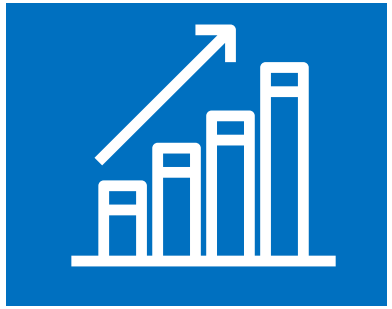
The Research of Energy Saving and Optimization of Steam Sterilizer



Reporter： Yunyu Jin
Hospital： The First Hospital Of Jilin University
Country： China

第一部分

SECTION ONE

Introduction

吉林大学第一医院
THE FIRST HOSPITAL OF JILIN UNIVERSITY

Founded in 1949, the largest hospital in Northeast of China.

4745 beds
top three in China

Every year

Outpatients 4.74 million

Operation volume 175,000

Operating rooms 81

SCI papers 300

Central Sterile Supply Department

Cleaning, disinfection and sterilization of all reusable medical instruments

Providing reprocessing services for three other hospitals

Floor area 4544.99m²

Automatic Logistic System
Kardex Remstar ASRS

Staffing

58 Employees: 21 nurses, 37 technicians

the first certified CSSD in China (CHC-Q0CSSD0001-2019)

第二部分

SECTION TWO

Background and Design

Steam Sterilizer Widely Used

- Steam sterilization is widely used in health care facilities due to high latent heat and good heat conductivity of saturated steam, easy operation, reliable efficacy, non-toxicity and relatively low cost.
- Steam sterilization is a common method of sterilizing reusable medical instruments.
- Steam sterilizer is an indispensable equipment in health care facilities.

Energy Consumption of Steam Sterilizer

Three modes of steam sterilizer： **operating** **standby** **power off**

standard sterilization cycles and auxiliary cycles

the sterilizer is not being operated while it is on

Standby Standby Standby Standby

erating energy consumpti ..... Power off

Standby Time

Steam Sterilizer Energy Consumption：

operating： water, power and steam

Standby： power and steam

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Energy Consumption of Steam Sterilizer

- The operation of steam sterilizer is an energy-intensive process, and it still consumes a lot of energy and resources in standby mode.
- The study on standby time and energy consumption of steam sterilizer has not been published in China.
- There is a lack of standardization management in China. Most health care facilities start early and shut down late according to the habits of operators.

Research Design

01 Investigate

- Investigating the current situation of sterilizer practices in China

02 Analyse

- Analysis of Influencing Factors of Energy consumption in Sterilizers

03 Formulate

- Taking our hospital as an example, making the energy-saving optimization measures for sterilizer

04 Implement

- Implementing optimization measures and improving them

05 Test

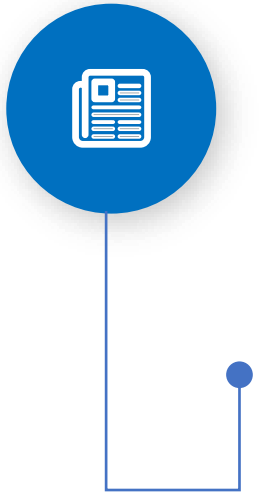
- Testing the results of energy-saving optimization measures for sterilizers

06 Summarize

- Summarizing the results of this study and offer a prospective on future research directions

第三部分

SECTION THREE



Survey of current status

Pre-investigation

- To ensure the quality of formal investigation
- Pre-investigation on the operation of 23

The results showed that all the 10 hospitals had different levels of energy consumption issues

to the results of the pre-investigation

Formal investigation -Current Situation of Energy Consumption of Sterilizers

- Investigation on Energy Consumption of Sterilizers in 395 Hospitals
- Investigation time: August-September 2017
- Method: Electronic Questionnaire
- The effective rate was 97.29% (406 questionnaires were collected and 395 questionnaires were valid)
- Statistical Analysis: Normal distribution measurements were expressed by “Mean±SD”, while non-normal distribution measurements were expressed by Median (IQR). One-way ANOVA, Mann-Whitney U test and Kruskal-Wallis H test were used to conduct univariate analysis. Multivariate regression analysis was used for multivariate linear regression analysis. The difference was statistically significant with $P < 0.05$.

