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The Evaluation method of HVAC System's operation performance based on Exergy Flow Analysis and DEA method

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ABSTRACT

An energy flow model of an airport terminal's HVAC system is established in this paper. Based on energy flow model, the exergy efficiency, exergy loss and exergy cost distribution ratio of each component are calculated and analyzed by the energy flow model. Optimization method and exergy balance equations are used to calculate the lowest exergy loss of HVAC system under different operation conditions. Data envelopment analysis (DEA) method is then applied to obtain the benchmarking frontier of lowest exergy loss of HVAC system, and the frontier line illustrates the optimum operation performance which the system can reach, namely the ideal operation level. In order to measure the gap between actual operation level and ideal operation level, a new index—control perfect index (*CPI*) is defined by the ratio between the actual exergy loss and exergy loss of ideal operation level of HVAC system, and it can reflect control influences on operation performance of HVAC system. Thus, a new evaluation method is presented which regards ideal operation level as the benchmark and uses *CPI* to evaluate actual operation performance of HVAC system. Two kinds of control strategies, optimal supply chilled water temperature reset strategy (*CHW Strategy*) and optimal load allocation control strategy (*Load Allocation Strategy*) are implemented to validate this evaluation method. Test's results show that *Load Allocation Strategy* can improve the operation performance of the system more greatly than the *CHW Strategy*. This evaluation method not only can evaluate the operation performance of HVAC system, but also can indicate the direction of optimal control of HVAC system.

1. INTRODUCTION

Heating, ventilation and air conditioning (HVAC) system is a complex energy system. The operation performance of HVAC system is deeply influenced by equipment's characters and control strategies. Recently, lots of new optimization techniques have been applied in control strategies for improving the operation performance of HVAC system. K.F. Fong et al. [1] presented robust evolutionary algorithm (REA) method to solve the HVAC optimization problems by simulation package or directly by explicit mathematical expressions. N. Nassif et al. [2] used a two-objective evolutionary algorithm to optimize set points. Results show that energy demand of the optimized control strategy is less than that of the actual one. Lu Lu et al. [3] developed a modified genetic algorithm to solve the optimization problem for overall HVAC systems through finding the optimal set points of the independent variables. Simulation results showed that comparing with the traditional method, the more energy consumption could be saved by this method.

Although optimization of control strategies is an effective way to save the energy consumption of HVAC system, it lacks a method to find the optimizing potential of HVAC system. It is important to ascertain HVAC system's optimum operation performance under all kinds of operation conditions, and use it as the benchmark to evaluate system's actual operation performance. Exergy analysis, which applies the second laws of thermodynamics, is a powerful evaluation method for complex energy systems [4]. In recent years, many kinds of exergy analysis approaches have been developed for various purposes, including assessment of physical criteria, local optimization and operational diagnosis.

Ahamed et al. [5] applied exergy analysis to evaluate the components of a vapor compression refrigeration system, and showed that the maximal exergy loses occurred in the compressor. Franconi et al. [6] combined the first and second laws of thermodynamics to analyze and evaluate the operation performance of HVAC system. Hepbasli [7] presented an energy analysis method for ground source heat pumps (GSHP), using an exergy diagram to provide quantitative information regarding the proportion of the exergy input that is dissipated in the various system components. Rong et al. [8][9] carried out exergy analysis, based on the second law of thermodynamics, of four subsystems in a thermodynamic model of an air conditioning system, and identified the reasons for the low energy efficiency of this system.

This paper presents an evaluation method for evaluating the operation performance of the HVAC system by the index of control perfect index (CPI). CPI is defined by the ratio of exergy loss of actual operation performance to that of ideal operation level. In order to ascertain "ideal operation level" of HVAC system under overall operation conditions, particle swarm optimization (PSO) methods and exergy balance equations are employed to obtain HVAC system's lowest exergy loss under different operation conditions. Then, data envelopment analysis (DEA) is applied to obtain the benchmarking frontier of lowest exergy loss of HVAC system, which is defined as the ideal operation level. Two kinds of control strategies are at last implemented in HVAC system, based on ideal operation level and CPI, the operation performance of HVAC system will be reasonable evaluated.

2. DESCRIPTION OF HVAC SYSTEM

In this study, an airport terminal's HVAC system is chosen as the studying object, which is located in Haikou, southern of China. Basic information about this building and its HVAC system are listed in Table 1.

