from Table 1 and 2, the usual assumption is to assume that the exergy of the fuel is approximately equal to the higher heating value (Goran Wall, 1990, Dincer I, 2003).

Table 3. Exergy grade function of different by products

By product	γ_f (ε_f/H_f)
Blast furnace gas	0.950
Coke oven gas	0.950
Waste gas	0.950
Petroleum coke	1.000
Pulping and back liquor	0.975
Wood chips	1.000
Waste oil	0.975

The thermal exergy transfer, E^Q, associated with heat transfer Q across a system boundary at constant temperature T is:

$$E^Q = (1 - \frac{T_0}{T})Q \quad (5)$$

From the definition of exergy, the mechanical work, W, and electricity, W_e, are identical to the physical exergy, E^W and E^{W_e}

$$E^W = W \quad (6)$$

$$E^{W_e} = W_e \quad (7)$$

Therefore, the exergy for progress i is the summation of exergy referring to all kinds of consumed energy and can be expressed as

$$E_i = \sum \varepsilon_j \times m_j \quad (8).$$

Exergy analysis of building material production energy use (embodied energy)

In this stage, all the building materials including materials for operation and maintenance are involved for manufacture energy calculation. Therefore, the exergy in this step includes the ones for producing materials, which are used for construction and maintenance of the building. The energy consumption of this stage is calculated as

$$E_{prod} = E_{prod,cons} + E_{prod,O\&M} = \sum E_{prod,cons,i} + \sum E_{prod,O\&M,i} \quad (9)$$

$$E_{prod,cons,i} = \sum m_j \times \left(1 + {w_j}/{100}\right) \times \varepsilon_j \quad (10)$$

Since the different life cycle of different kinds of materials, some should be multiple calculated in the life cycle assessment.

$$E_{prod,O\&M,i} = Eq.(10) \times \left[\frac{Y_{bui}}{Y_{mat,j}} - 1\right] \quad (11)$$

Exergy analysis of building operating energy use

The exergy consumed in this stage is the energy involved in facilities operation and maintenance, and it can be calculated as

$$E_{\ O\&M} = E_{oper} + E_{main} \quad (12)$$

$$E_{main} = E_{main,prod} + E_{main,trans} + E_{main,renew} \approx E_{main,trans} \quad (13)$$

In order to calculate energy consumed in building facilities accurately, energy simulation software, e.g. EnergyPlus is introduced for the energy simulation. After the simulation, the amount of different kinds of energy consumed in the life cycle of buildings $E_{oper,i}$ could be calculated according to the facility style. Therefore, the exergy consumption can be calculated according to the exergy calculation of different kinds of energy. The exergy consumption for facilities operation E'_{oper} can be calculated as:

$$E_{oper} = \sum E_{oper,i} = \sum \gamma_i H_i \quad (14)$$

Generally, the energy for facilities renewal is relatively small, and it is not taken into account in this paper for simplification. Since the energy consumed for manufacturing material for maintenance of the facilities $E_{prod,oper,i}$ has been involved in E_{prod} in Eq. (9), the energy for facilities maintenance (E_{main}) is equal to the energy involved in transportation of materials for maintenance ($E_{main,tran}$) .

$$E_{main,tran} = \sum m_j \times (1 + {}^{w_j}/_{100}) \times D_j \times \gamma_f H_f \quad (15)$$

Exergy analysis of building life cycle energy use

The total exergy consumption of embodied and operating energy use is calculated as

$$E_{total} = E_{pro} + E_{O\&M} \quad (16)$$

To balance the embodied operating energy, the total exergy consumption should be minimized according to different schemes.

DISCUSSION

The energy for producing material for buildings affects the first phase energy consumption (embodied energy) of building life cycle, while energy for operating the buildings accounts for large part of life cycle energy use. Meanwhile, different building envelopes cause different embodied energy, and thus demand different energy for operating facilities. Therefore, the interaction between embodied energy and operating should be balanced.

The exergy use of building materials production is the foundation of this research, which has attracted much attention. However, since there are thousands of kinds of materials for building, much more work should be done to analyze the energy consumption during the production phase, not only based on the method of energy but also exergy. All the progress related energy use should be taken into account. Therefore, not only can the exergy use be calculated, but the production progress can be also optimized by reducing the exergy loss. In this paper, thermodynamic progresses in the building envelopes and facilities, e.g. heat transfer through the wall, are not taken into consideration, which could lead to neglect how to optimize the thermal performance of building envelopes and facilities. In future, it is necessary to analyze the building envelopes and facilities based on the method of exergy for optimizing their thermal performance.

