EXERGY ANALYSIS METHODOLOGY FOR ALL AIR SYSTEMS

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Abstract: The energy performance of air conditioning systems is usually evaluated using the First Law of Thermodynamics. Exergy analysis can show with accuracy the location of inefficiencies.

Exergy analysis studies for air conditioning systems are less than for power systems, even if this type of analysis is accepted as a powerful tool used in design, optimization and improvement researches.

For all air systems is presented an algorithm of exergy analysis, thus being possible the calculation of exergy efficiency and irreversibility of processes taken place in the considered system.

Keywords: exergy analysis, air conditioning, irreversibility, exergy efficiency.

1. INTRODUCTION

Air conditioning is the second large area where refrigeration is met. The necessity of air conditioning varies from one part of the world to another very widely. In warm and humid countries, air conditioning is seen as a tool for development; in temperate countries, air conditioning is a sign of a specific standard of living.

The all air systems provide complete sensible and latent cooling capacity in the cold air supplied by the system. Heating might be done by the same air stream, in the central system or at a particular zone. All air systems can be of two types: single duct systems or dual duct systems.

Same advantages of these systems are: the central plant is located in unoccupied areas, there is no piping, electrical wiring and filters are placed inside the conditioned space, it allows the use of the greatest numbers of potential cooling seasons house with outside air in place of mechanical refrigeration, seasonal changeover is simple and readily adaptable to climatic control, adapts to winter

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humidification, etc. It presents also disadvantages like: air balancing is difficult and requires extra care.

2. PERFORMANCE OF AIR CONDITIONING SYSTEMS

Thermodynamics deals with energy transformation and its interaction with matter. Restrictions under which all transformations are observed are known as the First and Second Laws of Thermodynamics.

The first law affirm that energy cannot be created not even destroyed, during the processes the energy quantity remaining constant. In a steady-state process, the quantity of energy is given by thermodynamic function called “enthalpy”.

The second law affirms that energy is degraded during all processes being seen a decrease in its quality. The quality of energy is given by the thermodynamic function named “exergy”.

The total energy is composed by two parts: the useful energy (exergy), which is usable to accomplish an action and the useless energy (anergy). The useful part of the energy is revealed when the system is in thermodynamic equilibrium with the environment. In this way, exergy is proportional to the departure of the system from its environment, this departure being given by the difference in properties at the temperature, pressure and composition of the system and those of the environment. Reaching environment conditions, the useful energy needed to perform an action disappears. This state is called “dead state”, for which exergy is equal to zero.

The consumption of primary energy in buildings counts for about one third of the total world energy demand, that is why buildings represent an important contributor to global pollution. Air conditioning systems are a part of the building construction. The use of exergy analysis in building applications puts the energy supply into the focus of the sustainable building design.

It is observed that exergy analysis studies are less developed for air conditioning systems than for power systems. But improved design and operation of these systems ask a more comprehensive and deeper understanding of the processes developed in air conditioning plants.

In their study, Asada and Takeda [1] appreciate that ceiling radiant cooling system with well water has low exergy efficiency because pumps are great electricity consumers.

Badescu [2] affirms that in a vapor compression heat pump, the most important exergy losses are met during compression and condensation processes.

Kanoglu et al [3] studied an experimental open cycle desiccant cooling system and revealed that at the desiccant wheel is registered the major percentage of total exergy destruction, followed by the heating system.

Ren et al [4] assessed the performance of the evaporative cooling systems, resulting that the regenerative evaporative cooling system indicates the best performance. The exergy efficiency of the regenerative scheme can be improved by considering the effectiveness of the indirect evaporative heat exchange.
Exergy analysis is remarked as a powerful tool in this context, as it allows the evaluation of each process and the determination of losses. This kind of analysis can be used in design, optimization and improvement works.

According to the First Law of Thermodynamics it is not possible to detect the places of a plant with the highest irreversibility generation. To assess the exergy losses it is needed the exergetic analysis, which is introduced by the Second Law (it shows that for some energy forms, only a part of the energy is convertible to work, i.e. the exergy).

For the exergy (called also availability) are given different definitions [5].

By Szargut: the exergy is the quantity of work obtained when one mass is carried to an equilibrium state with the environment, through reversible processes with interactions only with the environment.

By Kostas: the exergy is the standard quality of energy, equal to the maximum useful work which can be obtained from an energy carrier, using the environment parameters \( P_0, T_0 \) as reference.

