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A Review of the Manifestations and Coping Strategies of Energy Degradation in Daily Life Based on the Second Law of Thermodynamics

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***Abstract*— *This study takes the second law of thermodynamics as its theoretical foundation to deeply analyze the specific manifestations of energy degradation in daily life and systematically explore coping strategies. By combining literature review with theoretical analysis, we investigate the mechanisms of energy degradation in fields such as household appliances, transportation, energy conversion, and ecosystems. The research reveals that energy degradation is ubiquitous in all aspects of daily life; its essence is the irreversible transformation process of energy revealed by the second law of thermodynamics. This phenomenon not only leads to reduced energy utilization efficiency but is also closely related to energy waste and environmental thermal pollution. To delay energy degradation, comprehensive strategies are proposed at three levels: technological, behavioral, and systemic. These strategies aim to improve energy utilization efficiency and contribute to achieving the goals of carbon peaking and carbon neutrality. This study holds significant importance for deepening public understanding of the laws of energy degradation and promoting the popularization of scientific energy-saving concepts.*

I. INTRODUCTION

1. Research Background and Significance

With the rapid development of the global economy, energy demand keeps rising. The dwindling reserves of fossil fuels and the worsening climate change have made improving energy efficiency one of the core tasks of global energy strategies. According to forecasts by the International Energy Agency (IEA), global energy demand is expected to increase by approximately 25% by 2030. Nevertheless, the excessive exploitation and consumption of fossil fuels have not only led to resource depletion, but also triggered severe environmental problems. Against this backdrop, enhancing energy efficiency in terms of both quantity and quality has become a major concern for academia and policymakers.

The Second Law of Thermodynamics reveals the irreversibility and entropy increase in energy conversion processes, providing a theoretical basis for understanding energy degradation. Energy degradation refers to the irreversible decline in energy quality rather than a mere reduction in energy quantity. This phenomenon directly undermines energy utilization efficiency and exacerbates environmental thermal pollution. Therefore, an in-depth study on energy degradation from the perspective of the Second Law of Thermodynamics helps uncover the underlying physical mechanisms of energy waste, and offers important theoretical support for achieving the goals of carbon peaking and carbon neutrality.

2.Research Status at Home and Abroad

In recent years, scholars at home and abroad have conducted extensive researches on the Second Law of Thermodynamics, the entropy increase principle and energy degradation. Theoretically, researchers have further refined the mathematical expressions and calculation models of the Second Law of Thermodynamics. For instance, studies on energy systems based on exergy analysis demonstrate how to improve energy conversion efficiency through technological innovation.

Although existing researches have achieved remarkable progress in industrial and energy systems, there is a lack of systematic reviews on energy degradation in daily life scenarios. Phenomena of energy degradation commonly seen in household appliances, transportation and other daily fields have not received sufficient attention. Accordingly, this paper aims to fill this research gap. By systematically sorting out the manifestations and mechanisms of energy degradation in daily life, it provides theoretical guidance for the public to save energy in a scientific manner.

3.Research Content and Framework

Based on core journal articles retrieved from CNKI in the past five years, this paper follows the logical framework of "theoretical mechanism — scenario manifestation — cross-border extension — countermeasures". Firstly, it explains the core connotation of the Second Law of Thermodynamics, as well as the microscopic essence of the entropy increase principle and energy degradation. Secondly, it systematically analyzes the specific manifestations and formation mechanisms of energy degradation in household appliances, transportation, energy conversion systems and ecological systems. Thirdly, it extends the concept of physical entropy to social systems, and discusses the internal correlations among social entropy, individual behaviors and energy consumption of modern civilization. Finally, it puts forward comprehensive strategies to slow down energy degradation from three dimensions: technological innovation, optimization of daily behaviors and top-leve system design.

II. ENERGY DEGRADATION IN CURRENT RESEARCH

1.Theoretical Foundations Underpinning Energy Degradation

The Second Law of Thermodynamics stands as an indispensable pillar of classical thermodynamics. Its two canonical formulations, namely the Clausius statement and the Kelvin-Planck statement, uncover the irreversible nature of energetic processes in nature from the respective perspectives of heat transmission and energy transformation.

