

# Study on the Applicability of Green and Efficient Refrigeration and Air Conditioning Based on Exhaust Air Heat Recovery Technology

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**Abstract:** With the sustained and stable development of the national economy, China has stepped into a new stage of green emission reduction. Under the environment of comprehensively promoting the market share of green and efficient refrigeration products, the popularization and use of exhaust air heat recovery technology in different fields will further promote the green and efficient transformation of the refrigeration industry, improve the industry's independent innovation technology, and accelerate the construction of ecological civilization. This project firstly analyzes the research background, reviews domestic and international research, and clarifies the research background and current situation; secondly, it builds a comprehensive evaluation system for green refrigeration development based on three major energy-saving concepts, and measures the level of green refrigeration development in China's first-tier cities; secondly, it applies empirical evidence based on the data of three districts and cities, namely, Beijing, Shanghai, and Guangzhou, in the period of 2011-2021, to analyze the effect of the exhaust heat recovery technology on the development of high-efficiency green refrigeration. Then, based on the data of Beijing, Shanghai and Guangzhou from 2011 to 2021, we use the empirical analysis to analyze the effect of exhaust air heat recovery technology on the development of high-efficiency green refrigeration.

**Keywords:** Green Cooling, Exhaust Heat Recovery, Text Mining, Integrated Effects Evaluation Models, State of Knowledge.

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## 1. Introductory

At present, China is already the world's largest producer and consumer of refrigeration and air-conditioning equipment. Refrigeration and air-conditioning system is an important energy-consuming object in China's building system, how to realize the energy-saving and environmentally friendly development of the industry has become an urgent issue common to the entire international community. Refrigeration and air conditioning in the creation of a cool living environment, but also consumes a lot of energy. According to estimates, due to the large population and environmental climate change, China has become a large country consuming refrigeration and air conditioning, refrigeration power consumption accounted for more than 15% of social electricity consumption, with an average annual growth rate of nearly 20%. The gradual increase in citizens' awareness of environmental protection also puts forward higher requirements for energy saving and economy of air-conditioning systems. These have caused China's refrigeration and air conditioning capacity for the development of energy saving and environmental protection attention. In 2019, the state issued the Action Program for Green and Efficient Refrigeration, which puts forward short-term and long-term goals for the development of the refrigeration industry, cultivates new momentum for green development, and helps the world to efficiently "cool down". As a new type of energy-saving technology, heat recovery of exhaust air in air conditioning system is a great practice of green and efficient refrigeration, which can reduce the energy consumption of fresh air treatment and improve the operating efficiency of air conditioning. It provides a good foundation

for China's refrigeration and air-conditioning industry to further improve its independent technological innovation capability and strength, and to promote the transformation and upgrading of the industry in a green and efficient way.

## 2. Literature Review

The new model of green refrigeration focuses on how to reduce energy consumption challenges while targeting the challenges of reducing carbon emissions to explore, with a view to discovering the relevant technology air conditioning exhaust air heat recovery. Therefore, it has high practical research value. By organizing and reviewing the existing literature, we find that scholars' attention to green refrigeration and related exhaust air heat recovery is on the rise. And the existing research on green refrigeration mainly focuses on the research and development innovation of exhaust air heat recovery technology routes and the application status quo of hospitals, shopping malls and other large public buildings. Further investigation found that the existing literature on green refrigeration core technology and refrigeration device research papers tend to be more, while the users of the air conditioning exhaust heat recovery mode of acceptance of the willingness to accept, suggestions and satisfaction level of the investigation is less, indicating that the relevant scholars generally tend to technology research and development, less concerned about the feasibility of green refrigeration air-conditioning and the user's sense of experience. After reading and analyzing the relevant data in multiple dimensions, the research team found that there is still a wide exploration space for the research of green cooling and air conditioning model in China.[2] The research team found that there is still plenty of room for exploration of the green

cooling and air conditioning model [2].

At present, the domestic and foreign research direction of the exhaust air heat recovery equipment: first, the application of exhaust air heat recovery equipment for air-conditioning systems to use the scope of research; second, the application of exhaust air heat recovery equipment for air-conditioning systems to use the effect of research.