Nomenclature

ε	Specific exergy
ke	Kinetic energy
pe	Potential energy
h	Specific enthalpy
T	temperature
μ	Chemical energy
x	Mass fraction
s	Specific enthalpy
γ	Exergy grade fraction
w	Mass fraction of moisture in the fuel
E	exergy
H_f	Fuel higher heat value
Q	Heat transfer
W	Work transfer
W_e	Work of electricity
m	Mass flow rate
w_j	Waste ratio of material in construction
Y	Life time, year
D_j	average transport distance of material *j*

Subscripts

en	envelope
fac	facility
prod	production
cons	construction
O&M	operating and maintenance
mat	material
trans	transport
total	total exergy
Inst	installation
main	maintenance
$()_0$	environmental condition
$()_{00}$	dead state
$()'$	exergy consumption of facility

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The Prospect for Using Airside Economizers in China

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ABSTRACT

An airside economizer is an energy-efficiency measure for buildings; this air damper and automatic control scheme is considered one of the most popular energy-saving measures for mid-sized and large buildings' all-air or air-water air-conditioning systems. Airside economizers have been widely used as part of many air-conditioning systems for commercial, institutional, industrial, and large residential buildings in the United States and elsewhere, and researchers continue to study the airside economizer's control algorithms, setpoints, and performance in different climates and for various building occupancies. But in mainland China (PRC), HVAC engineers have not typically considered use of airside economizers, due to unfamiliarity or poor initial experiences with them. Also, because of failure of components or poor maintenance airside economizers can be energy wasters instead of savers thus further hurting their reputation in China. Although many cities in China are located respectively at similar longitudes and latitudes as cities of the U.S., the weather in China is different and often more humid than in much of the heavily populated regions of the U.S. Outdoor air pollution is also severe in more major industrialized cities of China than in the U.S.. This paper analyses the usage prospect of airside economizer from a climate distribution perspective, and the air-quality situation and the typical "conventional" air-conditioning systems used in China.

INTRODUCTION

The airside economizer control scheme uses, when available, low-temperature or low-enthalpy outside air to cool the interiors of buildings and thus eliminate or reduce needed mechanical cooling energy. They generally operate when the outdoor air is above the building's balance point temperature, is cooler than the return air, and is below a high-limit cutoff temperature or enthalpy. Today, approximately 60% of buildings utilize air-side economizers in the United States, so economizers are considered as one of the most popular energy-saving measures for large buildings' air-conditioning systems (M.F.Taras. 2005, W.J.Fisk.2005). In fact, using outside air to cool a building isn't a new concept; natural ventilation uses the same principle but is dependent on oft-fickle occupants, where economizers operate automatically. In the U.S., airside economizers have enjoyed wide use for decades and ANSI/ASHRAE/IESNA Standard 90.1-2007 now requires each cooling system with a fan to include either an air or water economizer when certain conditions apply. However in China this technology has not been used for buildings until about five years ago. Now their use is becoming common in China for data centers to save energy, and some HVAC manufacturers in China can build the equipment necessary for wide use of airside economizers. With recognition of the potential savings, the economizer is being called a new, high-impact energy conservation technology for China. According to these manufacturers' tests, properly operating economizers can cut Chinese data centers' cooling energy costs as much as 30% to 60%. Although the indicated significant energy savings that can be achieved by proper application of economizers, many never achieve their design performance in real operating environments, and their operational-problems increase as they age. To make matters worse, a malfunctioning economizer can waste much more energy than they were intended to save (Platts. 2004). Whether this technology can be used successfully long term in China or not, it needs to be discussed and analyzed.

THE APPLICATION OF AIRSIDE ECONOMIZERS

The extra cost of, and slightly increased system-complexity when adding airside economizers needs to be compared to their potential savings and reliability. The base for comparison is a simple air conditioning system that admits the minimum required ventilation rate, and cycles its heating and cooling capacity as needed to maintain the indoor setpoints.

1.The components and control types of airside economizer

ANSI/ASHRAE/IESNA Standard 90.1-2007 Section 6.5 presents the prescriptive path that includes the requirements for airside economizers, design capacity, control signals, high-limit shutoffs, dampers, and relief of excess outdoor air (ANSI.2007). A high-efficiency economizer needs a good design concept, faultless coordination of its constituent components, and performance testing of its operation under a variety of conditions.

1.1 The basic components

An airside economizer is similar to a typical air handling unit (AHU), but with a more complicated control system, as shown in Figure 1(Y.Yao.2010, J.Zhou.2008). It consists of dampers, sensors, logic devices, and actuators, which together decide how much outside air to introduce into the building, and usually how much to exhaust to avoid building over-pressurization (L.Jayamaha. 2006). The dampers are installed in the outside-air, return-air, and exhaust-air ducting; although often called return air, in this situation this specific airflow and its dampers are more-corrected described as recirculated air. The control system often has two sets of sensors to separately measure the temperature and possibly the relative humidity of outside air and return air of the building. According to the sensor's signals, the controller's logic decides how far the outside- and exhaust-air dampers should be opened, and the recirculated air damper closed to change the percent of the outside air in the supply air, from the minimum needed for ventilation and up to typically 100% outside air.

