An energy efficiency evaluation method based on least squares combination weight in refrigeration system

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A new energy efficiency evaluation method, based on least squares combination weight (LSCW), is proposed in this paper. Furthermore, the method is based on the thorough analysis of Fuzzy Analytic Hierarchy Process (FAHP) and Information Entropy (IE). Because of the multi-parameter characteristic of the ammonia refrigeration system, some critical parameters are firstly selected with the help of detailed simulation. Subsequently, a new two-dimension matrix constructed by these parameters is designed. According to the actual working system, compared with the FAHP and IE, results show that the new method has better precision, smaller relative error and greater consistence with actual energy efficiency change.

Keywords: Energy efficiency evaluation, Two-dimension matrix, Combination weight, Relative error
Target audience: Design Process, Energy Management, Industrial Application

1 Introduction

Ammonia refrigeration system (ARS) is widely used in a large field of application like chemical, food industries and much more. Besides the better refrigeration effect, it is also natural environment friendly, for example, the Ozone Depression Potential (ODP) and Global Warming Potential (GWP) are zero /1/. Now, the mainly problem of ARS is the lower energy efficiency which is caused by the worse management of complexed multi-parameter system.

Nowadays, many experts are carrying out the research in two aspects. On one hand, here is the optimization of ARS's components by pro-simulation /2/, /3/. On the other hand, the developments of fault diagnosis method and energy consumption forecasting algorithm are performed /4/, /5/. However, there is still no effective method which was widely accepted.

In this paper a new two-dimension matrix based on the critical parameters, providing the basic energy efficiency evaluation model, is designed. Through comparing the influence degree to the ARS's Coefficient of Performance (COP) with the help of AMESim and MATLAB/Simulink, some critical parameters are selected. Combined with the advantages of two common evaluation methods, Fuzzy Analytic Hierarchy Process (FAHP) and Information Entropy (IE), a new evaluation method based on the least squares combination weight (LSCW), is proposed. Finally, the new method is validated and compared with FAHP and IE in actual ARS.

2 Two-dimension Matrix

2.1 Modelling of Ammonia Refrigeration System

Ammonia refrigeration system (ARS) generally consists of compressor, condenser, expansion valve/throttle, evaporator and accumulator. With the help of software AMESim, the basic model is firstly constructed, which is shown in Figure 1.

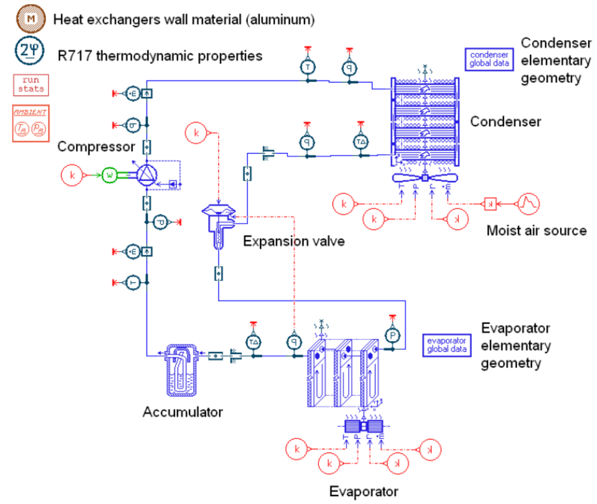

Figure 1: Simulation-model of ammonia refrigeration system

Refrigerant [ammonia, R717 is refrigerant grade high purity ammonia (NH_3). The product typically is 99.98% pure with minimal levels of moisture (<200 ppm) and other impurities (<5 ppm oil), making it ideal for use in all types of refrigeration systems] flows through the compressor firstly, which raises the pressure of ammonia. Subsequently, ammonia flows through the condenser, where it condenses from vapour form to liquid form, giving off heat in the process. After the condenser, it goes through the expansion valve, where it experiences a pressure drop. Finally, the ammonia goes to the evaporator. It draws heat from the evaporator which causes ammonia to vaporize. The evaporator draws heat from the region that is to be cooled. The vaporized ammonia goes back to the compressor to restart the cycle.

2.2 Selection of Critical Parameters

ARS is a multi-parameter system, including more than 30 parameters. Generally, the system's energy efficiency will be changed following with the change of each parameter. It is certainly that different parameter have different influence degree. The evaluation matrix will be so big that the calculation process is much slowly, if each parameter is considered /6/. So some critical parameters are usually selected. The select standard is the influence degree to the Coefficient of Performance (COP) of the system.