Research on the scope of use of air-conditioning systems applying exhaust air heat recovery equipment. A large number of studies have been conducted to verify the applicability of rotary heat recoverers in office buildings and large shopping malls, in SPF animal experiments, hotels, libraries, hospitals, subways, and historical museums air-conditioning systems (Han Junzao, 2008; A. Mardiana-Idayu, 2012; Xu Huqing, 2010; Gu Jianbin, 2006; Yu Youli, 2012; Yang Zhenxiao, 2021), and especially In Yang Zhenxiao's "Study on the Applicability of Exhaust Air Heat Recovery Technology in Hospital Air Conditioning Systems", it was mentioned that the air conditioning of hospital buildings is suitable for the use of exhaust air heat recovery systems with a short payback period and high operational efficiency[3], economy and safety are strong. The applicability of plate-fin heat recycler in large supermarkets and automobile showrooms can also be applied to the applicability of decentralized independent systems (Sun Yongxia et al., 2013; Xu Jingfeng et al., 1999); and the applicability and economic benefits of heat pipe heat recycler in swimming pools, edible fungus cultivation rooms, and animal clean rooms (Sun Lijing, 2013; Zhou Gemming, 2013). Liquid circulation heat recycler in cigarette factory (Peng Rong et al., 2013), solution circulation heat recycler in industrial building (Wang Xinhua, 2013), and the adaptability of heat pump heat recycler in mining plant (An Qiang, 2012). Therefore, the exhaust air heat recovery equipment has a wide range of applicability, and users can choose different types of exhaust air heat recoverers according to the different characteristics of the premises.

Research on the use effect of air conditioning systems applying exhaust air heat recovery devices. The national GB50176-2016 Thermal Design Code for Civil Buildings, the Green and Efficient Refrigeration Action Program (NDRRC [2019] No. 1054), and other specifications all describe the conditions for the use of exhaust air heat recovery devices and point out that recycling the energy contained in air conditioning exhaust air has a desirable energy-saving benefit and environmental benefit. And in the Energy Consumption Handbook for Commercial Buildings (2020) published by the U.S. Department of Energy, exhaust air heat recovery technology is listed as one of the 15 HVAC energy-saving technologies that are most economically advantageous for the U.S. today and in the future. Therefore, air conditioning exhaust air heat recovery technology has a strong potential for energy savings (Xinhua Wang, 2011), and the use of heat recovery equipment not only saves energy for the system, but also meets indoor sanitation needs (Shahram Delfania, 2012).

In general, the relevant research at home and abroad can be summarized as the following characteristics: first, there are more research on the technology of exhaust air heat recovery industry abroad, while less attention is paid to this field domestically, and the relevant information is of long standing; second, there are more basic theoretical research on the technology of exhaust air heat recovery, but there are fewer researches on the application of innovations in actual buildings; third, there are more researches on the macro-

policy level of the development of the exhaust air heat recovery industry, and fewer researches on micro-deep-level problems. Thirdly, there is more research on the macro policy level of the development of the exhaust air heat recovery technology industry, and less research on the micro deep-level problems. As a result, the existing evaluation standards on exhaust air heat recovery technology have a relatively weak guiding function, low update frequency, and weak technical systematization.[4] Therefore, it is easier to cause the situation of "technology stacking". And there is a lack of clarity on the classification and conditions of use of exhaust air heat recovery devices, which is unfavorable to the implementation of the technology and the actual effect. This provides a very necessary and urgent theoretical and practical demand for this topic, which constitutes the basic entry point of this study.

The marginal contributions of this paper are as follows: based on the connotation of China's "14th Five-Year Plan" energy conservation and emission reduction development in the new era, combined with the actual development of green air-conditioning and refrigeration in North, Shanghai, and Guangzhou, we use the principal component analysis method to construct a comprehensive evaluation system for green refrigeration development with three dimensions of energy efficiency, energy-saving technology, and green management as the main indicators, and derive the green development quality index. quality index; and using stepwise regression STEPWISE method to quantify the intrinsic correlation between residents' acceptance willingness and environment, quality and energy, and comprehensively using hierarchical analysis to construct a comprehensive effect evaluation model. First, the selection of indicators. Using the gray correlation analysis method to select the indicators for unit electricity reduction, unitCO<sub>2</sub> exhaust volume, unit cooling capacity, and renewable utilization rate, which have an important relationship with green and sustainable development. Secondly, the model is constructed. The panel data model is used to analyze the influence mechanism of each green refrigeration indicator on the development of green and efficient refrigeration. Finally, empirical analysis[5]. Use SPSS software to analyze the degree of explanation and weight of each green refrigeration indicator on the level of efficient green high-quality development; explore the similarities and differences affecting the application of exhaust air heat recovery technology in the development of green high-efficiency refrigeration in different districts and municipalities according to the results of Moran's I; and change certain green refrigeration indicators to analyze the specific changes caused by the level of green high-efficiency refrigeration development in different regions.