Formal investigation -Current Situation of Energy Consumption of Sterilizers

表 1　395 家医院一般资料分布构成比(%)

Table 1　Distribution and constituent ratio of general information of 395 hospitals (%)

项　目		医院数量	构成比
医院级别	三级	191	48.35
	二级	204	51.65
压力蒸汽灭菌器数量(台)	1	167	42.28
	2	157	39.75
	否	124	31.39
是否所有压力蒸汽灭菌器同时关机	是	260	65.82
	否	135	34.18
夜间压力蒸汽灭菌器是否工作	是	80	20.25
	否	315	79.75
一天内是否有灭菌器关机后再次开机使用的情况	有	264	66.84
	无	131	33.16
一天内灭菌器关机后再次开机是否重新做 BD 试验	是	20	5.06
	否	244	61.77

Conclusion: Standby time is long, energy waste is obvious and managers do not pay attention to it.

General information

- The standby time of each steam sterilizer in 395 hospitals is **7.76** (4.85-9.34) hours per day. Among them, the tertiary hospital was 8.93 (6.75-11.25) h and the secondary hospital was 6.71 (3.34-8.48) H. There were 187 hospitals with [illegible] grade, the number of steam sterilizers, whether they were on or off at the same time, and whether the sterilizers were working at night.
- More than 70% of the steam sterilizers turn on and off at the same time

Analysis of current situation and influencing factors of standby time of steam sterilizer

Table Regression coefficient and test results

因素	偏回归系数 β	标准误差	标准化回归系数	*t*	*P*
常数项	0.666	0.049	-	13.525	
灭菌器所属医院的级别	0.132	0.041	0.234	3.21	**0.002**
所属医院拥有的压力蒸汽灭菌器数量	0.071	0.018	0.318	3.93	
所有压力蒸汽灭菌器是否同时开机	-0.117	0.043	-0.182	-2.713	**0.007**
夜间压力蒸汽灭菌器是否工作	0.155	0.063	0.187	2.46	**0.015**

注：R^2=0.341，F=19.144,P<0.001

Influencing factors of standby time:

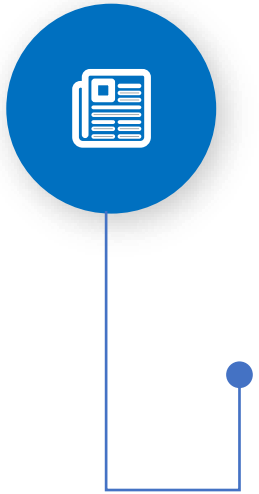
1. **Grade of hospitals**
2. **Quantity of steam sterilizers in hospitals**
3. **Whether the sterilizers are turned on at the same time and Whether the sterilizers were operated at night**

Main Reasons for Excessive Standby Time

- China has just begun domestic research on energy consumption of steam sterilizer. Research on sterilizer mainly focuses on sterilization efficacy and biological and chemical monitoring. **Attention is hardly paid to whether there is a long standby time and whether the standby state will consume energy.**
- There are usually more than one steam sterilizer in a hospital. Sterilization time can be divided into peak period and off-peak period. At off-peak period, only a few sterilizers are operated. At present, **the use of steam sterilizers is not adjusted according to the quantity of sterilized items in each period.**
- Personal Work Habits Factor: Turn on all sterilizers at the start of daily work, and do B-D test at the same time
- Chinese standard said that, the prevacuum steam sterilizer should be tested by B-D test in no-load every day before sterilization. But there is no clear stipulation on whether it is necessary to do B-D test again after power-off on the same day. Since the sterilization quantity cannot be determined, the sterilizer is always in a standby mode for a long time.

