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Review Article

Review on Waste Heat Recovery Techniques in Air Conditioning Application

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Abstract

The world today is facing a lot of difficulties in energy management and energy saving technologies is the need of the hour. This paper reviews the various techniques for heat recovery from Air Conditioning systems. The types of heat recovery techniques under consideration are: Fixed Plate, Heat Pipe, Rotary Wheel and Run-Around. A comparison of the development of these technologies has been done. For performance rating the efficiency of technology is considered.

Keyword: *Energy Management, Heat Recovery, Fixed Plate, Heat Pipe, Rotary Wheel and Run-Around.*

1. Introduction

AIR to air energy recovery is the process of recovering energy or/and moisture from an airstream at a high temperature or humidity to an airstream at a low temperature or humidity. This process is important in maintaining acceptable indoor air quality (IAQ) while maintaining low energy costs and reducing overall energy consumption. This paper describes various technologies for air-to-air energy recovery (ASHRAE 2005). Thermal and economic performance, maintenance, and related operational issues are presented, with emphasis on energy recovery for ventilation. Energy can be recovered either in its sensible (temperature only) or latent (moisture) form, or combination of both from multiple sources. Sensible energy can be extracted, for example, from outgoing airstreams in dryers, ovens, furnaces, combustion chambers, and gas turbine exhaust gases to heat supply air. Units used for this purpose are called sensible heat exchange devices or heat recovery ventilators (HRVs). Devices that transfer both heat and moisture are known as energy or enthalpy devices or energy recovery ventilators (ERVs) (A. Mardiana-Idayua 2011). HRVs and ERVs are available for commercial and industrial applications as well as for residential and small-scale commercial uses. Air conditioners use much energy to dehumidify moist airstreams. Excessive moisture in the air of a building can result in mold, allergies, and bacterial growth. ERVs can enhance dehumidification with packaged unitary air conditioners. Introducing outside or ventilation air is the primary means of diluting air contaminants to achieve acceptable indoor air quality. This paper focuses on heat recovery techniques in HRVs. Types of HRVs include compact air-to-air cross-flow fixed plate heat exchangers, rotary wheels, heat pipes and run-around loops. Performance is typically measured by effectiveness, pressure drop or pumping power of fluids, cross-flow, (the amount of air leakage from one stream to the other), and frost control (used to prevent frosting on the heat exchanger). Efficiency, the ratio of output of a device to its input, is also often considered. Fluid stream pressure drops because of the friction between the fluid and solid surface, and because of the geometrical complexity of the flow passages. Pumping power is the product of the fluid volume flow rate and pressure drop. Economic factors such as cost of energy recovered and capital and maintenance cost (including pumping power cost) play a vital role in determining the economic feasibility of recovery ventilators for a given application.

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2. Definition and concept

A heat recovery system in building consists of ducts for incoming fresh air and outgoing stale air, a heat exchanger core, where heat or energy is transferred from one stream to the other and two blower fans; one is to exhaust stale air and supply fresh air via the heat exchanger core(A. Mardiana-Idayua, S.B. Riffata 2011) . Fig. 1 shows a typical heat recovery system installed in ventilation system. In the core, the fresh air stream is automatically preheated or pre-cooled (depending on the season) by the exhausted air and distributed to the interior part of the buildings. The outgoing and incoming air passes next to each other but do not mix in the heat exchanger. They are often installed in a roof space or within the building interior, recover heat from the internal air before it is discharged to the outside and warm the incoming air. In an advance design of this system, sometimes the incoming air is filtered to reduce the incidence of pollen and dust while the outgoing air is filtered to protect the heat exchanger and internal components. This system is also used in building HVAC energy recovery systems, where building exhaust heat is returned to the comfort conditioning system. This device lowers the enthalpy of the building supply during warm weather and raises it during cold weather by transferring energy between the ventilation air supply and exhaust air streams.