### 3. Theoretical Mechanisms

Exhaust air heat recovery technology has been relatively mature in foreign countries, the relevant exhaust air heat recovery products have been widely used in many large commercial buildings, with the convening of the two sessions in 2021, "green refrigeration" this new refrigeration and air-conditioning model in the country gradually attracted widespread attention.

Through literature analysis, we know that scholars are less interested in the willingness of residents to use clean heating, and more interested in scientific and technological research and development. In the domestic air conditioning exhaust

heat recovery is maturing in the background, the technical difficulties are gradually overcome, but the academic community for the public in the green refrigeration air conditioning acceptance of the willingness of the research is still blank, this paper is for the green refrigeration air conditioning in the exhaust heat recovery technology as the core, to the first-tier cities, spanning China's north and south for the base of the residents of North and South as the main body of the research, the research is carried out in three aspects: First, the study of the residents of the city of North and South Guangzhou First, to study the basic knowledge of residents in North and South China about green refrigeration and air conditioning.[6] Second, the current status of the development prospects of exhaust air heat recovery air conditioning, in-depth investigation; Third, to analyze the acceptance of hospital workers on the new mode of air conditioning exhaust heat recovery willingness and the factors affecting; content, from the willingness to promote the form of preference, mode innovation and other perspectives of multi-dimensional excavation, is not limited to a certain level of the study, with a certain degree of creativity, analysis of the public and hospital workers on the new mode of green cooling It is innovative and analyzes the bottlenecks in the acceptance of new green cooling models by the public and hospital workers. On the one hand, it fills the gap of existing research content, and on the other hand, it is of great practical significance for the large-scale landing of heat recovery of air conditioning exhaust air and hospital promotion.

#### 4. Modeling and Analysis

Taking the potential user group as the object of our research, in the data research, we designed what factors would be the reason for purchasing exhaust heat recovery air conditioners for those who have not purchased exhaust heat recovery air conditioners, among which there are eight factors, such as whether it is friendly to the environment, whether it is economically priced, how the energy utilization rate is, whether the quality of the product is good, whether it is highly subsidized by the policy, highly advertised, used by people around us, and other factors. The probability of the factor "other" being selected was extremely low, and it was found to be unrelated to the other options, so it was not included in the analysis.

The basic principle of the principal component analysis method for categorical data is as follows: constructor:  $\delta(X; Y) = n_w^{-1} \sum_j c^{-1} \text{tr}[(X - G_j Y_j)' M_j W (X - G_j Y_j)]$ , constraints  $X' M_* W X = n_w m_w I$ . Where  $n$  represents how many records there are in total and  $m$  represents how many variables there are in total, and the first  $j$  variable is denoted by  $j$  is denoted by the first variable, and the first variable is denoted by the  $K$  group of variables, i.e., each variable has  $K$  multiple choices, and  $p$  represents the total number of typical correlation coefficients extracted by preselection.  $G_j$  represents the number of variables  $j$  of the indicator matrix, the diagnostic matrix is denoted by  $W M_* = \sum_k M_k$ , the  $I$  represents the  $p$  order unit array. The optimal transformation scores of the variables to be found are denoted by  $X$  denoted by  $X$ , and the combination of quantitative scores for a set of categorical variables is denoted by  $Y$  denoted by  $Y$ , and for multiple-choice questions by 0-1 scores.

Minimizing the value of the function is the most transformative purpose[7] The purpose of the transformation

is to minimize the function [7]. The transformation is to quantify the categorical variables of the scores, thus converting the categorical variables into continuous variables and making all correlations between the variables prior correlations. The result of the correlation calculation means that there is no correlation between price and 12 items: appearance, safety, after-sales service, policy subsidies, environmental friendliness, emissions, energy efficiency, quality, policy subsidies, publicity, usage in the neighborhood, and energy consumption.

