BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LX (LXIV), Fasc. 2, 2014
Secţia
CONSTRUCŢII. ARHITECTURĂ

MECHANICAL VENTILATION SYSTEMS WITH HEAT RECOVERY FOR REFURBISHMENT PROJECTS AND NEW BUILDINGS

BY

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Received: May 15, 2014
Accepted for publication: June 26, 2014

Abstract. Indoor air quality is important to human health because we spend over 80% of our time indoors. Tight insulation, too much humidity and other factors can lead to unhealthy air in our home or workplace, causing a number of health problems. In today's energy-conscious world, the regulation of thermal performance of buildings has created a need for more efficient ventilation systems to minimise heat loss and unneccessary energy consumption. It has also become increasingly obvious that traditional ventilation methods, like opening a window or use of a common bath fan, do not provide adequate ventilation. A properly designed and installed ventilation system is the solution to moisture control and will help to ensure a healthy indoor environment for the occupant. This paper discusses about heat/energy recovery systems in building and types of heat/energy recovery. The mechanical ventilation systems use fans to maintain a low-velocity flow of fresh outdoor air into the house (incoming air stream) while exhausting out an equal amount of stale indoor air (exhaust air stream).

Key words: energy recovery ventilators; heat recovery ventilators; improve indoor air quality; heat supply systems; efficient ventilation systems.

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1. Introduction

Building energy use is a major concern in the European Union, where the building sector accounts for the 40% of total primary energy use. The Member States of the European Union are required to implement energy efficiency measures for buildings under the Energy Performance of Building Directive. Ventilation has a significant impact on the energy performance of buildings, accounting for 30%...60% of the energy use in buildings (Dodooa *et al*., 2011). Energy is used to cover the heat losses due to the ventilation air and to move the ventilation air for mechanical ventilation. The ventilation system also influences the air infiltration through the building envelope.

The envelopes of buildings constructed in recent decades are made of materials with high thermal resistance. These buildings have strong air tightness in order to minimize heat loss and gain through the envelopes. This design contributes to the savings of heating and cooling energy in buildings, but it also causes important ventilation issues by cutting off natural infiltration rates through the envelopes. While the air tightness applied to building envelopes is effective for energy savings, it reduces infiltration rates, and consequently results in the deterioration of indoor air quality. Life inside today's tight home generates both moisture and pollutants. The moisture comes from cooking, washing, showers and breathing.

It is commonly understood that heat recovery ventilators (HRVs) are effective for saving energy and maintaining necessary ventilation rates. The type of HRVs that reuse the heat ejected from indoor spaces has been effectively utilized in buildings in countries throughout Europe. A variety of studies have been conducted to examine the influence of heat recovery systems on building energy performance. The studies have proved that the application of heat recovery ventilators conserves energy for heating; however, more energy for cooling is necessary to handle particular outdoor conditions in summer. Other studies have shown that “HRVs that are capable of exchanging latent and sensible heat have successfully reduced heating and cooling energy together” (Kima *et al*., 2012).

2. Heat/Energy Recovery System – Definition and Concept

Heat recovery as a term refers to an air-to-air heat or energy recovery system which is defined as the process of recovering energy (heat/mass) from a stream at a high temperature to a low temperature stream that is effective and economical to run, or that heat or energy recovery means any device that removes in terms of extracts, recovers or salvages heat or mass from one air stream and transfers it to another air stream. This means that the energy that would otherwise be lost is used to heat the incoming air, helping to maintain a comfortable temperature (Mardiana & Riffat, 2013).

While in industries, it is abbreviated as HRV (heat recovery ventilation) or ERV (energy recovery ventilation), the term has become of general use. There are many different types of heat recovery systems available for transferring energy from the exhaust air to the supply air or *vice versa*. These include sensible heat recovery and enthalpy (sensible and latent) heat recovery (Mardiana & Riffat, 2013). The heat transfer surfaces based on sensible heat recovery can only transfer sensible heat between the makeup and exhaust air, while in the enthalpy recovery, it can transfer both sensible and latent heat (moisture); however, they have greater maintenance requirements and are costlier than sensible heat recovery. Above all, these systems are significantly proved as "the most efficient single energy saving method of building in a cold climate "(Mardiana & Riffat, 2013).