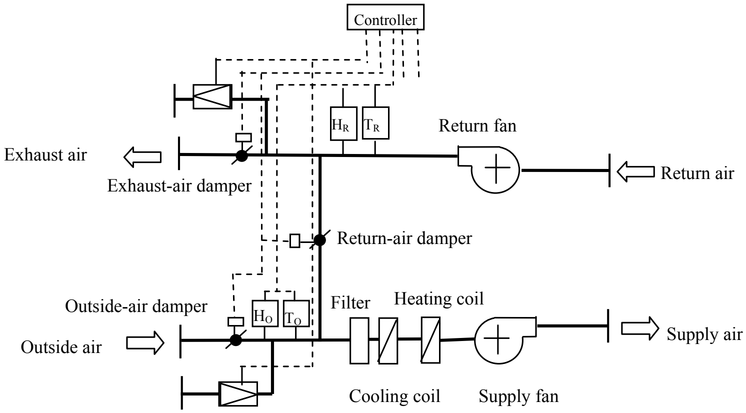

Figure 1. Schematic of AHU with an airside economizer

1.2 The control types for airside economizers

ASHRAE Standard 90.1 lists five different control types: fixed dry-bulb, differential dry-bulb, fixed enthalpy, differential enthalpy, and electronic enthalpy. Dew point-and-dry bulb control is also listed as a choice in Standard 90.1, but not its logical control concept. The first two types are often called dry-bulb-based or "sensible heat" controls, and the fixed enthalpy and differential enthalpy controls enthalpy-based or "total heat" controls; enthalpy controllers, in addition to the sensible heat also consider latent heat, the moisture in the air. The economizer control mode is typically enabled or disabled based on outside air dry-bulb temperature or outside air enthalpy in comparison with the return air temperature or enthalpy. Different climates need different control types. Fixed dry-bulb control is the most often-used control scheme and is simply based on the outside air dry-bulb temperature; it has the lowest initial ("first") and maintenance costs. The differential enthalpy control requires more and more-costly sensors, so it is the most expensive on first and maintenance costs but should result in more energy savings or improved indoor thermal comfort. But they can waste energy when the sensors drift out of calibration, often repeatedly, although these sensors are improving. Generally, hot and humid climates will require enthalpy-based control types if airside economizers are acceptable at all, where dry-bulb-based control types often work well in drier climates due to their lower cost and simplicity.

2. The operating modes of airside economizers

It is more economical to use airside economizers when a building needs cooling the whole year; high internal-heat-load data centers are an example of such. In addition, the economics improve when economizers are applied to larger buildings and systems, or are located in cooler and drier climates. ASHRAE Standard 90.1 recognizes this and varies its requirements with design capacities of air conditioning systems and climates. In dry or marine climate zones, air-conditioning systems with capacities more than 19 kW must use economizer cooling, and as same as systems with capacities more than 40 kW in moist or cool climate zone, however the economizer cooling is not required in moist and warm climate zones. To allow maximum benefit from the airside economizer, the air-conditioning systems must be designed to admit the minimum outside airflow required for ventilation and then up to full outside air flow for the maximum free cooling effect. Whatever the CAV or VAV air-conditioning system, the airside economizer has four operating modes and these modes let different outside airflow rates into the building as shown in Table 1. But "direct expansion" (DX) systems can be designed to enter the mechanical cooling mode directly from the modulated economizer mode, also known as "free cooling", in order to avoid unstable refrigerant system operation (D.Stanke. 2006).

Table 1. Operating modes with air-side economizers

Operating Mode	Outside airflow	Return airflow	Mechanical cooling
Heating mode	Minimum	Maximum	NO
Modulated economizer mode (Free cooling)	Partial	Partial	NO
Integrated economizer mode	Maximum (100%)	0	Mechanical cooling
Mechanical cooling mode	Minimum	Maximum	Mechanical cooling

3. The problems of airside economizers

Although an airside economizer when properly specified, installed, and operated can save significant energy and at times improve indoor air quality of a building, evidence shows that some economizers do not work properly and many are net-energy wasters, not energy savers. Many reasons lead to economizer failure.