In refrigeration system, COP is a basic standard of the energy efficiency, as shown in Equation (1).

$$COP = \frac{Q_{eva,w}}{W_{com}+W_{others}} = \frac{C_{eva,w} m \Delta t}{W_{com}+W_{others}} \tag{1}$$

where $Q_{eva,w}$ is the exchanged energy in evaporator, $C_{eva,w}$ is the Specific Heat Capacity of refrigerant, m is the mass flow, W_{com}, W_{others} are the energy consumption of compressor and other components.

The influence degree is the ratio of the change of COP to the size of COP's range. It reflects the influence of the parameter to the system's energy efficiency. Each parameter has its own working range. It means that the energy efficiency evaluation of the system is based on the healthy working state, without fault. According to the actual statistic and monitor of the testing ammonia refrigeration system, the detailed parameters' working ranges of the system are shown in Table 1.

Component	Parameter	Working range	Component	Parameter	Working range
Compressor	$p_{suc}(MPa)$	0,10~0,30	Throttle /Expansion Valve	$T_{ta,in}(°C)$	20~35
	$p_{dis}(MPa)$	1,10~1,50		$T_{ta,out}(°C)$	-10~-5
	$T_{suc}(°C)$	3,0~6,0		$p_{t,in}(MPa)$	0,8~1,4
	$T_{dis}(°C)$	60~90		$p_{t,out}(MPa)$	0,17~0,35
	$K_c(\%)$	10~100		$K_t(\%)$	10~100
	T_{oil} (°C)	25~65	Evaporator	$T_{ea,in}(°C)$	0~3
	$p_{oil}(MPa)$	0,15~0,30		$T_{ea,out}(°C)$	4~7
Condenser	$T_{ca,in}(°C)$	55~85		$T_{ew,in}(°C)$	7~10
	$T_{ca,out}(°C)$	20~38		$T_{ew,out}(°C)$	2~5
	$T_{atm}(°C)$	-5~38		$T_{eva}(°C)$	-15~5
	$T_{cw,in}(°C)$	5~22		$\theta_{sh}(°C)$	2~15
	$T_{cw,out}(°C)$	9~26		$m_w(m^3/min)$	3,39~4,71
	$T_{con}(°C)$	20~40		$m_a(m^3/min)$	5,30~7,66

Table 1: Parameters and their working ranges

With the help of AMESim and MATLAB, 15 critical parameters are selected by detailed simulation and comparison, as shown in Figure 2.

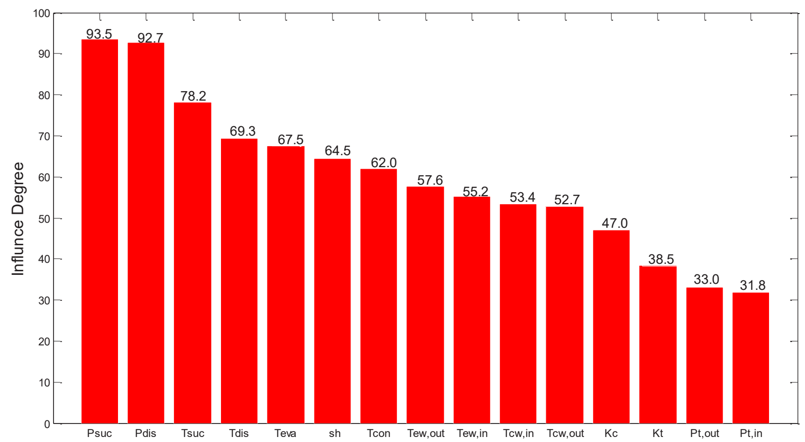

Figure 2: Critical parameters and their influence degree for COP

2.3 Design of Two-dimension Matrix

According to the selected parameters and simulation-model, a new two-dimension matrix is designed. It is composed of m evaluation states and n critical parameters, as shown in equation (2).

$$U = (u_{ij})_{mn} = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{m1} & u_{m2} & \cdots & u_{mn} \end{bmatrix}_{mn} \quad (2)$$

With the help of standardized method, a new matrix R can be obtained.

$$R = (r_{ij})_{mn} \quad (3)$$

Assumed that the evaluation weight is set to be w, W is set as the value of each energy efficiency evaluation.

$$w = [w_1, w_2, \cdots, w_m] \quad (4)$$

$$W = [W_{s1}, W_{s2}, \cdots, W_{sm}] = R \cdot w^T \quad (5)$$

where W_{sm} is the evaluation of working status m^{th} .