The Clausius statement dictates that heat is incapable of transferring spontaneously from a lower-temperature object to a higher-temperature one. Meanwhile, the Kelvin-Planck statement articulates that no device can absorb heat from a single heat reservoir and convert it completely into useful work without incurring any concomitant changes. These two statements are logically equivalent, and together impose constraints on the directionality and ultimate limits of energy conversion.

The principle of entropy increase further interprets this fundamental law from a microscopic viewpoint: the entropy of an isolated system will never decline. In practical physical processes, a positive entropy increment ($dS>0$) signifies that the system evolves from an orderly state toward a disordered state.

As explicitly elaborated by Professor Chen Zeshao in the monograph Advanced Engineering Thermodynamics, the core essence of energy degradation resides in the dissipation of high-grade available energy (exergy) triggered by irreversible processes, which serves as a direct corollary derived from the Second Law of Thermodynamics.

To quantify the phenomenon of energy degradation, scholars have adopted exergy analysis as a powerful and practical assessment tool. Latest academic investigations further verify that exergy analysis is not merely a practical application of the Second Law of Thermodynamics, but also acts as a crucial nexus linking energy systems with environmental repercussions [13]. By calculating the quality of internal energy within a system, researchers are able to pinpoint the dominant segments of energy wastage and furnish solid theoretical foundations for system optimization and design improvement.

2. Research Advances of Energy Degradation Across Diverse Fields

Over the past few years, academic circles have launched extensive and in-depth explorations into energy degradation prevailing in household electric appliances, transportation sectors, energy conversion facilities and ecological systems.

In the realm of household appliances, traditional incandescent light bulbs undergo drastic energy degradation, for the vast majority of electrical energy is dissipated into low-grade thermal energy. In stark contrast, LED lighting fixtures effectively alleviate this issue by virtue of elevated photoelectric conversion efficiency.

Within the transportation industry, the overall efficiency of internal combustion engines equipped on fuel-powered vehicles is commonly kept below 40%. This low efficiency primarily stems from energy degradation induced by incomplete combustion, exhaust energy loss and mechanical friction loss.

Thermal power generation represents a typical case of gradational energy degradation. During the multi-stage conversion process that transforms chemical energy into electrical energy, irreversible energy losses emerge at every single conversion step.

Furthermore, energy transmission within ecological systems also abides by the Second Law of Thermodynamics. The 10% rule of ecology indicates that the energy transfer efficiency between adjacent trophic levels in a food chain hovers around 10%.

3. Deficiencies in Current Studies and the Research Orientation of This Paper

Despite the fact that existing literatures have conducted thorough discussions on energy degradation in a wide range of fields, several prominent drawbacks still persist.

First and foremost, the majority of current studies concentrate on analyzing energy degradation of individual equipment or independent systems, while comprehensive and systematic researches targeting real-life daily scenarios remain insufficient. Secondly, extended researches associated with social dimensions are relatively scarce.

In view of the above gaps, this paper integrates existing research outcomes concerning energy degradation from multiple scenarios, so as to construct an all-round strategic framework covering technical approaches, human behaviors and systemic arrangements. Additionally, this research extends thermodynamic laws to social systems, and delves into the inherent correlations between individual conducts, social architectures and energy degradation.

III. THEORETICAL BASIS OF ENERGY DEGRADATION

1.The Core Tenets of the Second Law of Thermodynamics

The Second Law of Thermodynamics constitutes a cornerstone of classical thermodynamics, with two canonical formulations that illuminate the inherent irreversibility of energy-related processes in nature from the complementary perspectives of heat transfer and energy conversion.