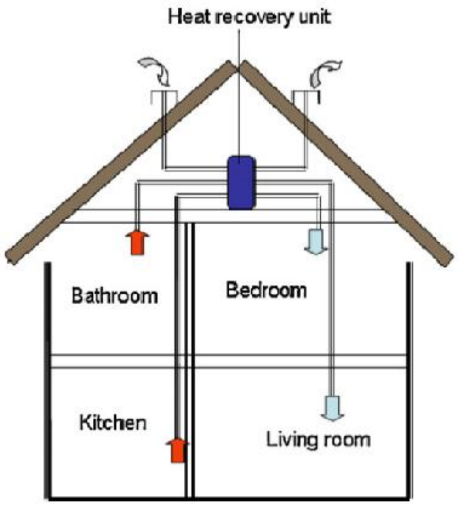

Fig. 1 Heat Recovery System(A. Mardiana-Idayua, S.B. Riffat 2011)

3. Types of heat recovery for building applications

These systems, generally classified according to their applications which are

Process-to-Process: In these applications, heat is captured from the process exhaust stream and transferred to the process supply airstream. Equipment is available to handle process exhaust temperatures as high as 870°C. Process-to-process recovery devices generally recover only sensible heat and do not transfer latent heat, because moisture transfer is usually detrimental to the process. Process-to-process applications usually recover the maximum amount of energy. In cases involving condensable gases, less recovery may be desired to prevent condensation and possible corrosion (ASHARE 2008).

Process-to-Comfort: In these applications, waste heat captured from process exhaust heats building makeup air during winter. Typical applications include foundries, strip-coating plants, can plants, plating operations, pulp and paper plants, and other processing areas with heated process exhaust and large makeup air volume requirements. Although full recovery is usually desired in process-to-process applications, recovery for process-to-comfort applications must be modulated during warm weather to prevent overheating the makeup air. During summer, no recovery is required. Because energy is saved only in the winter and recovery is modulated during moderate weather, process-to-comfort applications save less energy annually than do process-to-process applications. Process-to-comfort recovery devices generally recover sensible heat only and do not transfer moisture between airstreams (ASHARE 2008).

Comfort-to-Comfort: In these applications, the heat recovery device lowers the enthalpy of the building supply air during warm weather and raises it during cold weather by transferring energy between the ventilation air supply and exhaust airstreams. Air-to-air energy recovery devices for comfort-to-comfort applications may be sensible heat exchange devices (i.e., transferring sensible energy only) or energy exchange devices (i.e., transferring both sensible energy and moisture) (ASHARE 2008)..

HRVs are suitable when outside air humidity is low and latent space loads are high for most of the year, and also for use with swimming pools, chemical exhaust, paint booths, and indirect evaporative coolers.

4. Heat recovery techniques for building applications.

The following discussion considers the classification based on construction type of heat exchanger which is the heart of heat recovery system.

Fixed-plate

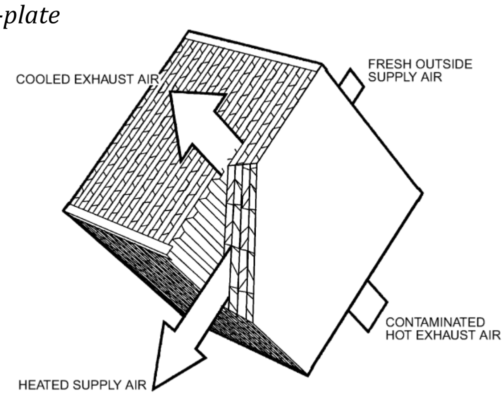

Fig. 2 Fixed-Plate Cross-Flow Heat Exchanger (ASHARE 2008)

Plate exchangers are available in many configurations, materials, sizes, and flow patterns. Many have modules that can be arranged to handle almost any airflow, effectiveness, and pressure drop requirement.

In this unit, the plate exchanger surfaces normally are constructed of thin plates that are stacked together or consist of individual solid panel with several internal airstreams. The plates maybe smooth or may have some form of corrugation. It operates by transferring thermal energy from outgoing to incoming air streams via plate heat exchanger surfaces. Figure shows the schematic diagram of heat transfer of fixed-plate. Typical effectiveness of sensible heat transfer is 50–80% and airflow arrangements are counter-flow, cross-flow and parallel flow.

Fixed-plate heat exchangers can achieve high sensible heat recovery and total energy effectiveness because they have only a primary heat transfer surface area separating the airstreams.