Table 1. Configuration of building and HVAC system

Building location	Haikou, China
Gross floor area	99,300m^2
Air-conditioned area	67,950m^2
Number of floor	4
Operating schedule	7:00 to 22:00
Cooling system	Water-cooled
Pump system	The primary pump, the secondary pump
Chillers	4 units
Air handling system	40 AHUs, 202 FCUs
Design indoor dry bulb temperature and relative humidity	25℃, 55%
Design outdoor dry bulb temperature and relative humidity (summer)	34.5℃, 60%
Design outdoor dry bulb temperature and relative humidity (winter)	10℃, 85%

AHUs of HVAC system mainly consist of 35 constant air volume (CAV) AHUs and 5 variable air volume (VAV) AHUs. The multi-chiller system contains four chillers. Three of them are the same and the rated capacity and input power of each one are 2461kW and 470kW respectively (hereafter denoted as Chiller T1,T2,T3). Another one's are 4640kW and 836kW respectively (hereafter denoted as Chiller Y1). The structure of the HVAC system is shown in Fig. 1.

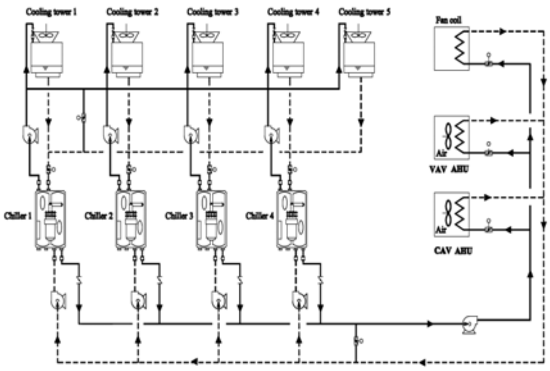

Figure 1: Schematic of HVAC system

3. THE EVALUATION METHOD

3.1 Exergy flow analysis

To apply the structural theory of thermo-economics, the exergy flow structure diagram of a system can be established to describe the energy flow process [10][11]. According to structural theory, the exergy flow entering a component is fuel flow, and the exergy flow leaving a component is product flow. Thus, the exergy flow process of the system can be described by fuel flow and product flow. The production capability and operational efficiency of each component are determined by its input fuels and output products.

According to the exergy flow structure diagram of the system, the exergy flow efficiency of the system can be calculated by Eq. (1)~Eq. (5),

$$F_i = g(x_i, P_i) \tag{1}$$

where Fi is the fuel flow of the i_{th} component; Pi is the product flow of the i_{th} component; and xi represent the operating parameters of the i_{th} component.

$$F_i = k_i \times P_i \tag{2}$$

where k_i is the exergy coefficient of the i_{th} component.

When only the flue cost is considered, the fuel exergy cost and product exergy of the i_{th} component can be calculated by Eq. (3) ~ Eq. (5).

$$\sum_{i=1}^{n} k_{F,i}^{*} \times F_i = \sum_{i=1}^{n} k_{P,i}^{*} \times P_i = F_c \tag{3}$$

$$k_{F,i}^{*} = \left(\frac{\partial F_c}{\partial F_i}\right) \tag{4}$$

$$k_{P,i}^{*} = \left(\frac{\partial F_c}{\partial P_i}\right) \tag{5}$$

where F_c is the sum of fuel flow exergy cost of system; $k^{*}_{F,j}$ is the unit fuel exergy cost of the i_{th} component; and $k^{*}_{P,j}$ is the unit product exergy cost of the i_{th} component, which can be calculated by Eq.(6), According to Eq.(6), production exergy cost equations of components can be established, it can be solved as linear equations.

$$k_{P,i}^{*} = \left(\frac{\partial F_c}{\partial P_i}\right) = \left(\frac{\partial F_c}{\partial F_i}\right) \times \left(\frac{\partial F_i}{\partial P_i}\right) = \left(\frac{\partial F_c}{\partial F_i}\right) \times k_i = k_{F,i}^{*} \times k_i \tag{6}$$

The object exergy efficiency, exergy loss ratio and exergy cost distribution ratio can be calculated by Eq. (7)~Eq. (9).

$$E_{object\_i} = \frac{P_i}{F_i} \times 100\% = \frac{1}{k_i} \times 100\% \tag{7}$$

$$E_{loss\_i} = \frac{E_i - P_i}{\sum_{i=1}^{n} E_i - \sum_{i=1}^{n} P_i} \times 100\% \tag{8}$$

$$E_{dis\_i} = \frac{P_i \times k^*_{p,i}}{\sum_{i=1}^{n} P_i \times k^*_{p,i}} \times 100\% \tag{9}$$

where E_{object_i} is the object exergy efficiency of the i_{th} component; E_{loss_i} is the exergy loss ratio of the i_{th} component; E_{dis_i} is the exergy cost distribution ratio of the i_{th} component; and n is the component number.