The Clausius statement posits that heat cannot spontaneously transfer from a lower-temperature body to a higher-temperature body without the expenditure of external work or other compensating changes. The Kelvin–Planck statement further elaborates that no cyclic device can operate by absorbing heat from a single thermal reservoir and converting it entirely into useful work while leaving no other effects on the surroundings. Despite their distinct framing, these two statements are logically equivalent: both unequivocally demonstrate that all real-world energy conversion processes are subject to unavoidable losses and fundamental limitations. This irreversibility manifests not only in macroscopic phenomena but also profoundly shapes the microscopic distribution and temporal evolution of energy states.

At its core, the Second Law articulates the directional nature of natural processes. For instance, mechanical energy dissipated as heat via friction cannot be fully recaptured and reconverted into work with the same efficiency. Similarly, heat transfer across a finite temperature gradient proceeds spontaneously from high to low temperatures, with the reverse requiring the input of external energy (e.g., in refrigeration cycles). This irreversibility arises from the statistical behavior of large ensembles of microscopic particles: as system size increases, the probability of evolving toward a more disordered, high-entropy state becomes overwhelmingly dominant, rendering the reverse process practically infeasible. This principle underpins the universal limitation that no energy conversion process can achieve 100% efficiency, forming the conceptual bedrock for the study of energy degradation.

2.The Entropy Principle and the Fundamental Nature of Energy Degradation

Entropy, a state function in thermodynamics that quantifies the degree of microscopic disorder within a system, evolves in a manner that directly dictates the system’s thermodynamic trajectory.

According to the Boltzmann entropy formula S = k \ln W, entropy is proportional to the natural logarithm of the number of accessible microscopic states (W) corresponding to a given macroscopic state. In an isolated system, entropy is non-decreasing (dS \geq 0); in real processes, however, irreversible phenomena (e.g., friction, heat transfer across finite temperature differences, and unrestrained expansion) drive the system toward ever higher entropy states ($dS > 0$). This entropy principle formalizes the directionality of all spontaneous processes: systems evolve irreversibly from ordered, low-entropy configurations to disordered, high-entropy states.

From a microscopic perspective, energy degradation is fundamentally the irreversible conversion of high-grade, ordered energy into low-grade, disordered energy. Forms such as electrical energy, mechanical work, and chemical energy represent high-quality, ordered energy with high exergetic value and the potential to perform useful work. In stark contrast, thermal energy—particularly low-grade heat near ambient conditions—represents disordered, low-quality energy with limited work potential. Although the First Law of Thermodynamics mandates the conservation of total energy quantity, the quality of energy continuously degrades during conversion processes. As articulated by Professor Chen Shao, the "degradation" of energy arises directly from the destruction of exergy (available work potential) induced by irreversible processes.

The link between entropy generation (S_{gen}) and exergy destruction (E_d) is quantitatively defined by the Gouy–Stodola theorem: $E_d = T_0 S_{\text{gen}}$, where T_0 is the temperature of the reference environment. This relationship confirms that every increment in entropy generation corresponds to a permanent loss of exergy, directly quantifying the degree of energy degradation. For example, heat transfer across a finite temperature difference generates net entropy, which in turn reduces the exergy content of the thermal energy, permanently eroding its work potential.

3. Quantitative Assessment of Energy Degradation via Exergy Analysis

To rigorously quantify and systematically evaluate energy degradation, exergy analysis has emerged as an indispensable thermodynamic tool for assessing energy system performance.

Exergy (or available energy) is defined as the maximum useful work obtainable from a system as it reaches complete thermodynamic equilibrium with a specified reference environment (typically defined by ambient temperature T_0, pressure p_0, and chemical composition). Its core framework unifies the First and Second Laws of Thermodynamics, enabling simultaneous evaluation of both the quantity and quality of energy streams. Through exergy analysis, critical sources of irreversibility and energy degradation can be precisely localized, including temperature difference losses in heat exchangers, mechanical dissipation due to friction, and exergy destruction during combustion and chemical reactions.