3. Heat Recovery Systems in Building

HRVs are relatively newcomers on the cold climate construction scene, yet have become almost indispensible in today's super-insulated, air tight homes. They are also becoming an increasingly common element in the current weatherization and insulation retrofitting trend. As older homes are undergoing energy facelifts, and becoming tighter and better insulated, they are also facing the same indoor air quality challenges one would see in new construction.

The HRV is principally designed to supply a regulated exchange of fresh air to the house, while simultaneously expelling stale indoor air. This is of particular importance in a home that is too tight to do so on its own, through passive means. At the core of the HRV unit is a heat exchanger (recuperator) where the airways exhausting the warm, moisture laden indoor air, flow next to the air passages bringing in outside air. At the junction, the cooler incoming air is warmed by the outgoing exhaust air, recovering a substantial amount of heat that would otherwise simply be lost. Typical heat recovery percentages can range from 60 to over 95 percent (Mardiana & Riffat, 2013), depending on the unit and the controls. This is where the HRV shines in comparison to a simple exhaust fan that blows warm air directly outside.

There are a number of possibilities and concepts for heat recovery from exhaust air in ventilation. The concept to be chosen depends on the possibilities for utilizing the recovered energy. A typical heat recovery system in building consists of ducts for incoming fresh air and outgoing stale air, a heat exchanger core (recuperator), 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 (Fig. 3).

This system is designed such that its ducts supply fresh air to bedrooms and living areas while exhausting stale, humid air from bathrooms, kitchens, and laundry rooms (Fig. 3). In the core, the fresh air stream is automatically pre-heated 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 does not mix in the heat exchanger. The system is often installed in a roof space or within the building interior, recovers heat from the internal air before it is discharged to the outside and warms the incoming air. This system is also used in building HVAC energy recovery systems, where building exhaust heat is returned to the comfort conditioning system. The 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. 3).

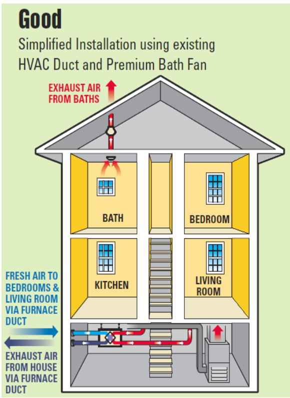

Fig. 1 – Installation using existing HVAC duct.

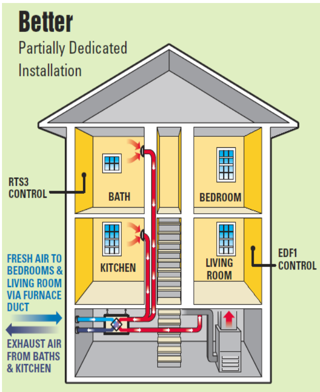

Fig. 2 – Partially dedicated installation.

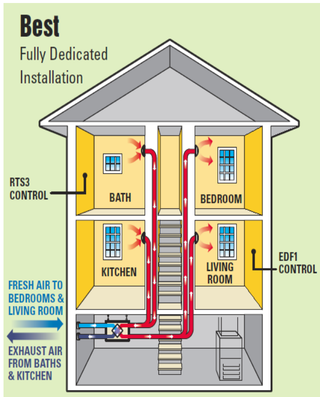

Fig. 3 – Fully dedicated duct system for the HRV/ERV.

Combining the HRV/ERV system with the existing air distribution system may be the only alternative for existing homes. Depending upon the design, the furnace or air-handling unit may have to run in conjunction with the HRV/ERV, which could add considerably to energy usage (Figs. 1 and 2).