3 Energy efficiency evaluation method of Least Squares Combination Weight

3.1 FAHP and IE

Nowadays, there are two methods, Fuzzy analytic hierarchy process (FAHP) and Information Entropy (IE), by which widely used in some state-evaluation systems /7/ /8/ /9/.

Fuzzy Analytic Hierarchy Process (FAHP) is developed from Analytic Hierarchy Process (AHP) which was introduced by Thomas L. Saaty in year 1971 to meet the needs of resource allocation for the military planning /10/. FAHP is used determining the weights of the criteria by decision makers and ranking the methods by AHP subsequently. The main steps of the FAHP are shown in Figure 3. As we know from the working process, the experiences and recommended value of experts are strongly affecting the final results. Therefore, it cannot match the precise evaluation requirement of the ARS's energy efficiency.

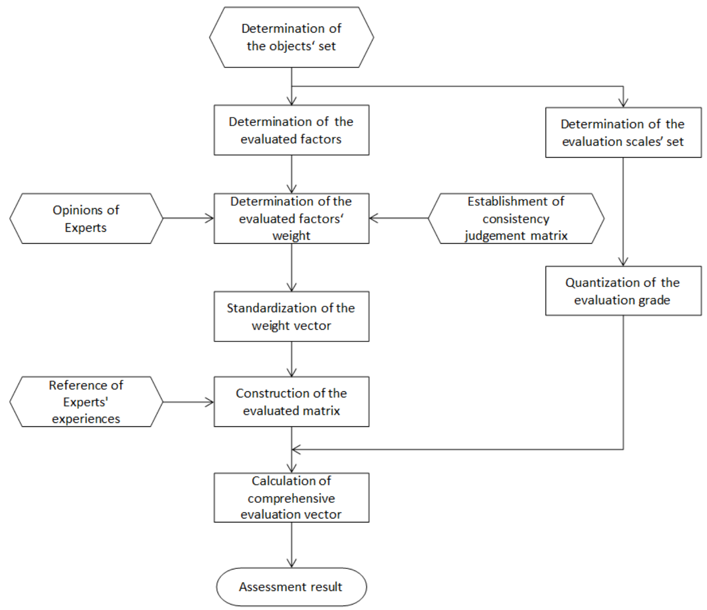

Figure 3: The working steps of FAHP/11/

Entropy is a concept of thermodynamics, statistical mechanics and information theory. Information Entropy (IE) is occasionally called Shannon's entropy in honour of Claude E. Shannon. It was introduced by Shannon in 1948 /12/. It tells how much information there is in an event. In general, the more uncertain or random the event is, the more information it will contain. More clearly stated information is a decrease in uncertainty or entropy. The working steps of IE are shown in Figure 4. To some extend IE can reduce the calculation-time of the evaluation; additionally, the critical parameters will be optimized furtherly. But meanwhile, the accuracy is also decreased.

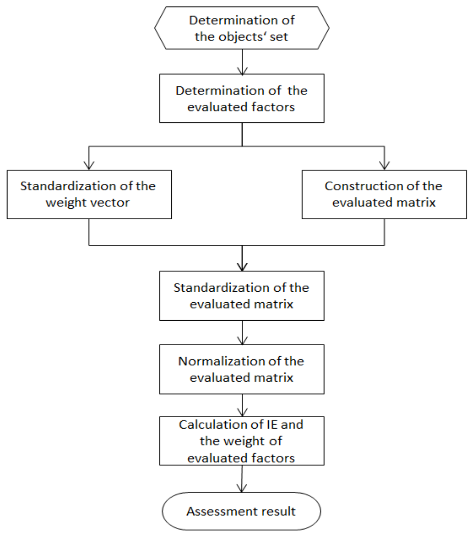

Figure 4: The working steps of IE

3.2 Mathematical model of LSCW

In this paper, a new energy evaluation method, Least Squares Combination Weight (LSCW), is proposed. Least Squares (LS) is a standard approach in regression analysis to the approximate solution of overdetermined system, i.e., sets of equations in which there are more equations than unknowns. LS means that the overall solution minimizes the sum of the residuals made in the results of every single equation. The most important application is in date fitting /13/. The best fit in the least-squares sense minimizes the sum of squared residuals /14/. Combined with the advantages of FAHP and IE, the combination weight consists of the weights from FAHP and IE respectively.

