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Energy analyses of buildings equipped with exhaust air heat pumps (EAHP)

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ABSTRACT

The article deals with the theme of thermal recovery from exhaust air through heat pumps (EAHP). After a description of the main features of this technology and a classification of the possible systems, the technical characteristics and performances of an EAHP, which have been validated through field and laboratory experimentation, are illustrated. The heating and cooling energy performances of buildings equipped with this kind of thermal machine have been validated, addressing themes such as the dimensioning of the EAHP, the fraction of the requirements of maximum power or of useful thermal or cooling energy covered by it, the mean seasonal yield and the primary energy requirements. The energy analyses, carried out on an elevated number of test cases in order to be able to draw as general considerations as possible, have been elaborated through an evaluation model of the dynamic thermal behaviour of the building-plant system, implemented in a Matlab Simulink® environment, and validated through a comparison with the most well known simulation programmes.

1. Introduction

Exhaust air heat pumps (EAHP) make it possible to recover heat from exhaust air and they are also often defined as *active regenerators* (in that an energy consumption takes place and a heat transfer occurs between the two fluid streams, a transfer that is absent in the case of heat exchangers, which is in fact defined *passive recovery*) or *thermodynamic regenerators* (since they operate according to a thermodynamic cycle). The theme of thermal recovery from exhaust air, carried out with either active or passive systems, has been widely dealt with in literature [1–4] and it will become increasingly more important, considering the realization of more and more insulating envelopes with the consequent increase in relevance of the ventilation loads in the energy balance of a building. One of the technological solutions used for the thermal recovery of exhaust air is analysed in detail in this article through theoretical and experimental evaluations: the solution based on a heat pump without any passive recovery. The evaluation of the EAHP performance has been conducted without referring to the exchange efficiency (as occurs for passive regenerators), but by analysing them as high efficiency generators which, as will be seen later on, frequently have to be used together with an auxiliary generator system.

Of all the heat pumps that are available, EAHPs have resulted to show some of the highest efficiency values, thanks to the use of a thermal source with a very favourable temperature [5]. This is the main reason why this technology is widely used in countries in North Europe, such as Sweden and Germany [6], where, because of the particularly rigid climatic conditions, it is not possible to obtain elevated efficiency with the more common heat pumps that utilize outdoor air as the thermal source (AWHP or AAHP). Moreover, this technology has a much lower plant complexity than ground source heat pumps (GSHP).

2. Classification of the EAHPs

A typical classification of heat pumps is based on the identification of the thermal sources and of the thermal sink [7]. The source of heat for EAHPs is always exhaust air, while from the point of view of the thermal sink, there are two possible fluids: air or water. When referring to air, the thermal sink is made up of outdoor replacement air. In this way, the outdoor replacement air is heated, thus avoiding the introduction of a too low temperature (draft risk), and a low temperature thermal sink is used (lower than that of the source) with consequent high values of the performance coefficient of the heat pump (Fig. 1).

Another subdivision of air–air type EAHPs is based on the fraction of the exhaust indoor air and the introduced outdoor air that flows through the two batteries. Defining the exchanger before the despatch into the building as the “internal exchanger” and the second one as the “outside exchanger”, it is possible to have the following types of systems:

- Systems with all outdoor air: the internal exchanger (condenser in winter and evaporator in summer) is only crossed by outdoor replacement air, while the outside one is only crossed by indoor air being exhausted.

