuv and arcon sections), it was observed that the lighting worked at full power even when there was no workforce or technological process.

Such manual control of the lighting system leads to unreasonable high consumption of electricity, inefficient operation and the appearance of overloads in the annual consumption structure. This situation causes significant losses during 8-12 hours of the day, especially in large-sized buildings. According to the results of measurements carried out in the workshops, the lighting system accounts for a significant share of the total electrical load, but its operation is not coordinated with real technological needs.

Automatic lighting control (PIR sensors, DALI/0-10V dimming, graphic timers, intelligent zone control) has not been implemented in any of the production workshops on the territory of the company. This drawback negatively affects the energy efficiency of the existing infrastructure and increases the overall operating costs.

The analysis shows that by introducing automation in the lighting system, energy savings of up to 12–25% can be achieved. The economic efficiency of this measure is high, and the payback period is usually 8–14 months. The transition to sensor control and zone lighting is especially important in large-scale and long-corridor workshops.

The power supply system at the enterprise is satisfactory in terms of its general technical condition, and the requirements of category II consumers are met through two independent input lines with a voltage of 10 kV, and the main technological and auxiliary consumers are provided with stable power through 5 transformer points and a total of 10 1600 kVA TM type transformers. As a result of the measurements, it was confirmed that the load factor of the transformers is in the range of 0.3–0.4, there are no dangerous situations in terms of thermal loads and insulation wear, and the voltage quality and harmonic content are within the limits of current standards. Transformer points and 0.4 kV distribution panels are in satisfactory technical condition according to the results of thermal imaging and visual inspection, and no defects leading to an emergency were identified.

Technical losses in electrical networks are formed mainly due to the running and load losses of transformers, losses in 0.4 kV cable networks, and reactive power flows. According to calculations, technical losses for each transformer are estimated at around 4–5 kW, and for cable networks at 3–6 kW. Total technical losses at the enterprise level are in the range of 60–80 kW per hour, which is considered standard for the current mode in which production is being restored. The level of harmonics in voltage and current, although low on the voltage side and increased on the current side due to inverter and pulse loads, does not have a significant negative impact on system stability.

Due to the installation of 34 k-t capacitor banks in all transformer points based on 30 kVAr sections, the power factor was in most cases above 0.95, and in some cases up to 0.99. This indicates that the existing compensation system is operating with sufficient efficiency under current load conditions. However, since the compensation does not have automatic control, dynamic optimization in accordance with load changes is not possible, and in the future, when the loads are fully commissioned, the need for adjustment may arise.

The commercial metering system is organized through 10 kV “Energomera SE-308” meters at four entry points, the last state metrological inspection was carried out in 2024 and the filling status is maintained. Commercial metering is satisfactory according to current requirements, but technical metering devices are not fully functional, separate metering is not maintained in the sections of the workshops. As a result, the ability to determine the internal energy balance, technical losses by points, and detailed analysis of large consumer groups is limited. The existing meters are not fully integrated into the ASKUE systems being implemented in the republic, which limits the possibility of remote monitoring, online load analysis, and automatic reporting. The analysis of the lighting system showed that lighting in production workshops is mainly controlled manually, zonal division and automatic shutdown systems (motion sensors, timers, zonal control) have not been introduced. Lighting is continuously switched on even in areas where work is not being carried out, which unnecessarily increases electricity consumption in large-scale workshops. Instead of separate lighting for local working zones in the warp opening and weaving workshops, the entire hall is provided with general lighting, which is also not advisable from an efficiency point of view.

The heat supply system at the enterprise consists of two 2.5 t/h steam-generating, natural gas-fired steam boilers, of which only one boiler is in operation, and the other is kept as a reserve. The boiler room has a complete heat transfer infrastructure consisting of a deaerator, a condensate collection tank, feed pumps and steam distribution collectors.

The technical parameters measured during the audit (flue gas temperature, O_2, CO_2, CO, SO indicators, boiler load, steam consumption and pressure) showed that the current operating mode of the boiler units is not optimal. Flue gases are above the standard range, incomplete combustion of fuel and imperfect aerodynamic regime reduce the efficiency of the boiler. As a result of measurements, the actual fuel consumption of the boiler was determined to be 137 m^3/Gcal, which is higher than the normative values that should be recommended by the manufacturer.

The technical condition of the heat exchange surfaces is not entirely satisfactory. Steam pipes with a diameter of 25–300 mm inside the boiler room, as well as deaerator and hot water lines, do not have thermal insulation. According to calculations, the heat loss from the existing bare pipes is 95,000–110,000 kcal/h, which leads to an excess consumption of thousands of cubic meters of gas per year. In addition, the lack of insulation of hot water and condensate pipes in the painting, washing, drying and packaging shops is one of the important factors increasing steam consumption.