The expression of evaluation weight w and evaluation value are as described in equations (3), (4) and (5).

The weight by FAHP is defined as subjective weight:

$$w_{FAHP} = [w_{F1}, w_{F2}, \cdots, w_{Fm}]^T \tag{6}$$

The weight by IE is defined as objective weight:

$$w_{IE} = [w_{I1}, w_{I2}, \cdots, w_{Im}]^T \tag{7}$$

Based on LS, the optimized combination evaluation model is set to be $D(w)$, x, y are set to be the coefficient of w_a and w_b.

$$minD(w) = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[r_{ij}\left(xw_{Fj} - w_j\right)\right]^2 + \left[r_{ij}\left(yw_{Ij} - w_j\right)\right]^2\right\} \tag{8}$$

where

$$\sum_{j=1}^{m} w_j = 1 \quad w_j \geq 0, (j = 1,2,\cdots,m) \tag{9}$$

Construct the Lagrange Function,

$$F = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[r_{ij}\left(xw_{Fj} - w_j\right)\right]^2 + \left[r_{ij}\left(yw_{Ij} - w_j\right)\right]^2\right\} + 4\lambda\left(\sum_{j=1}^{m} w_j - 1\right) \tag{10}$$

Seeking partial derivative,

$$\frac{\partial F}{\partial w_j} = -\sum_{i=1}^{n} 2{r_{ij}}^2\left(xw_{Fj} + yw_{Ij} - 2w_j\right) + 4\lambda = 0 \tag{11}$$

$$\frac{\partial F}{\partial \lambda} = 4\left(\sum_{j=1}^{m} w_j - 1\right) = 0 \tag{12}$$

Then the application matrix is defined as:

$$\begin{bmatrix} A & e \\ e^T & 0 \end{bmatrix}\begin{bmatrix} W \\ \lambda \end{bmatrix} = \begin{bmatrix} B \\ 1 \end{bmatrix} \tag{13}$$

where A is diagonal matrix; e, w and B are vectors.

$$A = diag\left[\sum_{i=1}^{n} r_{i1}^2, \sum_{i=1}^{n} r_{i2}^2, \cdots, \sum_{i=1}^{n} r_{im}^2\right] \tag{14}$$

$$e = [1,1,\cdots,1]^T \tag{15}$$

$$B = \left[\sum_{i=1}^{n}\frac{1}{2}(xw_{F1} + yw_{I1}) \times r_{i1}^2, \sum_{i=1}^{n}\frac{1}{2}(xw_{F2} + yw_{I2}) \times r_{i2}^2, \cdots, \sum_{i=1}^{n}\frac{1}{2}(xw_{Fm} + yw_{Im}) \times r_{im}^2\right]^T \tag{16}$$

Solving the equation (13), the combination weight can be obtained.

$$w = A^{-1} \cdot \left[B + \frac{1 - e^T A^{-1} B}{e^T A^{-1} e} \cdot e\right] \tag{17}$$

4 Comparison of different evaluation methods

The comparison of evaluation effect among different methods is based on an actual ammonia refrigeration system, which belongs to a resin factory in Sichuan Province in China. All of the parameters come from the online monitoring system. According to the selected fifteen parameters, eight online working states are selected. The values of the parameters are shown in Table 2.

Parameters	Evaluated working states							
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
$p_{suc}(MPa)$	0.24	0.28	0.20	0.20	0.22	0.20	0.26	0.28
$p_{dis}(MPa)$	1.25	1.20	1.28	1.27	1.26	1.26	1.22	1.20
T_{suc}(℃)	4.7	4.4	6.0	5.8	5.5	6.0	5.0	4.0
T_{dis}(℃)	70.2	66.2	85.6	80.0	78.5	82.6	70.0	65.0
K_c(%)	50	47	67	70	60	65	60	60
$T_{ca,in}$(℃)	24	24	24	24	23	23	23	22
$T_{ca,out}$(℃)	33	32	36	37	35	36	33	30
T_{con}(℃)	34	33	40	38	36	38	34	32
$T_{ew,in}$(℃)	32	32	32	33	33	33	32	32
$T_{ew,out}$(℃)	4.2	3.6	4.8	4.8	5.0	5.0	4.0	3.2
T_{eva}(℃)	-6.0	-4.0	-7.0	-6.5	-6.0	-6.6	-5.0	-4.0
θ_{sh}(℃)	10	8	13	12	11	13	10	8
$p_{t,in}(MPa)$	1.24	1.19	1.27	1.26	1.25	1.25	1.20	1.18
$p_{t,out}(MPa)$	0.26	0.30	0.21	0.22	0.24	0.23	0.27	0.30
K_t(%)	70	70	82	85	80	85	75	75