3.2 Control Perfectness Index (CPI)

In order to evaluate the influence of the control strategy on operation performance of HVAC system, it is important to develop a new index——*CPI* (Control Perfectness Index).

The *CPI* of HVAC system is expressed as Eq.(10).

$$CPI_{sys,j} = EL^{c}_{sys,j} / EL^{0}_{sys,j} \tag{10}$$

Where, $CPI_{sys,j}$ is the *CPI* of HVAC system under the j_{th} operation condition; $EL^{0}_{sys,j}$ is the actual exergy loss of the HVAC system under the j_{th} operation condition; $EL^{c}_{sys,j}$ is the lowest exergy loss of HVAC system (the lowest exergy loss) under the j_{th} operation condition. The larger the $CPI_{sys,i}$ is, the better the operation performance will be, i.e., the control strategy is more suitable for the system operation.

Where $H_{sys,j}$ is the optimum potential of HVAC system under the j_{th} operation condition.

To evaluate the operation performance of the HVAC system during a certain time (day, month or year), the operation condition during this time should be divided N operation conditions, *CPI* and the optimum potential of the HVAC system during this time can be calculated using Eq.(11) and Eq.(11).

$$CPI_{sys} = \sum_{i=1}^{N} EL^{c}_{sys,j} / \sum_{i=1}^{N} EL^{0}_{sys,j} \tag{11}$$

Where CPI_{sys} is the *CPI* of HVAC system in the running period; N is the total number of the operation conditions.

3.3 Data Envelopment Analysis (DEA)

Though based on energy flow analysis, the lowest exergy loss of HVAC system under a certain operation condition can be obtained. It still lacks a method to get the ideal operation level of HVAC system under all kinds of operation conditions.

Data envelopment analysis (DEA)，as developed by Charnes et al (1978) (CCR)，is a non-parametric technique used to measure the relative efficiency of decision making units (DMU) with the same general goals and objectives [12, 13]. DEA seeks to identify a given level of output the operating units which achieved the lowest observed costs, or for a given level of costs the operating units which achieved the highest observed output [14, 15]. Within a set of DMUs, the ones which own optimal efficiencies form the frontier. By measuring the distance between frontier and non-frontier DMUs, the efficiencies of DMUs will be identified.

Fig.2 illustrates the concepts of using DEA to analyze optimal efficiencies of given data points. Data points from P_1 to P_5 are looked upon as DMUs, and DEA draws on a linear programming technique to assess the efficiencies of DMUs [16]. As shown in Fig 3，P_3 owns the maximum ratio of input to output among all the DMUs, namely the line passing P_3 has the maximum slope. The line joining P_1, P_3, and P_5 is a piecewise envelope which forms the frontier among all DMUs. For a DMU below the envelope line, taking P_2 for an example, in maximum slope line and envelop line, there are two DMUs (B and C) which have the same output with P_2. DEA defines the ratio of B’s input to P_2’s input as overall efficiency (E_o), and the ratio of B’s input to C’s input as technical efficiency (E_t). Hence, DMUs lying on the maximum slope line mean their E_o equal to 1, DMUs lying on the envelop line mean their E_t equal to 1. Scale efficiency (E_s) is defined as E_o divided by E_t. DMUs’ efficiencies are given by Eqs. (12)~(14).