第四部分

SECTION FOUR



Implementation of Energy Saving Plan

Energy saving research in our hospital

Calculation Table of Sterilizer Energy Consumption

Sterilizer status	Method of calculation
operating mode	Power consumption（kW•h）$=P_1 \times t_1 \times 2/3 + P_2 \times t_1$
	Water consumption= 1.7T(full)×runs OR =1.5T（empty）×runs
Standby mode	Steam consumption(kg)=16.56kg/h×t_2

The cost of power and steam consumption is 5 RMB/h in standby mode

Description: P1 is the power rating of sterilizer vacuum pump, P2 is the power rating of control system, t_1 is the operating time, 2/3 indicates that the working time of vacuum pump is pulsating and drying stage, accounting for 2/3 of the operating time. The above calculation method takes the steam sterilizer with capacity of 1500 liters as an example, and the different capacity is converted proportionally.

Energy saving research in our hospital

- Statistics on the switching time of the sterilizer
- Summarize the peak period and off-peak period: aggregate in working days and non-working days respectively

2017年1月~6月非工作日各时段灭菌器标准程序运行情况

时间	总天数	仅1台运行的天数		仅2台运行的天数		仅3台运行的天数		大于3台运行的天数	
		n	%	n	%	n	%	n	%
6:00-7:00	59	0	0	0	0	0	0	0	0
15:00-16:00	59	7	11.9	0	0	0	0	0	0
16:00-17:00	59	25	42.4	3	5.1	0	0	0	0
17:00-18:00	59	17	28.8	1	1.7	1	1.7	0	0
18:00-19:00	59	11	18.6	0	0	0	0	0	0
19:00-20:00	59	8	13.6	0	0	0	0	0	0
20:00-21:00	59	5	8.5	0	0	1	1.7	0	0
21:00-22:00	59	4	6.8	0	0	0	0	0	0
22:00-23:00	59	1	1.7	0	0	0	0	0	0
23:00-00:00	59	0	0	0	0	0	0	0	0
次日0:00-1:00	59	2	3.4	1	1.7	0	0	0	0
次日1:00-2:00	59	1	1.7	0	0	0	0	0	0

2017年1月~6月工作日各时段灭菌器标准程序运行情况

时间	总天数	仅1台运行的天数		仅2台运行的天数		仅3台运行的天数		大于3台运行的天数	
		n	%	n	%	n	%	n	%
6:00-7:00	122	3	2.5	0	0	0	0	0	0
16:00-17:00	122	38	31.1	54	44.3	20	16.4	3	2.5
17:00-18:00	122	56	45.9	8	6.6	0	0	0	0
18:00-19:00	122	59	48.4	11	9.0	0	0	0	0
19:00-20:00	122	42	34.4	17	13.9	3	2.5	0	0
20:00-21:00	122	42	34.4	18	14.8	3	2.5	2	1.6
21:00-22:00	122	39	32.0	18	14.8	8	6.6	0	0
22:00-23:00	122	30	24.6	17	13.9	7	5.7	2	1.6
23:00-00:00	122	26	21.3	11	9.0	7	5.7	3	2.5
次日0:00-1:00	122	18	14.8	12	9.8	8	6.6	0	0
次日1:00-2:00	122	12	9.8	7	5.7	3	2.5	1	0.8
次日2:00-3:00	122	5	4.1	6	4.9	0	0	0	0
次日3:00-4:00	122	1	0.8	0	0	1	0.8	0	0
次日4:00-5:00	122	1	0.8	0	0	0	0	0	0

CONCLUSION: Simultaneously turning on and off of the sterilizer results in long standby time of the sterilizer

Relationship between Energy Consumption and Weight of Sterilized Items in Operating Mode

Analysis of the correlation between energy consumption per kilogram of sterilized items and the weight of sterilized items（n=470，r）

Items	Power consumption per Kg of items	Steam consumption per Kg of items	Water consumption per Kg of items
Weight	-0.596**	-0.596**	-0.613**

Note: **. There was a significant correlation in P < 0.01.