Table 2: Values of the selected states' parameters

4.1 Verification of FAHP and IE

4.1.1 Verification of FAHP

The set of evaluated object is shown in Equation (18),

$$P = \{p_1, p_2, \cdots, p_8\}^T = \{S_1, S_2, \cdots, S_8\} \tag{18}$$

According to the working steps of FAHP, the decision matrix of four mainly components (compressor, condenser, evaporator, expansion valve) can be firstly obtained.

$$Q = \begin{bmatrix} 1 & \frac{9}{7} & \frac{9}{7} & \frac{9}{5} \\ \frac{7}{9} & 1 & 1 & \frac{7}{5} \\ \frac{7}{9} & 1 & 1 & \frac{7}{5} \\ \frac{5}{9} & \frac{5}{7} & \frac{5}{7} & 1 \end{bmatrix} \tag{19}$$

Taking advantage of the maximum eigenvalue, the corresponding feature vector can be derived, and then normalized, which is the final weight of four major components, as given by the Equation (20).

$$w = [w_{com}, w_{con}, w_{eva}, w_{exp}] = [0.32, 0.25, 0.25, 0.18] \tag{20}$$

Similarly, the inner weight of every parameter can also be calculated.

$$w'_{com} = [p_{suc}, p_{dis}, T_{suc}, T_{dis}, K_c] = [0.257, 0.250, 0.200, 0.200, 0,086] \tag{21}$$

$$w'_{con} = [T_{ca,in}, T_{ca,out}, T_{con}] = [0.263, 0.263, 0.474] \tag{22}$$

$$w'_{eva} = [T_{ew,in}, T_{ew,out}, T_{eva}, \theta_{sh}] = [0.230, 0.230, 0.310, 0.230] \tag{23}$$

$$w'_{exp} = [p_{t,in}, p_{t,out}, K_t] = [0.294, 0.294, 0.412] \tag{24}$$

Determine the set of evaluation scales,

$$S = \{S_1, S_2, \cdots, S_n\}^T \tag{25}$$

Quantize every parameter of each evaluation state, and then construct the fuzzy relation matrix *R*. Finally, the comprehensive evaluation vector *V* can be obtained, which is composed by the resulting weight vector *w* and fuzzy relation matrix *R*.

$$V = w \cdot R = w \cdot [v_1, v_2, \cdots, v_n]^{-1} \tag{26}$$

At last, the comprehensive evaluation value of the selected 8 states can be calculated.

$$W_{FAHP} = V \cdot S = [2.369, 2.561, 2.364, 2.331, 2.396, 2.345, 2.509, 2.674] \tag{27}$$

4.1.2 Verification of IE

Due to the characteristic of big calculation set in IE, in order to reduce the calculation period, combining with the different influence degree, 9 parameters are further selected in the verification of IE, as given by Matrix (28).

$$[p_{suc}, p_{dis}, T_{suc}, T_{dis}, K_c, T_{con}, T_{eva}, \theta_{sh,}, K_t] \tag{28}$$

Construct the evaluation matrix:

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{19} \\ u_{21} & u_{22} & \cdots & u_{29} \\ \vdots & \vdots & \ddots & \vdots \\ u_{81} & u_{82} & \cdots & u_{89} \end{bmatrix}_{8\times 9} \tag{29}$$

As the parameters have different units, the index normalization method is used to map the values to the interval (0, 1). Because the scope of each parameter differs the interval indicators standardization method is selected, as shown in the following equation (30) /15/.

$$r_i = \begin{cases} 1 - \frac{u_i}{c_1} & u_i \in [u_{min}, c_1) \\ 1 & u_i \in [c_1, c_2] \\ 1 + \frac{c_2}{u_{max}} - \frac{u_i}{u_{min}} & u_i \in (c_2, u_{max}] \end{cases} \tag{30}$$

where

r_i is the normalized value of i^{th} parameter;

u_{min}, u_{max} are the minimum and maximum value of parameter;

$[c_1, c_2]$ is the fixed working range of parameter.