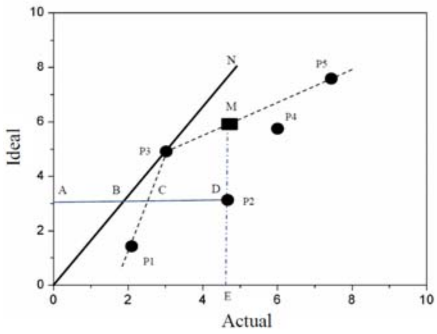

Figure 2: Efficiencies' analysis of DMUs based on DEA method

Overall efficiency: $$E_o = \frac{AB}{AD} \tag{12}$$

Technical efficiency: $$E_t = \frac{AC}{AD} \tag{13}$$

Scale efficiency: $$E_s = \frac{AB}{AC} \tag{14}$$

Among three kinds of DEA efficiencies, past studies have proven that technical efficiency could be used to evaluate HVAC system's operation performance and control condition [17]. When DEA method is applied in analyzing HVAC system's operation performance, the X axis stands for reciprocal of actual exergy loss and Y axis stands for reciprocal of ideal exergy loss, DMU stands for the actual exergy loss .vs. its corresponding ideal exergy loss of HVAC system under certain operation condition. Thus, the frontier will reflect the ideal operation level of HVAC system under all kinds of operation conditions.

4. IDEAL OPERATION LEVEL OF HVAC SYSTEM

4.1 Global optimization of HVAC system based on lowest exergy loss

The energy flow model of the HVAC system includes 6 main components: Component *I*: cooling towers; Component *II ~V*: chiller T_1, T_2, T_3 ,Y_1 and chilled water pumps; Component *VI*: AHUs and secondary pumps. (Fig.3)

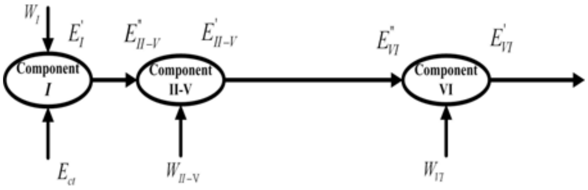

Figure 3: Analysis diagram of energy flow of the HVAC system

According to the analysis diagram of the energy flow of HVAC system, the exergy balance equations of the HVAC system are setup in Eq.(16)~Eq.(19).

$$Y_{tot} = W_I + E_{ct} - E_I^{'} + W_{II-V} + E_{II-V}^{''} - E_{II-V}^{'} + W_{VI} + E_{VI}^{''} - E_{VI}^{'} \tag{15}$$

$$E_I^{'} = E^{''}_{II-V} \tag{16}$$

$$E^{'}_{II-V} = E^{''}_{VI} \tag{17}$$

$$Y_{tot} = W_I + E_{ct} + W_{II-V} + W_{VI} - E^{'}_{VI} \tag{18}$$

Where, W_I is the power consumption of the cooling towers; W_{II-V} is the sum of the power consumptions of the chilled water pumps (W_{chp}), the chillers (W_{ch}) and the cooling water pumps (W_{cdp}); W_V is the sum of the power consumptions of the second pumps and the fans of the AHUs; $E^{'}_I$ is the outflow exergy of component *I*; $E^{''}_{II-V}$ is the inflow exergy of components *II-V*; E_{ct} is the specific exergy of the cooling tower water flow; $E^{'}_{II-V}$ is the outflow exergy of components *II-V*; E''_{VI} is the inflow exergy of component *VI*; and E'_{VI} is the outflow exergy of component *VI*.

For the *ideal operation level*, all the fans and pumps are running at their rated conditions (i.e., the highest efficiency) [18]. According to the object function Eq.(14), the total exergy loss (Y_{tot}) of the HVAC system is obtained. The PSO algorithm [19] is used to search for minimum value of the total exergy loss of HVAC system with constraints of operation parameters.

Eq.(24) is the object function of minimum Y_{tot}. Cooling tower outlet water temperature set point ($T_{ctw\_out\_set}$), part load ratio (*PLR*) of the chiller, evaporator outlet water temperature set-point ($T_{chw\_out\_set}$) and the supply air temperature set point of the AHU (T_{sa_set}) are used as the variables to search for the lowest exergy loss of the HVAC system under different operation conditions. The constraints of the global optimization are described as Eq.(20)~Eq.(27).