First of all, it is the polluted air. Dirt and moisture will gather on dampers, their linkages, and actuators. These components can eventually corrode and jam. As the outside-air damper corrodes to the point that it freezes in place, the flow rate of outside air introduced into the building cannot be varied. The corrosion problems, certainly, can be improved with selection of resistant materials and improved operation and maintenance (O&M). But failure of individual component is not the cause for all economizer failures. Each component works well, sometimes, but the way components have been installed or controlled is incorrect, leading to ineffective performance of economizers (S. Liescheidt.2010). If the outside-air sensor was installed in the wrong place, it will provide erroneous signals, and the outside-air damper will not be opened and closed at the appropriate times. So installation and optimization through test, adjust, and balance (TAB) commissioning procedures is very important.

Then choosing the optimal high limit (upper setpoint) is difficult in an airside economizer. Each climate has a different high limit, and this setpoint varies depending on if dry-bulb temperature or enthalpy control is used. If the setpoint is set too low, the economizer will operate less often than it could, leading to higher mechanical cooling costs. If the setpoint is set too high, mechanical cooling costs will increase during warm weather because of higher ventilation rates, and comfort may be compromised if this extra load exceeds available cooling capacity. With dry-bulb-only control, too high a high-limit can cause periods of high humidity within the building, so this setpoint tends to be lower in higher-humidity climates.

After the system is put in operation, periodic observation and maintenance is needed to ensure proper operation; this maintenance can be performed by well-trained employees, but is often provided through qualified external vendors via maintenance contracts.

THE PROSPECT FOR USAGE OF AIRSIDE ECONOMIZER IN CHINA

With its potential for large cooling energy savings, and low implementation rates in buildings other than new data centers, the airside economizer, at a glance, appears to be a very attractive addition to new HVAC systems being designed for mainland China. But designers need to be aware of China's specifics to help assure proper choices.

1. The climate distribution in China

According the Standard of Building Climate Regions (GB50179-93) of China, there are seven climate regions (I to VII), and five thermal-climate regions. These five thermal regions are 1) very cold, 2) cold, 3) hot-summer and cold-winter, 4) hot-summer and warm-winter, and 5) mild regions as shown in Table 2. The summer design temperatures in many locations do not exceed 25˚C, such as in climate regions I, V, VI and VII. In these less-than "hot" climates there are few buildings that need cooling year round. Only the modern, often-sealed commercial buildings need air conditioning in summer, and most other buildings use natural ventilation. In climate regions III and IV, the summer is often hot and humid, and has high humidity all year long, so regions III and IV are humid climate regions where airside economizers without enthalpy control will not likely perform well. Although lots of cities of China respectively are located at the similar longitudes and latitudes as cities of the U.S., the humidity in China is often higher than that in much of the U.S.. HVAC engineers in China need to understand the limits of airside economizer controls, and need to gain experience with the peoples and climates of China, types of HVAC systems, and where use of airside economizers can be successful.

Table 2. The climate regions for buildings in China

Climate Region		Thermal region	Main Climate Indices	
			Average Indices in January	Average Indices in July
I	IA, IB, IC, ID	Extreme cold region	T≤-10°C	T≤25°C RH≥50%
II	IIA, IIB	Cold region	-10°C<T<0°C	18°C<T<28°C
III	IIIA, IIIB, IIIC	Hot-summer and cold-winter region	0°C<T<10°C	25°C<T<30°C RH>50%
IV	IVA, IVB	Hot-summer and warm-winter region	T>10°C	25°C<T<29°C RH>50%
V	VA, VB	Mild region	0°C<T<13°C	18°C<T<25°C
VI	VIA,VIB	Extreme cold region	-22°C<T<0°C	T<18°C
	VIC	Cold region		
VII	VIIA,VIIB,VIIC	Extreme cold region	-20°C<T<-5°C	T≥18°C RH<50%
	VIID	Cold region		

2. The air-quality situation of cities in China

The World Health Organization (WHO) report of 2000, indicated eight of the 10 most polluted cities on the world exist in China. Fortunately, through intervention, the trend of worsening air quality in the cities of China has slowed down, and even is improving in some locations. However, the whole pollution level is still very high. Some regions had serious sulfur dioxide (SO_2) pollution, and 20.7% of the cities had higher average annual concentration of SO_2 than the limit value of the national standard of Grade II in China, but this is down 8% as compared with 1999, only one year earlier.

There's also acid rain in China, largely attributed to its coal dependence, and the area seriously affected by acid rain makes up 30% of the total land area of the country. The cities whose average annual precipitation with pH value lower than 5.6 are mainly located in the vast regions south of the Yangtse River, east of the Qinghai-Tibet Plateau and the Sichuan Valley. Central, South, Southwest and East China are still the regions with serious acid rain impacts. In 2000, among 254 monitored cities, the pH value of the precipitation ranged from 3.98 to 7.70. Acid