Unlike energy balance analyses (rooted in the First Law), which only track energy conservation, exergy analysis focuses on the work potential of energy streams, providing a true measure of system performance. The exergy of mechanical and electrical energy is nearly equal to its total energy content, as these forms can theoretically be fully converted into work. In contrast, the exergy of heat transfer at temperature T relative to the environment is given by $E_x = Q\left(1 - \frac{T_0}{T}\right)$, which decreases as T approaches T_0, reaching zero at ambient conditions.

For complex integrated energy systems—such as fossil-fired power plants, combined heat and power cycles, and industrial process heating networks—comprehensive exergy analysis reveals hidden thermodynamic inefficiencies and untapped improvement potential. By calculating the exergy efficiency of individual components (e.g., boilers, turbines, pumps, and heat exchangers) and identifying the sites of maximum exergy destruction, engineers can prioritize optimization efforts. For instance, in a coal-fired power plant, the majority of exergy destruction typically occurs in the combustion process, where the chemical exergy of the fuel is converted to high-temperature heat with substantial entropy generation. Mitigating this irreversibility through advanced combustion technologies, combined cycles, or waste heat recovery systems directly reduces exergy destruction and improves overall plant efficiency. In this way, exergy analysis serves not only as a theoretical framework for understanding energy degradation but also as a practical guide for designing high-efficiency, sustainable energy systems.

IV. TYPICAL MANIFESTATIONS OF ENERGY DEGRADATION IN DAILY LIFE

1.Energy Degradation in Household Appliances

1.1 Energy Degradation in Lighting Equipment

Traditional incandescent lamps, as widely used lighting devices in daily life, operate based on the high-temperature radiation generated by electric current passing through tungsten filaments. However, this process is accompanied by significant energy degradation. Studies show that incandescent lamps have extremely low electrical energy utilization efficiency: only about 5% of the energy is converted into visible light, while the remaining 95% is dissipated in the form of infrared thermal radiation.

1.2 Energy Degradation in Refrigeration Equipment

The widespread use of refrigeration equipment such as air conditioners and refrigerators in daily life is also accompanied by significant energy degradation. The core of the refrigeration cycle lies in the compression and expansion of the working fluid by the compressor. However, this process is not ideally reversible, a view supported by empirical research. Studies on household refrigeration systems have shown that thermodynamic optimization can significantly reduce the system's entropy production rate, thereby improving energy efficiency ratio [2]. First, in the heat transfer process, due to the temperature difference between the evaporator and the condenser, heat transfer is inevitably accompanied by an increase in entropy, leading to the loss of available energy (exergy). In addition, case analysis of residential heating, ventilation, and air conditioning (HVAC) systems has also confirmed that irreversible heat transfer is the main cause of energy degradation [4].

2.Energy Degradation in Transportation

2.1 Energy Degradation in Traditional Fuel Vehicles

Traditional fuel vehicles, as the main tool of modern transportation, are subject to the strict constraints of the second law of thermodynamics in their energy conversion processes. The actual efficiency of internal combustion engines is far lower than the theoretical value. Studies show that the actual thermal efficiency of gasoline engines is usually only 20% to 30%. This energy degradation phenomenon in the power conversion process is universal. Optimization studies of urban transportation systems based on the second law of thermodynamics show that the irreversible losses of the traditional fuel-driven mode are higher than expected [3].

2.2 Energy Degradation Due to Braking Losses

During vehicle operation, braking loss is another typical manifestation of energy degradation. When a vehicle decelerates or stops, the kinetic energy is converted into heat energy and dissipated into the environment through the braking system, and this process is almost completely irreversible.

2.3 Energy Degradation in Electric Vehicles

Although electric vehicles have overcome the energy conversion bottleneck of traditional fuel vehicles to a certain extent, their energy conversion processes also have non-negligible energy degradation phenomena. The main energy losses come from internal resistance heating during battery charging and discharging, line losses, and electromagnetic losses during motor operation.

