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Research Paper

Optimization strategy for air handling units in spacecraft launching site

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HIGHLIGHTS

- A novel energy optimization strategy for AHU in SLS is proposed.
- A reasonable and simplified energy consumption model is built.
- The optimization variable is well analyzed and selected.
- Air process routes are well analyzed with psychrometric chart.
- Optimal air processing routes for typical working conditions are obtained.

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ABSTRACT

Air handling units (AHUs) in spacecraft launching site (SLS) can maintain the spacecraft in specific air conditions before launching, however, the current air processing method is backward and consumes great deal of energy. This paper proposes an optimization strategy for AHUs in SLS to reduce energy consumption. Firstly a reasonable and simplified energy consumption model of the AHU in SLS is built, and the working characteristic of each piece of equipment is analyzed. Secondly minimum energy consumption is taken as optimization target, and corresponding constraints and optimization algorithm are analyzed. By these means, a complete optimization model is built. Next the psychrometric chart is introduced to zone the fresh air working conditions and analyze the air processing routes existing. Fourthly the optimization of each air processing route is implemented and the route demanding minimum energy consumption will be selected as the optimal air processing route. Finally the optimization strategy is applied to analyze the air processing routes for single point and multi-point of typical working conditions, demonstrating its strong ability to save energy.

1. Introduction

Air handling units (AHUs) in spacecraft launching site (SLS) can provide air of certain state (namely specified temperature, humidity and purity) for spacecraft before its launching [1].

Compared with traditional air handling units, AHUs in SLS pay more attention to air state in air supply outlet, and care less about the air state in whole confined space or room. The air handling process can be treated as a route, i.e. air processing route, which includes two aspects: (1) the facilities needed to be turned on; (2) set point of air temperature and humidity after being processed. Because of the inborn functional redundancy of AHUs in SLS, there may be several processing routes to achieve the final air state. Determining air processing route is a key problem because it affects the energy consumption. The method determining air processing route at present is backward, which usually takes much manual intervention and huge energy consumption. Hence, a more automatic and energy saving optimization strategy is needed.

The optimization strategies for AHUs can be roughly divided into local optimization strategy and global optimization strategy. The former strategy mainly depends on the construction or operators' experience to improve the performance of AHUs, and often fails to study the system in a global view and lacks of complete thermodynamic basis, so its optimization ability is limited. But for its simplicity, local optimization strategy is widely used, such as Tuan [2] studies the optimization of an air-conditioning for thermal comfort and energy-saving by analyzing the effects of key parameters, Zhang [3] studies COP performance optimization of air source heater also by analyzing key parameters. The global optimization strategy consists of two forms, collaborative optimization

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Nomenclature

Symbol description

P	power (kW)
ρ	air density (kg/m^3)
G	air ventilation rate (m^3/h)
T	temperature (°C)
D	humidity (g/kg)
h	enthalpy per kilogram (kJ/kg)
φ	relative humidity (%)
η	efficient parameters

Subscripts

in	inlet
out	outlet
ht	electrical heater
rg	refrigerant
evp	evaporator
cps	compressor
sac	surface air cooler
cf	condenser fan
fre	fresh air
rd	rotary dehumidifier
R	regenerating wind
whl	desiccant wheel
rwf	regenerating wind fan
eh	electrothermal humidifier
f	fresh air fan
tgt	target
col	cooling air
min	minimum
max	*maximum*

Others

c_{pa}	air heat capacity at constant pressure (kJ/(kg K)
T_0	indoor temperature, 20 °C
$\varDelta D$	dehumidifying quantity at 140 °C (g/kg)

and target optimization. The prior method decomposes the complicated system into several subsystems, solves the coupling within the AHUs. Rentel-Gomez [4] and Barata [5] study the application of this strategy on AHUs. But this method doesn't build concrete optimization functions, it is difficult to obtain global optimization results. The target optimization method establishes optimization target functions and searches for their extreme values, thus obtains the global optimization results [6,7], this method is based on both thermodynamic theory and concrete construction of AHUs, possesses a good application prospect. Target optimization method is widely used, Zhang[8] studies the thermo-economic optimization of small size central air conditioner by developing corresponding objective functions and analyzing constraints, Kashani [9] studies thermal-economic optimization of an air-cooled heat exchanger by building a multi-object function, in addition, Sanaye [10] and Safikhani [11] have similar researches, these explorations all have achieved excellent optimization results.

Aiming at decreasing energy consumption of AHU in SLS, this paper proposes an optimization strategy basing on psychrometric chart and multi-population genetic algorithm. In Section 2, this paper introduces the construction of AHU in SLS and builds corresponding models. In Section 3, optimization model is built, related constraints and optimization variables are studied. In Section 4, air working conditions of AHUs are zoned and air processing routes are analyzed. In Section 5, the optimization strategy for air processing is proposed and applied to typical conditions, which demonstrate its advantage and application mechanism.

2. Introduction and modeling for AHU in SLS

2.1. Introduction of AHU in SLS

Fig. 1 shows a typical construction of AHU in SLS, from which we can see that, most pieces of equipment are located in air conditioning room. The AHU takes in fresh air from the environment, processes it into target state and then transmits it to small space (named *A*1 and expressed as square with blue thin lines in Fig. 1) where a key component of spacecraft is located, then the air flows out of *A*1 and goes into spacecraft room. The space *A*1 is very small and inside air state is always neglected by engineers. The by-pass is totally open when rotary dehumidifier doesn't participate in air treatment. The air inside spacecraft room is exhausted by blower fan. To assure the air purity and stable operation of AHU, blower fan works at fixed frequency.

2.2. Introduction and modeling for the key components of AHU in SLS

In the following, the working features of key components will be illuminated and related models will be built, which lay foundation for later optimization.

2.2.1. Electrical heater

Electrical heater is used to heat the air by heating wire when energized, it is surface heater. During heating process, humidity of air is constant, which can be expressed as line A_1B in Fig. 2, the power of electrical heater P_{ht} can be calculated according to Formula (1), (2). The efficient parameter of heater η_{ht} is 1.3.

$$P_{ht} = \eta_{ht} G c_{pa} \rho (T_{ht,out} - T_{ht,in})/3600 \tag{1}$$

$$D_{ht,in} = D_{ht,out} \tag{2}$$

2.2.2. Surface air cooler

Surface air cooler transfers heat via metal interface, the refrigerant is compressed and cooled by compressor and condenser which is located outside. The air state change during cooling process can be denoted as A_2B line in Fig. 2.

The physical model of surface air cooler is relatively complex, here we adopt the simplified fitting model to decrease the computational complexity during optimization. The coefficient of performance of Surface air cooler K_{COP} is a fitting function of dry-bulb temperatures and humidity of inlet process air (namely $T_{air,evp,in}$ and $D_{air,evp,in}$), dry-bulb temperatures of inlet cooling air ($T_{air,cl,in}$) as well as the cooling capacity ($Q_{air,evp}$), which is obtained by experiment data and can be expressed in Formula (3).

$$Q_{air,evp} = G\rho(h_{air,evp,in} - h_{air,evp,out})/3600 \tag{3}$$

$$\begin{aligned} K_{COP} = {} & -0.10276 Q_{air,evp} + 0.03564 T_{air,evp,in} \\ & + 0.00906387 D_{air,evp,in} - 0.092198 T_{air,cl,in} + 3.2811 \end{aligned} \tag{4}$$

The power of compressor P_{cps} and total power of surface air cooler P_{sac} are:

$$P_{cps} = Q_{air,evp}/K_{COP} \tag{5}$$