Acceptance model and the theory of planned behavior as the theoretical basis to explore the relationship between latent variables, health care workers in the acceptance of the new model of green refrigeration, will first perceive the purpose of the project, the value of the corresponding cost-effective, so we categorize it as a perceptual norms, according to the above assumptions, is now the use of multiple correspondence analysis MCA model summary table lists the dimensionality reduction of the dimensionality of each of the eigenroot value (inertia Inertia), explanation rate and cumulative explanation rate. In order to facilitate the graphical presentation and analysis, the default setting of SPSSAU for multiple correspondence analysis is 3 dimensions; if the cumulative explanation rate of the 3 dimensions is greater than 80%, it means that the correspondence analysis is effective. Correlation analysis was used to investigate the correlation between high economic costs and lack of subsidies, difficulty in replacing traditional attitudes, difficulty in implementing retrofitting technologies, long retrofitting time, insufficient supply sources, and climate impacts, totaling 6 items.

We use ease of use, energy efficiency, and cost effectiveness as the criterion layers respectively. The different criteria levels are divided into different evaluation aspects. Through the hierarchical analysis method, the air conditioner with heat recovery system is not significantly different from other air conditioners in terms of comfort, low noise, and fast startup, but it has the advantages of low carbon emission, low pollution inside the air conditioning system from the recovered heat, and low air conditioning refrigerant pollution to the atmosphere, which are enough for people to ignore the shortcomings of the slightly more expensive price, and the hospital, as a public large-scale place, is worthwhile to invest more in the environment in exchange for a lot of benefits. In terms of more in exchange for a lot of benefits to the environment it is also very worthwhile. So after a comprehensive evaluation can be seen in the hospital, if used, with air conditioning heat recovery system of air conditioning and other air conditioning compared to have a greater advantage.

#### 5. Research Findings and Policy Implications

The current residents of the surveyed provinces and cities have a certain cognitive foundation for green refrigeration and air conditioning systems, but the overall cognitive level of exhaust air heat recovery needs to be improved, while the willingness to accept the new green refrigeration model is relatively high, and in general, the development prospects of exhaust air heat recovery air conditioning applications are better[9] Overall, the development prospect of exhaust air heat recovery air conditioning application is better [9]. Based on the above research on the development of exhaust air heat recovery air conditioning application in 12 provinces and

cities, the feasibility of promoting the popularization of the new model of clean heating in 12 provinces and cities and even in the whole country is now proposed from the four levels of the government, enterprises, communities and individual residents.

### 5.1. For the population

In modern life, the application of air conditioning is ubiquitous and involves many areas, such as living rooms, hospitals, schools and other buildings. However, for the air pollution and energy consumption brought about by air conditioning, consumers often know but do not think, many people only know that air conditioning performance is not good, it will be very costly, but the air conditioning operation of the energy consumed and the emissions of exhaust, we are not enough to pay attention to. On the other hand, for running the air conditioning brought about by the air closure, air circulation, but also consumers experience a strong sense of some, many manufacturers of air conditioning, but also often only focus on the appearance of the air conditioning, performance and other sales impact factors[10] The air-conditioning industry has been a major contributor to the development of energy-saving and emission reduction. Energy saving and emission reduction should be the common responsibility and goal of all mankind. Therefore, we suggest in-depth energy saving and emission reduction actions for all citizens, advocating civilized conservation, opposing society-wide extravagance and waste, opposing energy waste, and promoting the establishment of green living and green consumption concepts. Consumers should be encouraged to use green refrigeration and air-conditioning as soon as possible, and the promotion of exhaust air heat recovery air-conditioning should be accelerated from large-scale establishments to residential apartments, so as to effectively avoid large-scale remodeling of buildings in the future in order to conserve energy, which would result in a waste of resources.

### 5.2. Hospitals

Hospital air conditioning energy consumption as the hospital's total energy consumption, accounting for up to 50% -70%, the application of air conditioning exhaust air heat recovery device in a timely manner for the medical and nursing work environment and the patient's living environment to provide fresh air at the same time, and to a greater extent to reduce the air conditioning power consumption. Exhaust air heat recovery utilizes the sensible heat or total heat exchange generated between the incoming air and exhaust air, recycles the waste heat of the air conditioning exhaust air, reduces the energy consumption of fresh air treatment, reduces the host load and auxiliary equipment energy consumption, solves the air conditioning exhaust problem, reduces the operating costs, achieves the purpose of energy saving, and conforms to the requirements of the green and environmentally friendly sustainable development, especially in the hospitals and other air conditioning places with high energy consumption and high hygiene requirements, and is able to generate positive Social and environmental benefits. The majority of hospitals should actively promote the application of exhaust air heat recovery devices air conditioning.