Another option is to run a dedicated duct system for the HRV/ERV. This arrangement may be the only choice for houses without other air distribution. A technique is to pull exhaust air from one or more bathrooms (Fig. 3). Some advanced technologies offer further efficiency improvements, such as a defrost function. Although more expensive, they may be appropriate, depending upon the building requirements and the efficiency goal (Babota *et al*., 2013).

Properly applied, HRV/ERVs are a great way to improve indoor air quality by introducing outside air, while recovering much of the energy in exhaust air. Although there is a higher capital cost compared to simple exhaust fans, the HRV/ERV system will save energy (and money) over the long term, while providing a quieter, healthier indoor environment.

4. Types of Heat/Energy Recovery Devices

Heat/Energy recovery system or air-to-air heat recovery systems are made in so many types, sizes, configurations and flow arrangements. There are many types of heat recovery units which are in use in building applications and these depend on the heat exchanger core, such as fixed plate, heat pipe, rotary wheel and run-around.

4.1. Fixed-Plate

Fixed-plate heat recovery is the most common type of heat recovery device which is obviously named after the construction of its exchanger. In this unit, the plate exchanger surfaces are normally constructed of thin plates that are stacked together or consist of individual solid panel with several internal airstreams. The plates may be 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. The typical effectiveness of sensible heat transfer is 50%...90% and airflow arrangements are cross-flow (Fig. 4) and counter-flow (Fig. 5). Fixed-plate types provide an excellent means of achieving highly efficient heat recovery because their high heat transfer coefficients, coupled with counter-current flow, enable the production of close end-temperature differences (Mardiana & Riffat, 2013).

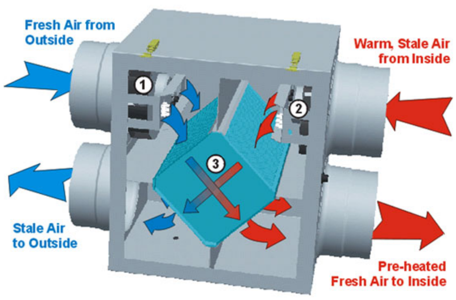

Fig. 4 – Cross-flow heat recovery.

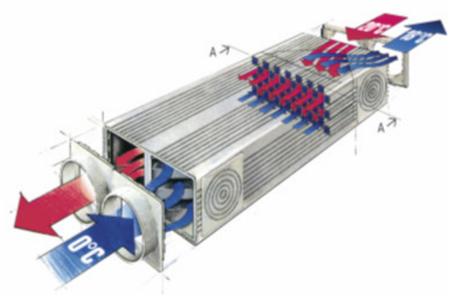

Fig. 5 – Counter-flow heat recovery.

In heating, ventilation and air-conditioning systems, HVAC, recuperators (fixed-plate types) are commonly used to re-use waste heat from exhaust air normally expelled to atmosphere. Devices typically comprise a series of parallel plates of aluminium, plastic, stainless steel, or synthetic fibre, in alternate pairs are enclosed on two sides to form twin sets of ducts at right angles to each other, and which contain the supply and extract air streams.

In this manner, heat from the exhaust air stream is transferred through the separating plates, and into the supply air stream. Manufacturers claim gross efficiencies of up to 90% depending upon the specification of the unit.

4.2. Heat Pipe

A heat pipe or heat pin is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces (Fig. 6).

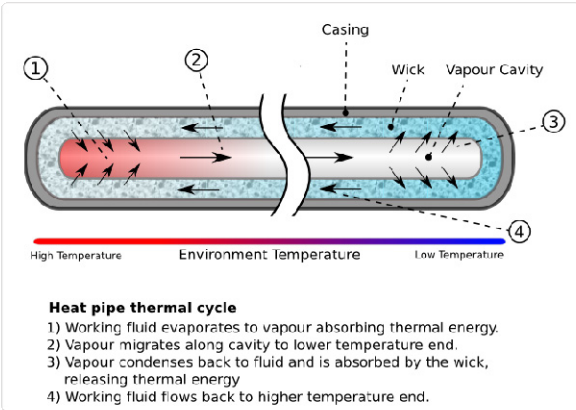

Fig. 6 – Heat pipe mechanism.