3. Cascade Energy Degradation in Energy Conversion Systems

As a core component of the modern energy system, multi-stage energy conversion processes in energy conversion systems are also accompanied by significant cascade energy degradation. Taking thermal power generation as an example, the chemical energy of fuel is first converted into thermal energy in the boiler, then into mechanical energy through the steam turbine, and finally into electrical energy via the generator. In this process, each stage of energy conversion is constrained by the second law of thermodynamics, leading to the gradual reduction of available energy (exergy).

4.Energy Degradation in Ecosystems

Energy flow and conversion in ecosystems also follow the second law of thermodynamics, showing significant energy degradation. According to the "ten percent law" in ecology, the transfer efficiency of energy in the food chain is usually only about 10%.

V. CROSS-BORDER EXTENSION: FROM PHYSICAL ENTROPY TO SOCIAL ENTROPY

1.Entropy Increase and Energy Degradation in Social Systems

As complex ordered structures, the operation and maintenance of social systems are profoundly influenced by the Second Law of Thermodynamics. Analogous to entropy increase in physical systems, issues such as unequal distribution of social resources, widening wealth gaps, and information asymmetry can all be viewed as specific manifestations of social entropy increase. According to thermodynamic theory, the entropy of an isolated system always tends to increase; therefore, to maintain its orderliness, a social system must continuously invest material and energy resources to counteract this trend. For instance, the uneven distribution of educational resources, healthcare, and economic opportunities not only leads to increased disorder within the social structure but also weakens the overall stability and sustainability of the system. Furthermore, social entropy increase is reflected in the accumulation of problems like environmental pollution and aging infrastructure. These issues are essentially the result of high-grade energy being converted into low-grade heat and dissipated during utilization, further exacerbating the phenomenon of energy degradation in social systems. Thus, from a thermodynamic perspective, the orderly development of social systems relies on continuous energy input, which inevitably accompanies a decline in energy quality and an increase in social entropy.

2.An Anti-entropy Interpretation of the "Tangping" Behavior

In recent years, the phenomenon of "tangping" (lying flat) has garnered widespread attention as a socio-cultural trend. Viewed through the lens of the Second Law of Thermodynamics, "tangping" can be regarded as an anti-entropy strategy adopted by individuals when confronted with increasing social entropy. In modern society, individuals typically need to engage in fierce competition to acquire limited resources—a process that inevitably involves energy dissipation and heightened psychological stress. When individuals choose to "lie flat," they are effectively reducing futile competitive behaviors, thereby lowering their own energy dissipation and the accumulation of social entropy. This behavioral pattern can be understood as a self-protection mechanism aimed at maintaining a low-entropy internal state by reducing active adaptation to the external environment. Notably, "tangping" is not entirely negative; rather, it represents a rational choice for individuals coping with the high-energy-consumption modes of society. From the perspective of energy degradation, by minimizing unnecessary energy expenditure, individuals are actually optimizing their own energy utilization efficiency, albeit at the cost of reduced social participation. Therefore, the "tangping" phenomenon not only reflects individuals' sensitivity to energy degradation in modern society but also reveals the complex dynamics of social systems under the pressure of entropy increase.

3.The Energy Consumption Paradox of Modern Civilization

The development of human civilization is fundamentally a process of combating entropy increase, with the formation and operation of modern cities serving as a concentrated manifestation of this process. As highly ordered social structures, cities depend on the continuous input of large amounts of high-grade energy to sustain themselves. However, this energy input not only supports the low-entropy state of cities but also leads to the high-entropization of the overall environment. Specifically, activities such as industrial production, transportation, and building operations during urbanization are accompanied by significant energy degradation. For example, the conversion of chemical energy into electricity in thermal power generation is accompanied by massive heat loss, while the inefficient operation of internal combustion engines in urban transportation systems further exacerbates ineffective energy consumption. Moreover, modern civilization's pursuit of high-energy lifestyles—such as overconsumption and long-distance commuting—has driven global growth in energy demand and an increase in entropy production. Although technological innovation has improved energy efficiency to some extent, the overall energy consumption pattern of human civilization still exhibits unsustainable linear growth. This energy consumption paradox indicates that the low-entropy structure of modern society is achieved at the expense of high-entropization of the global environment, posing severe challenges for future sustainable development.