The standard matrix *R* can be obtained and then normalized as

$$R = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 0.83 & 0.62 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0.77 & 1 \\ 1 & 0.97 & 0.83 & 0.94 & 1 & 0.88 & 0.71 & 0.39 & 1 \\ 1 & 0.98 & 0.87 & 1 & 1 & 0.93 & 0.77 & 0.46 & 1 \\ 1 & 0.99 & 0.92 & 1 & 1 & 0.98 & 0.83 & 0.54 & 1 \\ 1 & 0.99 & 0.83 & 0.97 & 1 & 0.93 & 0.76 & 0.39 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0.62 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0.77 & 1 \end{bmatrix} \tag{31}$$

Assumed that the information entropy of output attribute is set to be *E*:

$$E = [E_1, E_2, \cdots, E_9] \tag{32}$$

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^{m} \dot{r}_{ij} \ln \dot{r}_{ij} \quad j = 1, 2, \cdots, n \tag{33}$$

The information entropy can be calculated,

$$E = [1.000, 0.999, 0.997, 0.999, 1.000, 1.000, 0.996, 0.985, 1.000] \tag{34}$$

Following the equation (35), the weight of output attribute can be got, as shown in (36).

$$w_j = \frac{1 - E_j}{\sum_{i=1}^{m} (1 - E_i)} \quad j \in n \tag{35}$$

$$w_{IE} = [0, 0.042, 0.125, 0.042, 0, 0, 0.167, 0.625, 0] \tag{36}$$

The comprehensive evaluation value of every state can be obtained,

$$W_{IE} = R \cdot w^T = [0.735, 0.864, 0.532, 0.608, 0.675, 0.557, 0.763, 0.864] \tag{37}$$

4.2 LSCW

According to the description of LSCW's working principle in above 3.2, it is also that nine parameters are selected as the selection in IE. The standard matrix can be constructed, as shown in equation (31).

The attribute weight from IE is the same as the equation (36).

$$w_{IE} = [0, 0.042, 0.125, 0.042, 0, 0, 0.167, 0.625, 0]$$

In accordance with the principle of FAHP, the attribute weight from FAHP can be obtained,

$$w_{FAHP} = [0.153, 0.153, 0.119, 0.119, 0.051, 0.119, 0.119, 0.083, 0.083] \tag{38}$$

In accordance with Equations (13), (14), (15), (16) and (17), the attribute weight w_{LSCW} are calculated with different reliabilities which are set in proportion. Subsequently, the corresponding comprehensive evaluation values W_{LSCW} are obtained by calculation in Equation (5), are shown in Table 3 /16/.

Reliability	Comprehensive evaluation value W_{LSCW}
$^x/_y = 1/9$	$[0.819, 0.887, 0.716, 0.747, 0.815, 0.725, 0.840, 0.892]$
$^x/_y = 2/8$	$[0.834, 0.895, 0.717, 0.752, 0.813, 0.733, 0.857, 0.897]$
$^x/_y = 3/7$	$[0.854, 0.916, 0.725, 0.763, 0.813, 0.744, 0.866, 0.920]$
$^x/_y = 4/6$	$[0.855, 0.925, 0.727, 0.761, 0.814, 0.746, 0.875, 0.929]$
$^x/_y = 1$	$[0.857, 0.924, 0.732, 0.774, 0.818, 0.745, 0.878, 0.930]$
$^x/_y = 6/4$	$[0.857, 0.926, 0.730, 0.775, 0.820, 0.743, 0.875, 0.932]$
$^x/_y = 7/3$	$[0.859, 0.926, 0.731, 0.777, 0.816, 0.744, 0.882, 0.932]$
$^x/_y = 8/2$	$[0.870, 0.932, 0.740, 0.782, 0.822, 0.750, 0.893, 0.940]$
$^x/_y = 9/1$	$[0.876, 0.935, 0.741, 0.785, 0.819, 0.752, 0.892, 0.942]$

Table 3: Different evaluation values in different reliabilities between FAHP and IE

The relationship among different reliabilities corresponded with Table 3 is shown in the following Figure.