$$MinY_{tot} = f(T_{ctw\_out\_set}, PLR_i, T_{chw\_out\_set\_i}, T_{sa\_set}) \tag{19}$$

$$\begin{gathered} T_{ctw\_out\min} \le T_{ctw\_out} \le T_{ctw\_out\max} \\ T_{ctw\_out\min} = T_{wb\_out} + \Delta T_{ctwD\_\min} \qquad if\ T_{ctw\_out\min} < T_{wb\_out} + \Delta T_{ctwD\_\min} \end{gathered} \tag{20}$$

$$T_{chw\_out\min} \le T_{chw\_out} \le T_{chw\_out\max} \tag{21}$$

$$T_{sa\min} \le T_{sa} \le T_{sa\max} \tag{22}$$

$$PLR_{\min} \le PLR \le 1 \tag{23}$$

$$Q_{ch\_sum} = \sum_{i=1}^{N} PLR_i \times Q_{ch\_des,i} \tag{24}$$

$$M_{\sec pw} \le M_{chw\_sum} \tag{25}$$

$$W_{ch\_sum} + Q_{ch\_sum} = Q_{ct\_sum} \tag{26}$$

Where $\triangle T_{ctwD\_min}$ is the minimum temperature difference between the outlet water temperature of the cooling tower and the outdoor air wet bulb temperature; T_{ctmax} is the maximum outlet water temperature set-point of the cooling tower, T_{ctmin} is the minimum outlet water temperature set-point of the cooling tower, T_{chw_outmax} is the maximum outlet chilled water temperature set-point of the chiller, T_{chw_outmin} is the minimum outlet chilled water temperature set-point of the chiller, M_{chw_sum} is the sum of chilled water flow rate; M_{secpw} is the water flow rate of the secondary pump; T_{samax} is the maximum supply air temperature set-point of AHU; T_{samin} is the minimum supply air temperature set-point of AHU. W_{ch_sum} is the sum of the power consumptions of the chillers; Q_{ch_sum} is the total cooling load of chillers; $Q_{ch\_des,i}$ is the rated refrigerating capacity of the i_{th} chiller; PLR_i is the part load ratio of the i_{th} chiller; PLR_{min} is the minimum part load ratio of the i_{th} chiller; Q_{ct_sum} is the sum of the heat exchange capacities of the cooling towers.

By solving above optimization problem, hourly lowest exergy loss of the HVAC system under vary operation conditions could be obtained.

4.2 *Ideal operation level* of HVAC system

Based on the results of global optimization in 4.1, under certain operation condition, the original exergy loss and lowest exergy loss of HVAC system can be calculated. Fig.4 gives the plot of original exergy loss of HVAC system against lowest exergy loss of HVAC system under all kinds of operation conditions in a whole year. By applying DEA method, the frontier line of all of data points could be ascertained. As the frontier line illustrates the best operation performance which the HVAC system could reach by adjusting control parameters, we define it as the *ideal operation level*.

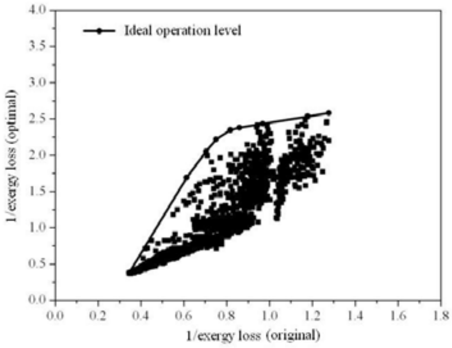

Figure 4: The definition of *ideal operation level* based on DEA method

According to the *ideal operation level*, it is obvious that the *CPI* value of HVAC system under any operation condition can be obtained by Eq.(28).

$$CPI = \frac{1/\,actual\ exegy\ loss}{1/\,ideal\ exegy\ loss} \tag{27}$$

As Eq.(28) has demonstrated, *CPI* is able to evaluate HVAC system's operation performance influenced by control strategy under any operation condition.

5. EVALUATION OF OPERATION PERFORMANCE OF HVAC BASED ON CPI

5.1 The process of evaluation based on *ideal operation level*

Fig.5 illustrates the processes of evaluation of HVAC system's operation performance based on *ideal operation level*.

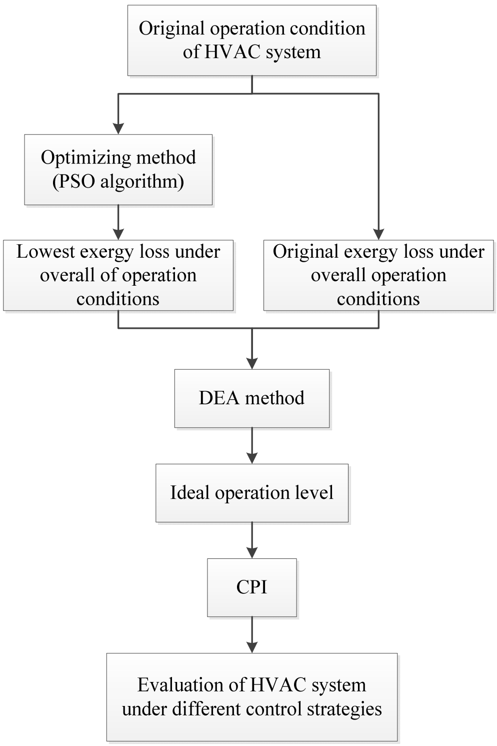

Figure 5: The evaluation progresses of HVAC system

The detailed evaluation processes are as follows:

Firstly, on the basis of exergy flow model of HVAC system, the exergy loss of HVAC system under original control strategy in a whole year will be calculated. According to global optimization of HVAC system (as described in 4.1), the lowest exergy of HVAC system under different operation conditions will be obtained. Apply DEA method to get the frontier of lowest exergy of HVAC system under all kinds of operation conditions, and the *ideal operation level* could be determined. Secondly, based on the *ideal operation level* of HVAC system, *PCI* value of current operation condition can be obtained according which presents HVAC system's operation performance. Thirdly, two control strategies (optimal supply chilled water temperature reset strategy and optimal load allocation strategy) are implemented in HVAC system in contrast of original control strategy. *CPI* of HVAC system will give reasonable assessments on control strategies.

5.2 Optimal control strategies for HVAC system

5.2.1 The optimal supply chilled water temperature reset strategy

The optimal supply chilled water temperature reset strategy (*CHW Strategy*) is applied for improving operation efficiency of HVAC system by changing set point of chilled water temperature.

The function of the optimization is formed by Eq.(29). The objection function is used to obtain the minimum total power consumption of HVAC system in the whole year [20]. The optimal set point of chilled water temperature can be obtained by Hooke-Jeeves optimization algorithm. The Hooke-Jeeves algorithm is a member of the family of generalized pattern search (GPS) algorithms and has the same convergence properties on smooth cost functions as the coordinate search algorithm [21].

$$MinJ = function(T_{chw,set}) \tag{28}$$

Where J is total power consumption of HVAC system; $T_{chw,set}$ is chilled water temperature set-point, $7℃ \le T_{chw,set} \le 12℃$.

5.2.2 The optimal load allocation control strategy

The optimal load allocation control strategy (*Load Allocation Strategy*) is applied for improving operation performance of HVAC system by use of relationship of COP vs. PLR of chiller[22]. The problem of the optimal load allocation for multi-chillers is described as a nonlinear programming problem with hybrid constraints. The objection function and constraint conditions of the problem can be expressed as Eq.(30)~Eq.(34). The optimal load allocation of each chiller can be obtained by the branch and bound optimization algorithm.

$$MinJ = \sum_{i=1}^{N} \frac{PLR_i \times CAP_i \times X_i}{COP_i} \tag{29}$$

$$\sum_{i=1}^{N} \frac{PLR_i \times CAP_i \times X_i}{CL} = 1.0 \tag{30}$$

$$PLR_{\min} \le PLR_i \le 1.0 \tag{31}$$

$$0 \le \frac{PLR_i \times CAP_i \times X_i}{CL} \le 1.0 \tag{32}$$

$$0 \le PLR_i \times X_i \le 1.0 \tag{33}$$

Where CAP_i is the refrigerating capacity of the i_{th} chiller; X_i is the on/off state of the i_{th} chiller, "0"means off and "1"means on; PLR_i is the PLR of the i_{th} chiller; PLR_{min} is of minimum of PLR, PLR_{min}=0.25; CL is the total cooling load of systems; COP_i is the coefficient of performance of the i_{th} chiller.

5.3 Results and discussion

Three control strategies, i.e., *Original Strategy*, *chilled CHW Strategy*, *Load Allocation Strategy* are applied in HVAC system respectively. Fig.6 shows the *ideal operation level* and three frontier lines of HVAC system under different control strategies based on annual operating data.