When the condensate return rate was fully studied, it was found that, although the existing collectors were working, the enterprise did not fully ensure the complete collection and return of condensate to the boiler. In the section of the workshops, it was noted that the condensate drains were incorrectly selected and the residual pressure of the heat exchangers was insufficient at some points. If the condensate return rate was increased, the fuel consumption required to heat the boiler water would be reduced by 8–12%.

In general, although the heat supply system at the enterprise is operational, fuel consumption is increasing due to existing technical and operational shortcomings. By adjusting the aerodynamic mode of the boiler, restoring thermal insulation, increasing the level of condensate collection, revising the settings in the smoke exhaust system, and completely insulating the hot pipes inside the workshop, heat savings can be up to 12–18%.

Recommendations:

1. Conduct a full regime-setting process for boiler units.

2. Cover all uninsulated pipes (from 25 mm to 300 mm) with thermal insulation.

3. Restore thermal insulation for the deaerator and condensate collector.

4. Review the condensate return system, optimize drainage points.

5. Fully insulate hot water and condensate pipes inside the workshops.

6. Optimize combustion air consumption in order to increase boiler efficiency, not to exceed the CO indicator by 0.01%.

7. According to the results of the energy consumption inventory conducted in the administrative building of the enterprise, the installed capacities of the following electrical equipment were determined in the office building: 32 air conditioners with a capacity of 1.8 kW, 26 computers with a capacity of 1 kW, 2 air conditioners with a capacity of 8 kW, as well as 168 lighting fixtures of various types. The total installed capacity of these consumers is 106 kW.

8. Renewable energy sources are not used in current production and administrative processes. However, taking into account the high insolation rates of the Bukhara region (an average of 1500–1600 kWh/m² per year), the enterprise has sufficient technical and economic capabilities to install a solar photovoltaic power plant with a capacity of at least 50 kW. Installing a 50 kW solar panel system to cover part of the 106 kW installed capacity in the administrative building from renewable sources will reduce the enterprise's external need for electricity, optimize consumption during peak hours, and increase overall energy efficiency.

9. There are no alternative energy resources on the territory of the enterprise, but the convenient geographical location and high level of solar radiation can serve as the basis for the implementation of solar energy projects in the future. Therefore, it is recommended to gradually introduce the use of renewable energy sources.

Conclusion

As a result of measurements in Selnikel steam boilers, it was found that the concentration of CO and nCO is higher than the norm, the temperature of the flue gases is at the level of 142–145 °C, and the air-gas mixture is not brought to the optimal ratio. These factors indicate incomplete combustion, partial combustion of the fuel, and a decrease in thermal efficiency.

During the mode adjustment process, air consumption, gas consumption, fan frequency, valve opening angle, and all burner operating stages are adjusted to the actual boiler load.

Annual natural gas economy: Annual gas consumption*1.5%=2209300*0.015=33 140 m3/year

A total of 92 meters of steel pipes with a diameter of 32 mm to 200 mm leading from the boiler room to the steam and heating systems are currently operating without insulation. In pipes without thermal insulation, convective and radiant heat losses are high on the surface, resulting in a temperature drop in the steam line and excessive fuel consumption of the boiler. By covering the pipes with completely new mineral wool-based insulation, heat losses are reduced.

Annual natural gas savings: 34,082 m3/year.

A total of 866 meters (d25–d150) of heat pipes in the dyeing, washing, drying, packaging and finishing shops are currently operating without insulation, resulting in a heat loss of 165.45 kW. These losses lead to excess steam production in the boiler, which causes an inefficient consumption of approximately 151,840 m^3 of natural gas per year. By fully insulating the pipes, these losses are stopped and the heat load of the boiler room is reduced.

The existing condensate collectors at the enterprise are technically outdated, their internal mechanisms are clogged, and the steam traps cannot fully perform their opening and closing functions. As a result, the transfer of condensate to the central return system is slowed down, the steam pressure is not maintained at the same level, and a certain part of the condensate is lost in the production area. Due to the technical malfunction of the condensate collectors, the boiler load increases, and the annual natural gas consumption increases.

In order to eliminate these shortcomings, it is planned to replace 5 condensate collectors installed in the enterprise's steam system with new, highly efficient float-type or thermostatic condensate collectors. The new devices will ensure continuous and stable return of condensate, prevent unnecessary steam leakage, and increase pressure stability within the system.

Annual natural gas economy: Annual gas consumption*1%=2209300*0.01=22,093 m3/year

The RDUK-200 gas distribution and pressure reduction equipment available at the enterprise has been in use for a long time. During operation, the internal valves, membranes and sealing elements of the equipment have worn out, and interruptions, micro-leakages (gaps) and inaccurate adjustments are observed in ensuring gas pressure stability. This situation leads to an excessive increase in natural gas consumption, especially in unstable operating modes of boiler rooms, steam generators and technological heating equipment.

As part of this event, it is proposed to replace the existing RDUK-200 gas distribution unit with a new model with modern, high-precision, two-stage protection. The new equipment accurately and stably controls gas pressure and completely eliminates micro-gaps. This reduces the company's overall gas consumption by an average of 2%.

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