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Nomenclature

AAHP	air to air heat pump
ACH	air changes per hour
AWHP	air to water heat pump
COP	coefficient of performance
DD	degree-days
EAHP	exhaust air heat pump
EER	energy efficiency ratio
GSHP	ground source heat pump
H	enthalpy (kJ/kg)
MVHR	mechanical ventilation heat recovery
PER	primary energy ratio
Q	energy
T	temperature (°C)

Greek symbols

Φ	power [W]
φ	power per unit of air rate [W/(m^3/h)]

Subscripts

AUX	auxiliary plant
C	cooling
COND	condenser
E	exhaust
EL	electric
EVAP	evaporator
G	global
H	heating
I	indoor
MAX	maximum
O	outdoor
PE	primary energy
PLR	part load factor
S	supply
SENS	sensible
T	transmission
TOT	total
UE	useful energy
V	ventilation

- Systems with partial recycling: the internal exchanger is crossed not only by outdoor replacement air, but also by indoor air; in the same way, the outside exchanger is crossed not only by indoor air being exhausted, but also by outdoor air.

The first solution is the one that guarantees the best efficiency, because of the temperature levels of the thermal source and of the thermal sink. The temperature of the thermal sink is in fact almost always lower than that of the heat source, which makes it possible to use even simple heat exchangers. The second solution, instead, makes it possible to increase the amount of power transferred to the air-conditioned building, and was first thought up in view of becoming the only air-conditioning plant, without the necessity of an auxiliary plant.

The first solution is typical of residential buildings, while the second is applied in office buildings, commercial centres and public performance premises (cinemas, auditoria, conference halls, sports centres). The second solution is also characterised by:

- Decidedly larger machine sizes, both in terms of exchanged thermal power and of handled air flow rate.
- Installation in buildings with remarkably higher air change rates than residential buildings and where the design choices are frequently oriented towards all-air plants.
- The possibility of regulating the fractions of recycled air (both inside and outside) in order to privilege a greater efficiency or the exchanged power, in function of the boundary conditions.

It is therefore also possible, with this second solution, that there is no air change, or, in other words, that the two exchangers deal with only indoor air or only outdoor air.

In this case, during, e.g. the heating season, the indoor heat exchanger (condenser) is crossed only by indoor air, while the outdoor exchanger (evaporator) is crossed by outdoor air. The EAHP therefore becomes an AAHP in order to provide the building with a greater thermal power and quickly reach the set-point temperature when no air change is needed, as, for example, in an auditorium before the people entry.

A second classification is based on the final use. EAHP can in fact:

- Handle the replacement air (heating and/or cooling with dehumidification).
- Air-condition the buildings, producing hot/cooled water.
- Produce hot water for hygiene-sanitary use.

"Hybrid" solutions are also possible:

- In the case in which the outdoor replacement air is the thermal sink, this air is not introduced in a "neutral" manner into the building ($T_S = T_I$), but at a higher temperature for heating ($T_S > T_I$) and lower temperature for cooling ($T_S < T_I$), thus not being limited only for ventilation purposes, but also contributing, either totally

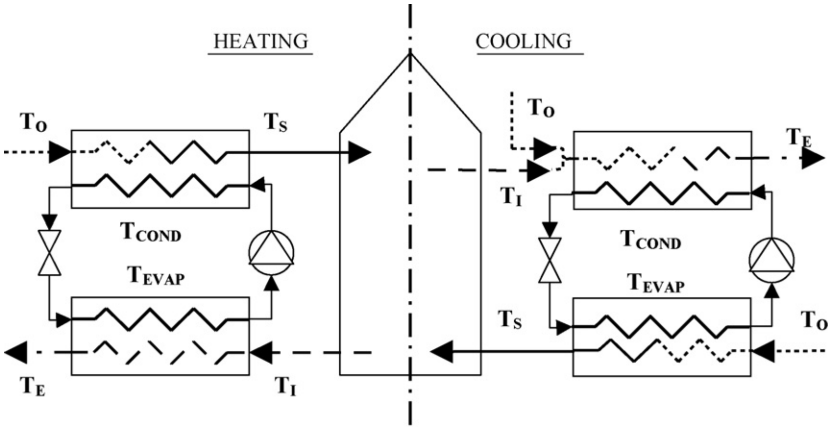

Fig. 1. Functioning scheme of the EAHP in heating and cooling mode.