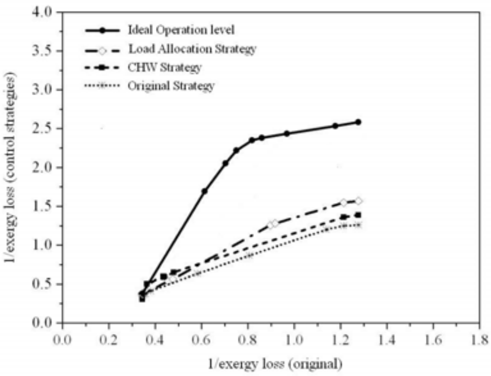

Figure 6: *Ideal operation level* and three frontier lines of HVAC system

As shown in the Fig.6, the frontier line of *Load Allocation Strategy* is the highest among all of the three frontier lines, i.e., the distance between it with *ideal operation level* is the least. The frontier line of *chilled CHW Strategy* is higher than that of *Original Strategy*, and lower than that of *Load Allocation Strategy*. The frontier line of *Original Strategy* is the lowest among the three lines.

According to the *ideal operation level* and three frontier lines of HVAC system, the average value of *CPI* of each control strategy can be calculated. The results of average *CPI* of the system of three control strategies are shown in Fig.7.

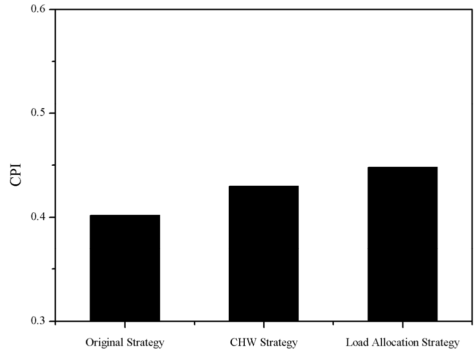

Figure 7: *CPI* of different control strategies

The results show that, comparing to *Original Strategy*, *chilled SWT Strategy* improves the *CPI* of the total system from 0.77 to 0.78, and *Load Allocation Strategy* improves the *CPI* of HVAC system from 0.77 to 0.82. It is obvious that the operation performance of HVAC system under *Load Allocation Strategy* is better than that under two other control strategies. In conclusion, *CPI* can be used as a reliable index to evaluate HVAC system's operation performance under any control strategy.

6. CONCLUSIONS

This study demonstrates how exergy flow analysis and data envelopment analysis (DEA) can be used to evaluate the operation performance under control strategies. Based on the simulation model of an airport terminal's building and HVAC system, PSO algorithm is used as optimization algorithm to search for the lowest exergy loss of the HVAC system under different operation conditions. Cooling tower outlet water temperature set-point ($T_{ctw\_out\_set}$), part load ratio (*PLR*) of the chiller, evaporator outlet water temperature set-point ($T_{chw\_out\_set}$), and the supply air temperature set-point of the AHU (T_{sa_set}) are used as optimization variables. DEA method is then applied to ascertain the frontier line of the optimal exergy loss v.s. actual exergy loss of HVAC system. The frontier line is defined as the *ideal operation level* of HVAC system in this study describing the lowest loss which the system can reach by control strategies. The performance index—*CPI* is introduced to evaluate HVAC system's actual operation level according to the *ideal operation level*, which is defined by the ratio of actual exergy loss of HVAC system to the lowest exergy loss of HVAC system.

In order to validate the evaluation method based on *CPI*, two different control strategies are implemented in HVAC system except for the *Original Strategy*. Those are optimal supply chilled water temperature reset strategy (*CHW Strategy*) and optimal load allocation control strategy (*Load Allocation Strategy*). Results show that comparing to *Original Strategy*, *CHW Strategy* improves the *CPI* of the total system from 0.41 to 0.43, *Load Allocation Strategy* improves the *CPI* of the total system from 0.41 to 0.45. It can be concluded that *Load Allocation Strategy* can improve the operation performance of HVAC system more greatly than other control strategies. As a result, evaluation method based on exergy analysis and DEA method not only evaluates the operation performance of HVAC system, but also gives the direction of optimal control of the system.

NOMENCLATURE

E	exergy	
F	exergic fuel	
P	exergic product	
k	the exergy coefficient	
m	flow rate	(kg/s)
T	temperature	(◦C)
W	power consumption	(kW)

Subscript and superscript

a	air
c	the ideal
cd	condenser
ch	chiller
CH	chemical
ct	cooling tower
db	dry bulb
in	inlet
loss	the exergy loss ratio
out	outlet
object	the object exergy efficiency
oa	outdoor air
PH	physical
ra	return air
sa	supply air
sum	sum
w	water
wb	wet bulb
set	set point
0	the actual
cal	culated

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