- **The correlation between the power consumption, water consumption and steam consumption per kilogram of sterilized items and their weight was analyzed. The results showed that the power consumption, water consumption and steam consumption per kilogram of sterilized items were negatively correlated with their weight (P<0.001). That means, the heavier the weight of sterilized items, the higher the utilization rate of water, power and steam.**

Regression Analysis of Power Consumption and Weight of Sterilized items

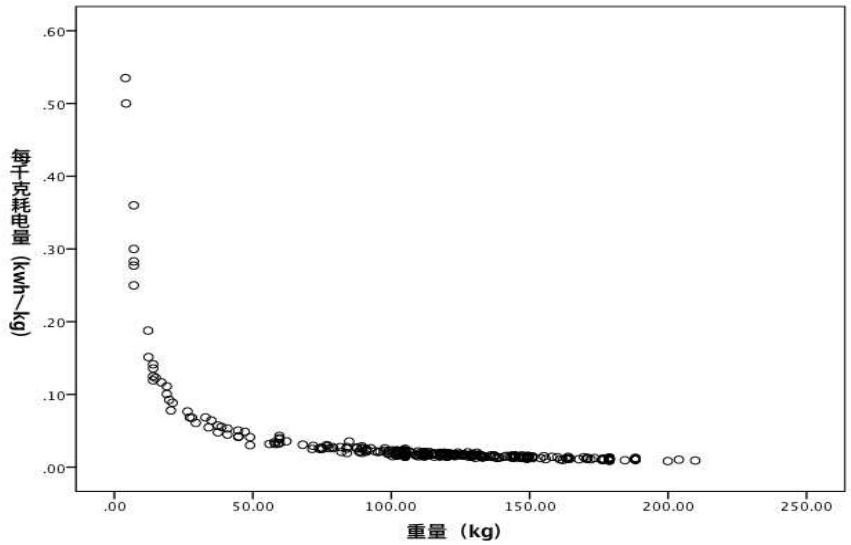


Fig Dispersion plot of power consumption per Kg of sterilized items and weight of sterilized items（n=470）

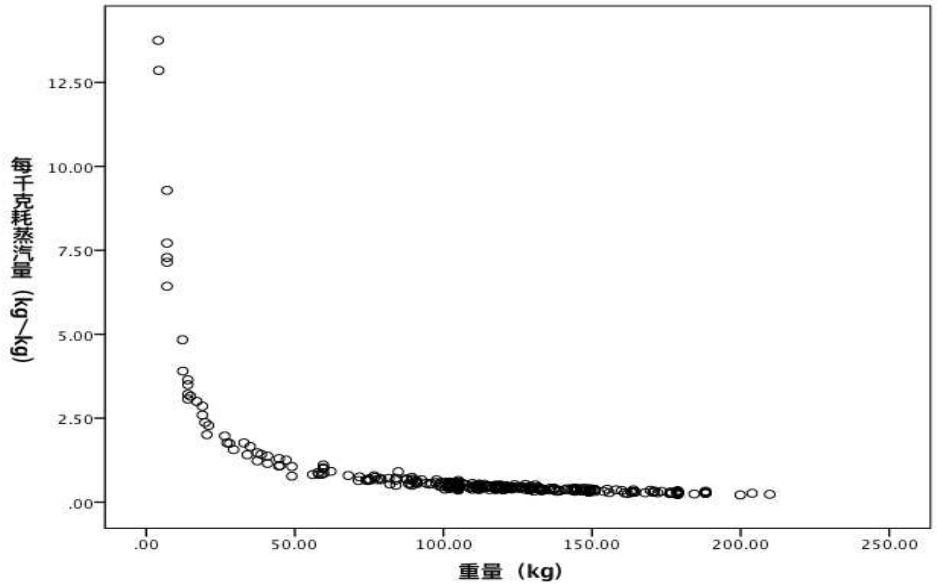
Table Curve regression analysis of power consumption per Kg of for sterilized of items and items weight (Reciprocal Model)）（n=470）