### 5.3. Manufacturing enterprises

Relevant enterprises should guide the green refrigeration

project supporting the selection of target customers, through the scheduling means, coordination of air conditioning to meet the demand for energy saving and emission reduction, to provide air conditioning operating capacity and exhaust utilization efficiency, and to make full use of the difference between the energy of the old air and the new air discharged, to play the role of energy transfer to alleviate the pressure of the refrigeration system. Not only that, the enterprise can be based on the user profile, targeted at the target customers to launch marketing campaigns, increase the popularization of the general population groups, stimulate the enhancement of the user demand for the use of green refrigeration[11] At the same time, for the size of the hospital, the introduction of the green refrigeration pressure. At the same time, for the size of the hospital, the introduction of package equipment services to meet the needs of some of the larger hospitals, and focus on the residents and hospitals and other mass concerns, and strive to improve the level of green refrigeration-related technology, reduce the cost of use, and do a good job of equipment maintenance services.

### 5.4. Government

Energy saving and emission reduction is beneficial to the country and the people, and in order to realize the goal of energy saving and emission reduction, the state has issued relevant policies in many fields. However, refrigeration and air conditioning as one of the most important aspects of green refrigeration and energy saving. Therefore, based on the survey results, it is recommended that the state increase its support for green refrigeration and green air conditioning industries, use policies to promote market-oriented operations, and provide financial support for the required green building materials. Through the energy-saving glass industry, the public's acquisition cost should be reduced, and strict quality standards should be formulated to further improve the industry norms and inspections at source to guide society to emphasize building energy efficiency. Specifically, it can be expressed as the role of government procurement, prioritizing the provision of energy-efficient glass products for government agencies and public buildings, and providing market opportunities for the promotion of new products. The development of energy saving and emission reduction not only needs to play a decisive role in the allocation of market resources, but also requires government departments to give full play to the guiding and complementary role of the market, and further improve and implement supporting policies[12] .

### Acknowledgment

This work is supported by 2022 National Undergraduate Innovation and Entrepreneurship Training Program, Project number: 202210378169.

### References

- [1] WANG Xinhua, LIU Zehua, JIN Lei, LI Penghui, YANG Xiaomin. Analysis of energy saving potential of air conditioning exhaust air heat recovery for application in China. *Energy Conservation*, 2011, 30(9): 17-20.
- [2] ZHANG Chong, WANG Jinbai, TANG Benwang, CHENG Min. Analysis of energy saving effect of exhaust air full heat recovery air conditioning system in different climate zones. *Refrigeration and Air Conditioning*, 2016, 16(6): 59-62.
- [3] National Development and Reform Commission, Ministry of Industry and Information Technology, Ministry of Finance, et

- al. Circular on the Issuance of the Action Program for Green and Efficient Refrigeration (NDRC EIA [2019] No. 1054) [EB/OL]. [2019-06-13]
- [4] Dong Changjin. Application analysis of heat recovery for hospital air conditioning exhaust air[J]. Clean and air conditioning technology, 2017(4):96-99.
- [5] YANG Zhenxiao. Study on the applicability of exhaust air heat recovery technology in hospital air conditioning system[J]. Refrigeration and air conditioning[J]. Refrigeration and Air Conditioning(Sichuan),2021,35(3):427-431
- [6] Liu Yunxiang. Discussion on the application of exhaust air heat recovery system[J]. HVAC,2012,42(7):72-77.
- [7] ZHANG Zhaohui, WANG Ruonan, LIU Huicheng, GAO Yu, LIU Lulu, CHEN Jingliang. Analysis and Prospect of the Development of Green and Efficient Refrigeration and Air Conditioning Industry. Refrigeration and Air Conditioning, 2020, 20(1):1-6.
- [8] Zheng Yuanfei. Air-to-air heat exchanger for ventilation and air conditioning of Panasonic Japan. HVAC
- [9] Earl B. Muir. The direction of refrigerant replacement in the United States [J]. Household Appliance Technology, 2001 (2): 14-16.
- [10] Zhang Jubo. Exhaust air heat recovery equipment of Swedish Fidelity Company[J]. Building Technology Newsletter (HVAC), 1982(02): 35-39.
- [11] LIU Huzhou, WU Xiping, ZHANG Chen, SHEN Kai, LI Yong, NING Zhilin. Discussion on the energy saving effect of heat recovery of exhaust air of air-conditioning system in Shanghai[J]. Fluid Machinery, 2009, 37(4): 69-71+63.
- [12] HE Peng, XUAN Yongmei. Application of air conditioning exhaust air heat recovery combined with evaporative cooling[J]. Clean and air conditioning technology, 2014(1): 61-64.