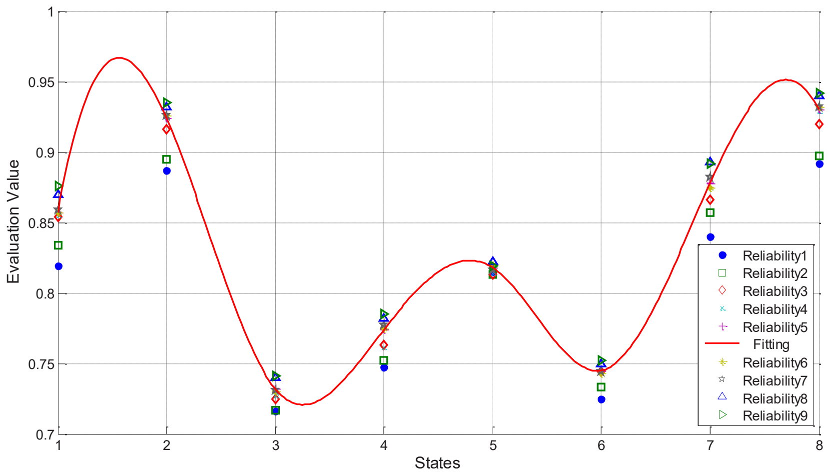

Figure 5: The relationship among different reliabilities

Through fitting the values, the reliability $^x/_y = 1$ is selected. Then the comprehensive weight can be calculated.

$$w_{LSCW} = [0.092, 0.103, 0.120, 0.075, 0.031, 0.071, 0.135, 0.316, 0.057] \quad (40)$$

The final comprehensive evaluation value of every state is shown in equation (41).

$$W_{LSCW} = R \cdot w^T = [0.857, 0.927, 0.732, 0.776, 0.820, 0.746, 0.880, 0.933] \quad (41)$$

4.3 Comparison

Online operation energy consumption can be calculated by equation (1), in which the data from the measured sensors /17/.

Eight selected states' value of COP are shown in the following,

$$S_{COP} = [3.6, 4.0, 3.2, 3.3, 3.4, 3.3, 3.8, 4.1] \quad (42)$$

Normalize equation (27), (37), (41) and (42), the results are shown in Table 4. The detailed comparison between three evaluation methods and real COP can be shown in Figure 6.

	Results of normalization
FAHP	$[0.8859, 0.9577, 0.8841, 0.8717, 0.8960, 0.8770, 0.9383, 1.000]$
IE	$[0.8507, 1.000, 0.6157, 0.7037, 0.7813, 0.6447, 0.8831, 1.000]$
LSCW	$[0.9185, 0.9936, 0.7846, 0.8317, 0.8789, 0.7996, 0.9432, 1.000]$
S_{COP}	$[0.8780, 0.9756, 0.7805, 0.8049, 0.8293, 0.8049, 0.9268, 1.000]$

Table 4: Results of normalization

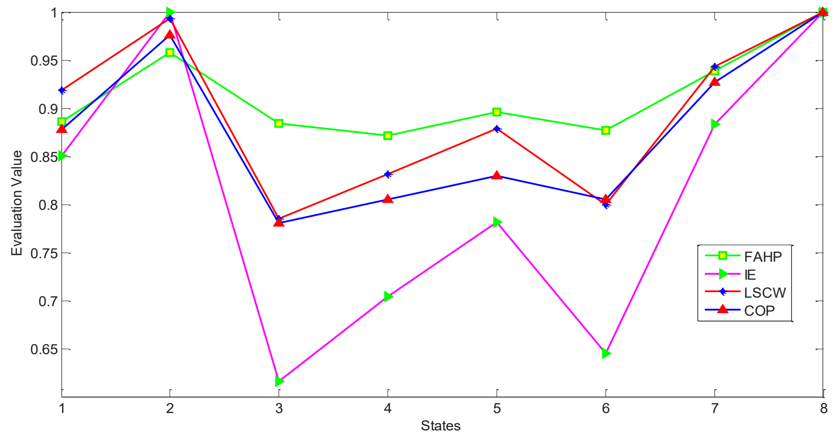

Figure 6: Comparison of different evaluation methods in eight states

The results of comparison show that LSCW has better precision and consistence with the actual energy efficiency change than FAHP and IE.

With the help of the real monitoring system, a day's data in minutes are selected. Then the further comparison in deviation points and relative error are shown in Table 5. The detailed comparison between three methods and real changing COP is shown in Figure 7. It shows that the advantage of LSCW will be better expressed following with the long-time application. Now, it has been developed as a self-learning module in a real central energy management of the refrigeration system, optimizing the energy efficiency in further.