因素	偏回归系数β	标准误差	标准化回归系数	*t*	*p*
1/重量	53.997	0.316	0.994	167.632	<0.001
常数项	0.010	0.010	-	-1.063	0.288

Notes：R^2=0.988，*F*=28255.638,*P*<0.001。

- **The regression equation of power consumption and weight per kilogram of sterilized items：E=0.001+2.060/m(R^2=0.988, *P*<0.001)**
- **The heavier sterilized items, the lower power consumption per kilogram of sterilized items, and the higher utilization rate of power.**

Regression Analysis of Steam Consumption and Weight of Sterilized items



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1/重量	53.997	0.316	0.994	167.632	<0.001
常数项	0.010	0.010	-	-1.063	0.288

注：R^2=0.988，F=28100.324,P<0.001。

- **The regression equation of steam consumption and weight per kilogram of sterilized items: $S=0.010+53.997/m(R^2=0.988, P<0.001)$**
- **The heavier sterilized items, the lower steam consumption per kilogram of sterilized items, and the higher utilization rate of steam.**

Energy-saving optimization strategy-stepwise switching sterilizer

	Mode	Period	Qty
Work day	On	6:00-7:00	6
	Off	0:00-2:00	6

	Mode	period	Qty
Non-work day	On	7:00-8:00	6
	Off	22:00-23:00	6

Before the implementation of energy-saving optimization strategy

	Mode	Period	Qty
Work day	On	6:30	3
		8:30	3
	Off	15:00	3
		17:00	1
		All done	2

	Mode	Period	Qty
Non-work day	On	7:00	1
		8:30	2
	Off	15:00	1
		17:00	1
		All done	1

After the implementation of energy-saving optimization strategy

Energy-saving Optimization Strategy-Rational Distribution of Loading Weight

Instant sterilization without considering weight factor

- 2/3 textile items are loaded immediately after they are delivered to sterilization area every day
- The rest 1/3 will be loaded and sterilized in the off-peak period in order to fill the vacancy.

Optimized results - stepwise switching of sterilizers

Table Comparison of Standby Time of All Sterilizers before and after Stepped Switching of Sterilizer in off-Peak Period on Workdays $(\overline{x} \pm s)$

时间	所有灭菌器的待机时间	统计量	
	管理前（n=6）管理后（n=6）	*t*	*P*
6:00-7:00		150.669	< 0.001
7:00-8:00		16.382	< 0.001
15:00-16:00		19.861	< 0.001
16:00-17:00		24.371	< 0.001
17:00-18:00		50.942	< 0.001
18:00-19:00		48.983	< 0.001
19:00-20:00		40.158	< 0.001
20:00-21:00		33.326	< 0.001
21:00-22:00		35.851	< 0.001
22:00-23:00		30.744	< 0.001
23:00-0:00		29.478	< 0.001

Table Comparison of Standby Time of All Sterilizers before and after Stepped Switching of Sterilizer in off-Peak Period on non-Workdays $(\overline{x} \pm s)$

时间	所有灭菌器的待机时间		统计量	
	管理前（n=3）	管理后（n=3）	*t*	*P*
7:00-8:00	2.95±0.22	0.95±0.22	49.026	< 0.001
8:00-9:00	2.75±0.63	0.81±0.39	19.939	< 0.001
13:00-14:00	2.75±0.54	1.75±0.54	9.978	< 0.001
14:00-15:00	2.75±0.57	1.76±0.50	9.882	< 0.001
15:00-16:00	2.88±0.33	1.88±0.33	16.653	< 0.001
16:00-17:00	2.58±0.49	1.58±0.49	10.898	< 0.001
17:00-18:00	2.63±0.61	0.68±0.47	19.362	< 0.001
18:00-19:00	2.81±0.39	0.81±0.39	27.654	< 0.001
19:00-20:00	2.86±0.34	0.86±0.34	31.495	< 0.001
20:00-21:00	2.86±0.47	0.90±0.31	26.882	< 0.001
21:00-22:00	2.93±0.25	0.93±0.25	42.842	< 0.001