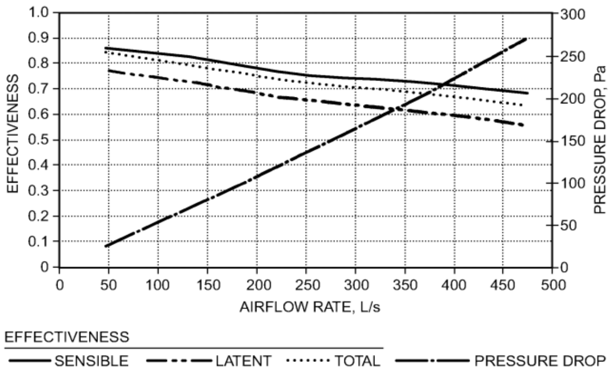

Fig.3 Variation of Pressure Drop and Effectiveness with Air Flow Rates for a Membrane Plate Exchanger (ASHARE 2008)

One advantage of the plate exchanger is that it is a static device with little or no leakage between airstreams. As velocity increases, the pressure difference between the two airstreams increases (Figure 3). High differential pressures may deform the separating plates and, if excessive, can permanently damage the exchanger, significantly reducing the airflow rate on the low-pressure side as well as the effectiveness and possibly causing excessive air leakage. This is not normally a problem because differential pressures in most applications are less than 1 kPa.

Heat pipe: Heat pipe recovery is a sealed self-contained, fluid evaporating condensing system (Fig. 4). It is a heat transfer device in which the latent heat of vaporization is utilized to transfer heat over a long distance with a corresponding small temperature difference (Amir Faghri 2012). The unit is divided into two sections for heat/energy exchanges between exhausts and supply air which are evaporator and condenser. Heat is transferred from hot incoming gas to the evaporator section of the heat pipe. Thermal efficiency of heat pipes is between 45% and 55%. There are some advantages in term of flow resistance, such as no moving parts, no external power requirements and so high reliability, no cross contamination, compact and suitable for all temperature application in heating, ventilation and air-conditioning, fully reversible and easy for cleaning. In addition, large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system.

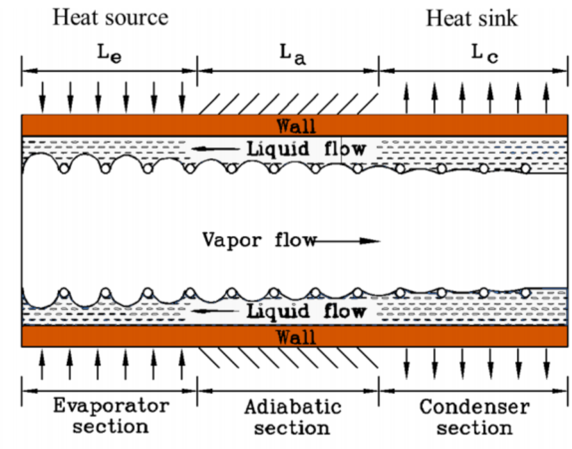

Fig. 4 Heat Pipe (Amir Faghri 2012)

Heat pipe heat transfer capacity depends on design and orientation. Figure 5 shows a typical effectiveness curves for various face velocities and rows of tubes. As the number of rows increases, effectiveness increases at a decreasing rate. For example, doubling the number of rows of tubes in a 60% effective heat exchanger increases the effectiveness to 75%. The effectiveness of a counter flow heat pipe heat exchanger depends on the total number of rows such that two units in series yield the same effectiveness as a single unit of the same total number of rows(Leonard L. Vasiliev 2004). Series units are often used to facilitate handling, cleaning, and maintenance. Effectiveness also depends on outside air temperature and the ratio of mass flow rates of the airstreams. Typically, heat capacity in the cooling season increases with a rise in outside air temperature. It has an opposite effect during the heating season. Effectiveness increases with the ratio of mass flow rates of the fluids (flow rate of the fluid with warmer entering temperature over that of cooler entering fluid temperature).

Rotary wheel: Rotary wheel recovery consists of a rotor with permeable storage mass fitted in a casing which operates intermittently between a hot and cold fluid (Fig. 6).

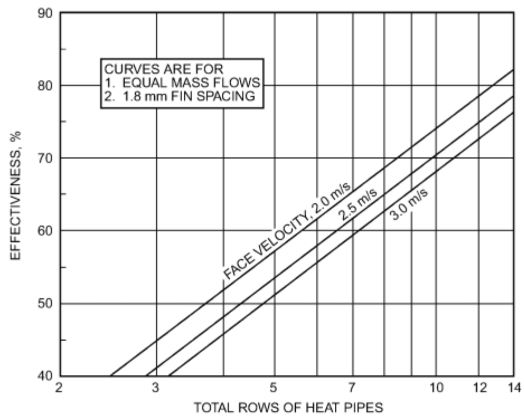

Fig. 5 Heat Pipe Exchanger Effectiveness (ASHARE 2008)

Table1 Heat recovery types, efficiency and advantages

Types of heat recovery	Typical efficiency	Advantages
Fixed-plate	50–80%	Compact, highly efficient due to high heat transfer coefficient, no cross contamination, can be coupled with counter-current flow which enabling to produce close en-temperature differences.
Heat pipe	45–55%	No moving parts, no external power requirements, high reliability, no cross contamination, compact, suitable for naturally ventilated building, fully reversible, easy cleaning.
Rotary wheel	Above 80%	High efficiency, capability of recovering sensible heat.
Run-around	45–65%	Does not require the supply and exhaust air ducts to be located side by side, supply and exhaust duct can be physically separated, no cross contamination.