VI. COPING STRATEGIES FOR ENERGY DEGRADATION

1.Technological Innovation: Improving Energy Conversion Efficiency

1.1 Combined Heat and Power (CHP) and Combined Cooling, Heating and Power (CCHP)

By integrating energy conversion processes, Combined Heat and Power (CHP) and Combined Cooling, Heating and Power (CCHP) technologies realize efficient cascade utilization of energy. Their core principle is to generate electricity using high-grade thermal energy and recover low-grade thermal energy for heating or cooling, which greatly improves the overall energy efficiency of the system.

In conventional thermal power plants, only approximately 40% of chemical energy is converted into electricity, while the rest is dissipated as waste heat. In contrast, the comprehensive energy efficiency of CHP systems can exceed 80%. The mode of temperature matching and cascade utilization effectively alleviates energy degradation and presents broad application prospects in industrial and residential areas.

Furthermore, CCHP adds a cooling function. Relying on the refrigerant cycle of absorption refrigerators, it converts low-grade thermal energy into cooling capacity to meet summer air conditioning demands, achieving multi-energy complementation and collaborative optimization. Relevant literature demonstrates that CHP and CCHP can cut primary energy consumption and substantially reduce carbon emissions, delivering technical support for the realization of the dual carbon goals.

1.2 Heat Pump Technology

Based on the reverse Carnot cycle, heat pumps consume a small amount of high-grade electric energy to drive compressors, absorb heat from low-temperature heat sources and transfer it to high-temperature heat sources for space heating and hot water supply. Their Coefficient of Performance (COP) is generally higher than that of traditional electric heating equipment, with prominent advantages especially in low-temperature environments.

For instance, air-source heat pumps can maintain a COP above 2.5 even in cold regions, indicating that more than 2.5 units of heat output can be obtained per unit of electric energy consumed. With the advancement of low-carbon development, heat pumps have been widely applied in building energy conservation.

Studies prove that replacing traditional gas-fired boilers and electric heaters with heat pump systems can remarkably reduce energy degradation during building operation and curtail fossil fuel consumption, thereby lowering greenhouse gas emissions. Ground-source and water-source heat pumps feature stable heat source temperatures, making them suitable for long-term operation and serving as an important supplement to distributed energy systems.

1.3 Promotion of High-efficiency Equipment

Popularizing high-efficiency equipment is a vital approach to mitigate energy degradation, with LED lighting and first-class energy-efficiency household appliances as typical examples. Compared with traditional incandescent and fluorescent lamps, LED lighting boasts higher photoelectric conversion efficiency and longer service life.

Experimental data show that the luminous efficacy of LED lamps reaches over 100 lumens per watt, while that of traditional incandescent lamps is merely 10 to 15 lumens per watt. Under the same lighting requirements, LED lamps can save around 80% of electric energy. Similarly, first-class energy-efficiency household appliances greatly cut energy loss during operation via optimized design and upgraded manufacturing techniques.

High-efficiency inverter air conditioners reduce energy waste caused by frequent start-stop through precise compressor speed regulation. First-class energy-efficiency refrigerators achieve lower energy consumption by adopting improved thermal insulation materials and optimized refrigeration systems. The widespread use of such equipment helps reduce residential power consumption, curb energy degradation at the source, and lay a solid foundation for achieving national energy conservation targets.

1.4 New Energy Replacement

The rapid development of new energy has provided a new solution to energy degradation occurring in multi-stage energy conversion. Clean energy sources such as photovoltaic power, wind power and hydrogen energy directly capture solar and wind energy and convert them into electric energy or chemical energy, effectively shortening the energy conversion chain.

Photovoltaic systems convert solar energy directly into electricity, avoiding multi-stage conversion losses from chemical energy to thermal energy and then to electric energy in conventional thermal power generation, and thus significantly boosting energy utilization efficiency. As a clean secondary energy source, hydrogen can be produced by water electrolysis and applied in fuel cell power generation and transportation. It features high energy density and zero emissions, and is regarded as a key component of the future energy system.