Methods	Total points	Deviation points	Relative error (%)
FAHP	1440	217	15.07
IE		193	13.40
LSCW		49	3.34

Table 5: Comparison in deviation points and relative error

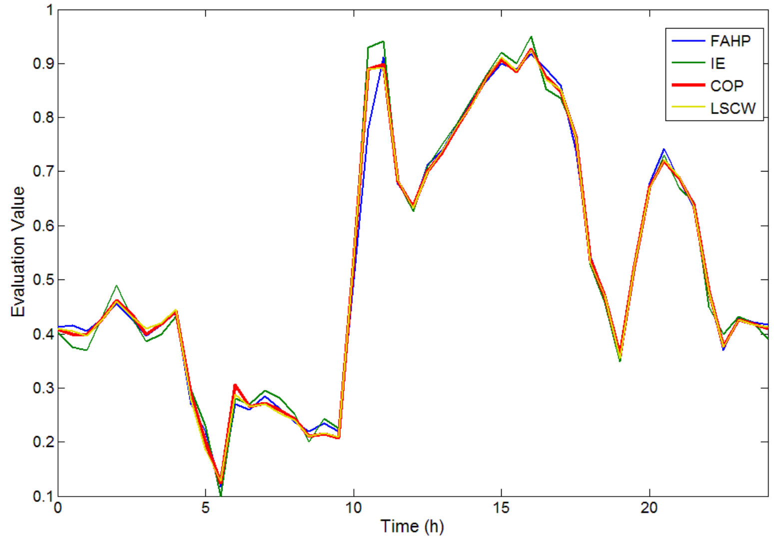

Figure 7: Comparison of different evaluation methods in a day-running

5 Summary and conclusion

The paper deals with the research and the development of a new energy efficiency evaluation method in refrigeration system. Considering the characteristic of complex multi-parameter, the major evaluation parameters (15 parameters) are firstly selected by simulation. Then a two-dimension evaluation matrix is designed. Based on the analysis of two general evaluation methods (FAHP and IE), a new energy efficiency evaluation method, Combination Weight based on Least Squares (LSCW) is proposed. Combined with an actual project, the evaluation effect of different methods are tested and compared. The results show that, the proposed method has better precision and greater consistence with the actual energy efficiency change. Furthermore, it has less derivation points with relative error at 3.34%, much better than the given two general evaluation methods. It can be developed to be a module in energy management system, by which the energy efficiency of refrigeration system can be real managed and optimized.

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Nomenclature

Variable	*Description*	*Unit*
p_{suc}	Suction Pressure of Compressor	$[MPa]$
p_{dis}	Discharge Pressure of Compressor	$[MPa]$
T_{suc}	Suction temperature of Compressor	[℃]
T_{dis}	Discharge temperature of Compressor	[℃]
K_c	Opening of Guiding Valve	[%]
T_{oil}	Temperature of oil	[℃]
p_{oil}	Pressure of Compressor oil	$[MPa]$
$T_{ca,in}$	Inlet Temperature of Ammonia in Condenser	[℃]
$T_{ca,out}$	Outlet Temperature of Ammonia in Condenser	[℃]
T_{atm}	Temperature of Atmosphere	[℃]
$T_{cw,in}$	Inlet Temperature of Water in Condenser	[℃]
$T_{cw,out}$	Outlet Temperature of Water in Condenser	[℃]
T_{con}	Condensing Temperature	[℃]
$T_{ew,in}$	Inlet Temperature of Water in Evaporator	[℃]
$T_{ew,out}$	Outlet Temperature of Water in Evaporator	[℃]
$T_{ta,in}$	Inlet Temperature of Ammonia in Throttle	[℃]
$T_{ta,out}$	Outlet Temperature of Ammonia in Throttle	[℃]
θ_{sh}	Degree of Superheat	[℃]
$T_{ea,in}$	Inlet Temperature of Ammonia in Evaporator	[℃]
$T_{ea,out}$	Outlet Temperature of Ammonia in Evaporator	[℃]
$p_{t,in}$	Inlet Pressure of Throttle/Expansion Valve	$[MPa]$
$p_{t,out}$	Outlet Pressure of Throttle/Expansion Valve	$[MPa]$
T_{eva}	Evaporating Temperature	[℃]
K_t	Opening of Throttle	[%]
m_w	Mass Flow of Water	$[m^3/min]$
m_a	Mass Flow of Ammonia	$[m^3/min]$

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