By Tsatsaronis: the exergy is the maximum useful work that can be obtained from an energy carrier, imagining that this energy carrier is conducted until the environment conditions through a reversible process.

3. EXERGY ANALYSIS FOR ALL AIR SYSTEMS

The air conditioning system called all air (see Figure 1) is analysed from the exergy efficiency and irreversibility production point of view in order to observe the use of energy in this kind of air conditioning system.

The exergy of the air stream in given by:

\[
e = \left( c_{pa} + x c_{pv} \right) \left( T - T_0 - T_0 \ln \frac{T}{T_0} \right) + \left( 1 + \bar{x} \right) R_a T_0 \ln \frac{P}{P_0} + R_a T_0 \left[ \left( 1 + \bar{x} \right) \ln \frac{1 + \bar{x}}{1 + x} + \bar{x} \ln \frac{\bar{x}}{x_0} \right]
\]  

(1)

In the above equation \( \bar{x} = x/0,622 \) and the reference state, defined by \( T_0 \) and \( P_0 \), is the one of outdoor.

The exergy of the condensate is given by:

\[
e = -R_a \ln \phi_0
\]  

(2)

The irreversibility of each component of the considered system is written using Gouy-Stodola equation:

\[
I = \sum_k \dot{m}_k \left[ e_1 - e_2 + \frac{c_1^2 + c_2^2}{2} + g(z_1 - z_2) \right] + \sum_j Q_j \left( 1 - \frac{T_0}{T_j} \right) - P
\]  

(3)
The specific irreversibility for the cooling coil is:

\[ i = \gamma(e_1 - e_2)_{cc} + e_M - e_F \]  

(4)

The effectiveness is defined as the rational way of knowing how well the block/equipment is performing its function, i.e. the desired effect. Equation 5 represents the definition of effectiveness, given by the exergy efficiency, \( \eta_{ex} \), which is defined as the ratio between the net useful exergy product to net exergy supply.

\[ \eta_{ex} = \frac{e_{sup}}{e_{ins}} \]  

(5)

For the cooling coil result the following form of the exergy efficiency:

\[ \eta_{ex} = \frac{e_F - e_M}{\gamma(e_1 - e_2)_{cc}} \]  

(6)
4. CONCLUSIONS

Beyond determining the exergy efficiencies for each control volume, the exergy analysis also allows to determine the quantity which each equipment contributes to the generation of the total system irreversibility.

Presented methodology permits calculation of exergy efficiency and irreversibility for processes developed during air treatment in all air systems: primary air mixing (AE→M), cooling and dehumidification (MF), re-heating (Fi).

In the present context, marked by the utilization of sustainable and alternative energy resources in buildings, are needed commercially and economically air-conditioning systems. Because it is known the fact that air conditioning systems operate with low exergetic efficiencies, exergy efficiency is much more important than thermal efficiency, as a measure of the quality of environmental protection and sustenance.

Nomenclature:
- \( e \): exergy, \([kJ/kg]\);
- \( c_p \): specific heat of humid air, \([kJ/(kg K)]\);
- \( x \): absolute humidity (vapor content);
- \( T \): temperature, \([K]\);
- \( R_a \): constant of dry air; \( R_a = 287 \, J/(kgK) \);
- \( p \): pressure, \([Pa]\);
- \( R_v \): constant of water vapor; \( R_v = 461.5 \, J/(kgK) \);
- \( l \): irreversibility, \([kJ]\);
- \( m \): mass flow rate, \([kg/s]\);
- \( c \): velocity, \([m/s]\);
- \( g \): potential energy, \([kJ/kg]\);
- \( Q \): thermal power, \([kW]\);
- \( P \): electric power, \([kW]\);
- \( i \): specific irreversibility, \([kJ/kg]\).

Greek Symbol:
- \( \phi \): relative humidity, \([\%]\);
- \( \gamma \): water flow rate to air flow rate ratio in the cooling coil;
- \( \eta_{ex} \): exergy efficiency;

Subindices:
- \( a \): dry air;
- \( v \): water vapor;
- \( 0 \): reference condition (dead state);
- \( 1 \): inlet;
- \( 2 \): outlet;
- \( cc \): cooling coil;
- $ntp$ – net produced;
- $nts$ – net supplied.

REFERENCES