Researches indicate that large-scale deployment of new energy technologies can reduce reliance on fossil fuels and decrease irreversible losses across the entire energy system, providing strong support for sustainable development.

2.Behavioral Optimization: Cultivating Energy-Saving Habits

2.1 Matching Energy Quality to Application

In daily life and industrial production, the phenomenon of utilizing high-grade energy for low-grade applications is widespread, such as the use of electric heaters for space heating. This method of energy consumption not only results in severe waste of energy quality but also exacerbates the contradiction between energy supply and demand. From the perspective of the Second Law of Thermodynamics, electricity is a high-grade, ordered form of energy, whereas thermal energy is a low-grade, disordered form. Directly converting electricity into heat for heating purposes leads to significant dissipation of available energy (exergy). Therefore, the principle of "matching energy quality to application" emphasizes the rational selection of energy utilization methods based on the quality characteristics of the energy. For instance, in winter heating, priority should be given to equipment such as heat pumps or natural gas wall-mounted boilers, which consume a small amount of high-grade energy to drive the utilization of low-grade energy, thereby achieving highly efficient energy allocation. Furthermore, in industrial production, high-grade steam should be avoided for direct use in low-temperature heating scenarios; instead, energy cascade utilization should be achieved through the optimization of heat exchange networks to minimize energy degradation to the greatest extent.

2.2 Simplifying Energy Chains

Shortening the energy conversion chain is one of the important strategies to delay energy degradation. Its core lies in reducing unnecessary conversions of energy forms, thereby lowering cumulative losses. In practical energy utilization, each additional energy conversion stage leads to a decline in energy quality due to irreversible losses. For example, traditional thermal power generation systems require multi-stage conversions from chemical energy to thermal energy, then to mechanical energy, and finally to electrical energy, with each step accompanied by entropy increase and energy degradation. In contrast, distributed energy systems reduce transmission and distribution losses by supplying energy locally, while also avoiding energy attenuation during long-distance transmission. Additionally, in household energy scenarios, minimizing the frequent start-stop cycles and mode switching of electrical equipment also helps to reduce cumulative losses during the energy conversion process. Research indicates that by optimizing the structure of energy systems and energy consumption behaviors, the energy conversion chain can be effectively shortened, thereby improving overall energy utilization efficiency.

2.3 Cultivating Green Living Habits

Cultivating green living habits is a crucial approach to delaying energy degradation. Specific measures include reducing the standby time of household appliances, setting air conditioner temperatures reasonably, and optimizing lighting usage. For instance, household appliances still consume a certain amount of electricity in standby mode; although the standby power of a single device is low, the cumulative effect is significant. It is estimated that the standby energy consumption of all appliances in a household may account for 5% to 10% of the total electricity consumption. Therefore, turning off unused appliances in a timely manner or unplugging them can effectively reduce invalid energy consumption. In addition, the setting of air conditioner temperature has a significant impact on energy consumption. Setting the air conditioner temperature above 26°C in summer can save approximately 30% of electricity compared to setting it below 20°C, while also avoiding energy degradation caused by overcooling. In daily life, making full use of natural lighting and ventilation can also significantly reduce the energy demand during building operation, contributing to the achievement of energy conservation and emission reduction goals.

3.Systemic Design: Policy Guidance and Management

3.1 Passive Design

Passive building design reduces building energy demand at the source by optimizing the performance of the building envelope and utilizing natural resources. Specific measures include high-efficiency thermal insulation, natural lighting, shading design, and ventilation optimization. For example, the adoption of high-performance insulation materials and double-layer insulated glazing can significantly reduce the heat transfer coefficient of the building envelope, thereby decreasing the energy demand for winter heating and summer cooling. Furthermore, reasonable design of building orientation and window placement allows for full utilization of natural lighting and ventilation, reducing reliance on artificial lighting and mechanical ventilation. Research shows that passive design can reduce heating energy consumption by approximately 40% in cold regions and lower cooling energy consumption by over 30% in hot regions. This method of reducing energy demand at the source not only delays energy degradation but also provides a sustainable solution for building energy efficiency.