- **The daily standby time of all sterilizers used on workdays decreases significantly in off-peak period after stepwise switching of sterilizers.**
- **The daily standby time of all sterilizers used on non-workdays decreases significantly in off-peak period after stepwise switching of sterilizers.**

Optimized results - Rational Distribution of Loading Weight

Table Comparison of Sterilizer Load before and after Rational Distribution of Loading Weight in off-Peak Period on Workdays[M (P25，P75)]

时间	装载重量（kg）		统计量	
	管理前（n=6）	管理后（n=6）	*Z*	*P*
6:00-7:00	3.90（3.80，4.00）	3.90（3.80，4.00）	-0.520	0.958
7:00-8:00	105.00(102.00，112.00)	102.00(92.70，105.00)	-4.405	0.686
15:00-16:00	105.00(59.60，132.80)	119.80(115.12，132.80)	-5.316	< 0.001
16:00-17:00	102.00(102.00，126.00)	123.10(116.60，127.80)	-5.154	< 0.001
17:00-18:00	105.80(105.80，126.00)	121.00(112.00，126.00)	-2.431	0.015
18:00-19:00	105.00(75.13，132.00)	124.25(117.00，132.00)	-2.632	0.008
19:00-20:00	102.00(35.00，119.00)	119.00(114.00，123.40)	-3.358	0.001
20:00-21:00	100.00(70.00，112.40)	122.42(111.75，124.50)	-3.999	< 0.001
21:00-22:00	105.00(84.00，125.40)	120.00(120.00，127.00)	-2.786	0.005
22:00-23:00	105.00(42.00，119.00)	119.00(109.87，122.00)	-3.308	0.001
23:00-0:00	102.00(82.25，125.30)	127.98(112.00，130.30)	-1.571	0.016

- **After rational distribution of loading weight on workdays, the loading weight increases significantly in each off-peak period (P < 0.05), except 6:00-7:00 and 7:00-8:00.**

Optimized results - Rational Distribution of Loading Weight

Table Comparison of Sterilizer Load before and after Rational Distribution of Loading Weight in off-Peak Period on non-Workdays[M (P25，P75)]