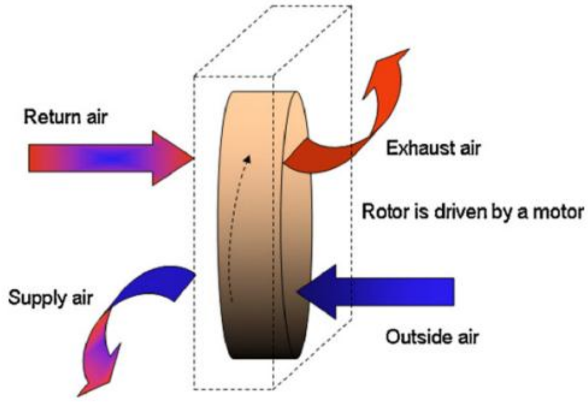

Fig.6 Rotary wheel recovery (A. Mardiana-Idayua 2011)

The rotor is driven by a motor so that the exhaust air and fresh air are alternately passed through each section. Rotor speed is normally relatively low and in a range of 3-15 rpm. A unique advantage of rotary wheels is the capability of recovering both sensible and latent heat. Rotary wheels are widely used and the units are known for their high efficiency and trouble-free operation.

Temperature efficiencies above 80% are not uncommon. Researches on this field keep active in recent years and involve many theoretical and experimental aspects of rotary wheel recovery for building applications (Riffat SB *et al*,1995). One of the earliest investigations of rotary wheel recovery was performed by Sauer and Howell (Sauer Jr HJ *et al*,1981)

Run-around: Run-around heat recovery system is the name given to a linking of two recuperative heat exchangers by a third fluid which exchanges heat with each fluid in turn as shown diagrammatically in Fig. 8. Run-around heat recovery use two physically separated heat exchangers (coils) in the air supply and exhaust ducts to recover and transfer heat between them. This system may require an expansion tank to accommodate expansion and contraction of heat transfer fluid. Unlike other heat recovery devices, the runaround system does not require the supply and exhaust air ducts to be located side by side. This gives run-around system an advantage over other available system when cross contamination is a concern. The heat is transferred from the exhaust to supply air using an intermediate heat transfer fluids such as water (Vali A, Simonson CJ *et al*, 2009). The main advantage of this system is that supply and extract duct can be physically separated, even in different part of the building. This provides maximum possible flexibility, as well as no possibility of cross contamination between air streams. The main disadvantages of this system is that because an intermediate fluid is used as a heat transfer medium, the system's efficiency is reduced and electricity is required for pumping fluid. However, pumping liquids remain significantly less energy-intensive than moving air with fans. Thermal efficiency of this type is normally from 45% to 65%. One of the first studies on the run-around heat recovery system was published by London and Kays.

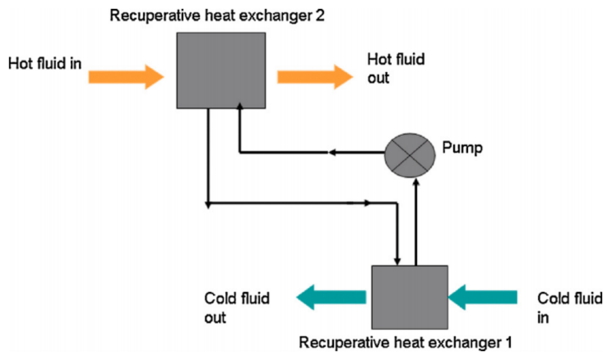

Fig. 7 Run-around system (A. Mardiana-Idayua 2011)

Conclusions

Findings from literature review shown that there are different types of heat recovery in the market nowadays such as fixed plate, heat pipe, and rotary wheel and run-around units utilized to recover energy loss.

From the above literature review, it has been found that heat pipe is more efficient than other devices.

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