3.2 Waste Heat Recovery

Industrial and urban waste heat recovery technologies effectively reduce energy dissipation and improve energy utilization efficiency by reusing low-grade waste heat. For instance, industries such as steel, chemical, and cement production generate substantial amounts of high-temperature flue gas or waste heat from cooling water during their processes. If this waste heat is not recovered, it will be discharged into the environment, resulting in severe energy degradation. Through waste heat recovery devices, such as waste heat boilers or Organic Rankine Cycle (ORC) systems, this low-grade thermal energy can be converted into steam or electricity to meet the demands of industrial processes or heating needs in surrounding residential areas. At the urban level, public facilities like data centers and subway systems also generate significant waste heat during operation. By utilizing waste heat recovery networks to supply district heating, the comprehensive efficiency of urban energy systems can be significantly improved. Literature indicates that the application of waste heat recovery technology not only reduces energy waste but also lowers carbon emissions, providing crucial support for achieving dual-carbon goals.

3.3 Integrated Energy Systems

Urban-scale Integrated Energy Systems (IES) achieve multi-energy complementarity and synergistic optimization by integrating various energy forms, providing a systematic solution to delay energy degradation. Such systems typically encompass multiple energy networks—including electricity, gas, and heat—alongside energy storage devices and intelligent control platforms. For example, through a Power-to-Gas (P2G) system, surplus electricity can be converted into hydrogen via water electrolysis for storage, and then reconverted into electricity via fuel cells during peak demand periods. This enables the spatiotemporal transfer and highly efficient utilization of energy. Furthermore, IES can dynamically adjust user energy consumption behaviors through demand-side management (DSM) technologies, thereby smoothing load fluctuations and reducing peak-to-valley differences. Research demonstrates that the introduction of Integrated Energy Systems not only enhances energy utilization efficiency but also strengthens system flexibility and reliability, providing vital support for the sustainable development of modern urban energy frameworks.

VII. CONCLUSION

1.Research Conclusions

As a direct corollary of the second law of thermodynamics, energy degradation is an objective law prevailing in nature. It is always accompanied by irreversible energy losses throughout energy conversion in household appliances, power dissipation in transportation, and multi-stage energy transfer within energy conversion systems. To address the challenges posed by energy degradation, this paper proposes comprehensive countermeasures from three dimensions: technology, human behavior and system optimization.From the technical perspective, combined heat and power (CHP) and combined cooling, heating and power (CCHP) systems remarkably improve energy efficiency via temperature matching and cascade energy utilization. Heat pump technology boasts a high coefficient of performance and thus enjoys broad application prospects. The popularization of high-efficiency equipment such as LED lighting and first-class energy-efficiency household appliances effectively curbs irreversible losses during energy conversion. The replacement of conventional energy with new energy cuts down multi-stage energy conversion processes and mitigates overall energy degradation.In terms of human behavior, strategies including energy utilization matching energy quality, simplification of energy conversion chains and cultivation of eco-friendly lifestyles further enhance public awareness of energy quality. At the system level, the adoption of passive building design, waste heat recovery technologies and integrated energy systems reduces energy demand at the source.

In summary, whether from the micro perspective of equipment exergy analysis or the macro perspective of global energy pathway planning energy-saving strategies based on the second law of thermodynamics constitute an indispensable approach to sustainable development.

2.Research Prospects

This paper systematically elaborates on the theoretical basis, practical manifestations and countermeasures of energy degradation, yet there remains room for further in-depth research. Future studies may focus on the construction and optimization of residential micro-energy systems. Furthermore, against the backdrop of accelerated global energy transition, coordinating energy supply and demand at various scales and optimizing energy structure allocation to slow down energy degradation to the greatest extent remain critical issues to be resolved urgently.

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