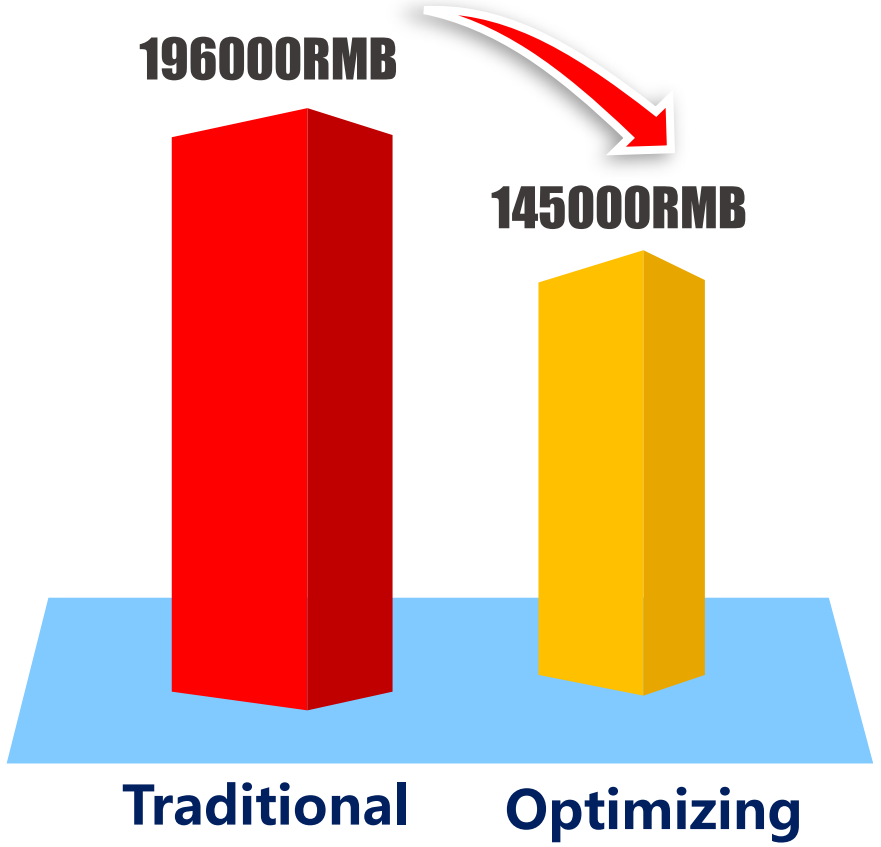
时间	装载重量（kg）		统计量	
	管理前（n=3）	管理后（n=3）	*Z*	*P*
7:00-8:00	3.90(3.80，4.00)	3.90(3.80，4.00)	-0.009	0.993
8:00-9:00	102.00(94.90，126.45)	113.90(103.50，133.70)	-1.549	0.121
13:00-14:00	127.30(93.12，178.80)	131.30(118.97，178.80)	-0.766	0.444
14:00-15:00	70.00(28.00，112.00)	118.00(112.00，129.40)	-2.500	0.012
15:00-16:00	7.50(7.00，17.50)	117.00(112.50，117.75)	-2.337	0.019
16:00-17:00	84.00(14.00，166.80)	124.00(117.00，176.80)	-1.793	0.013
17:00-18:00	63.00(21.00，104.65)	117.00(111.00，132.00)	-3.367	0.001
18:00-19:00	14.00(7.00，21.00)	124.00(117.00，127.00)	-2.313	0.021
19:00-20:00	14.00(7.00，92.45)	117.00(114.00，143.95)	-1.687	0.022
20:00-21:00	14.00(7.00，42.00)	117.00(117.00，124.00)	-3.097	0.002
21:00-22:00	17.50(8.75，26.25)	117.50(112.50，122.50)	-2.309	0.021

- **After rational distribution of loading weight on non-workdays, the loading weight increases significantly in each off-peak period ($P < 0.05$), except 7:00-8:00, 8:00-9:00 and 13:00-14:00.**

Optimizing results – energy and cost savings

Table energy Consumption and Cost Comparison of Sterilizers before and after Optimization Research

items	Before	After
Run Qty	5154	4620
Run time（h）	4221	3820
operating state steam consumption（kg）	253260	229200
operating state power consumption（KW·h）	13674	10030
operating state water consumption（t）	8762	6963
operating state total cost（RMB）	135052	113543
Standby time（h）	11871	6053
Standby state steam consumption（kg）	196584	100238
Standby state power consumption（KW·h）	5936	3027
Standby state total cost（RMB）	60977	30966



- The standby time has been reduced by 5818h, and the steam and power consumption has been reduced by 96346 kg and 2909 kW·h, respectively.
- The operating time has been reduced by 401h, and the steam, power and water consumption has been reduced by 24060kg, 3644kW·h and 1799t, respectively.
- The cost savings has been more than 50,000 RMB.

Prospective on future research directions

- Involving labor cost in future research
- Remote controlling steam sterilizer depends on Intelligent Cloud Technology
- Exploring impact of sterilized article materials on energy consumption in future research

Thank you for listening