The unit is divided into two sections for heat/energy exchanges between exhaust and supply air which are the evaporator and condenser. Heat is transferred from the hot incoming gas to the evaporator section of the heat pipe. The thermal efficiency of heat pipes is between 45% and 55%. There are some advantages in terms of flow resistance, such as no moving parts, no external power requirements and high reliability, no cross contamination, compact and suitable for all temperature applications in heating, ventilation and air-conditioning, fully reversible and easy to clean. 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. Heat pipe recovery units are suitable to use in naturally ventilated buildings because they offer several advantages over conventional heat recovery device.

In heating, ventilation and air-conditioning systems, HVAC, heat pipes are positioned within the supply and exhaust air streams of an air handling system or in the exhaust gases of an industrial process, in order to recover the heat energy. The device consists of a battery of multi-row finned heat pipe tubes located within both the supply and exhaust air streams. Within the exhaust air side of the heat pipe, the refrigerant evaporates, taking its heat from the extract air. The refrigerant vapour moves towards the cooler end of the tube, within the supply air side of the device, where it condenses and gives up its heat. The condensed refrigerant returns by a combination of gravity and capillary action in the wick. Thus heat is transferred from the exhaust air stream through the tube wall to the refrigerant, and then from the refrigerant through the tube wall to the supply air stream.

Because of the characteristics of the device, better efficiencies are obtained when the unit is positioned upright with the supply air side mounted over the exhaust air side, which allows the liquid refrigerant to flow quickly back to the evaporator aided by the force of gravity. Generally, gross heat transfer efficiencies of up to 75% are claimed by manufacturers.

4.3. Thermal Wheel (Rotary Wheel)

A thermal wheel (rotary wheel) consists of a circular honeycomb matrix of heat-absorbing material, which is slowly rotated within the supply and exhaust air streams of an air handling system (Fig. 7). As the thermal wheel rotates heat is picked up from the exhaust air stream in one half of the rotation, and given up to the fresh air stream in the other half of the rotation. Thus, waste

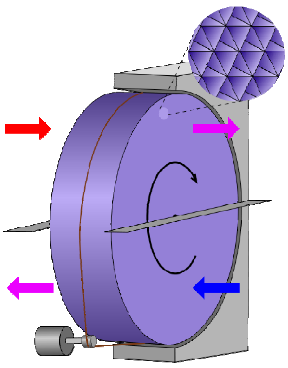

Fig. 7 – Thermal wheel (rotary wheel).

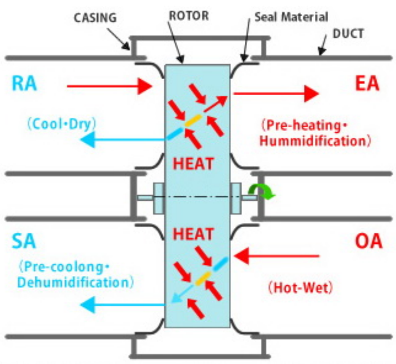

Fig. 8 – Operation principles of rotary wheels.

heat energy from the exhaust air stream is transferred to the matrix material and then from the matrix material to the fresh air stream (Fig. 8), raising the temperature of the supply air stream by an amount proportional to the temperature difference between air streams, or 'thermal gradient', and depending upon the efficiency of the device. Heat exchange is most efficient when the streams flow in opposite directions, since this causes a favourable temperature gradient across the thickness of the wheel.

The heat exchange matrix is normally manufactured in aluminium, which has good heat transfer properties, but can also be manufactured from plastics and synthetic fibres. The heat exchanger is rotated by a small electric motor and belt drive system.

4.4. Run-Around Coil

A run-around coil is a type of energy recovery heat exchanger most often positioned within the supply and exhaust air streams of an air handling system, or in the exhaust gases of an industrial process, to recover the heat energy.

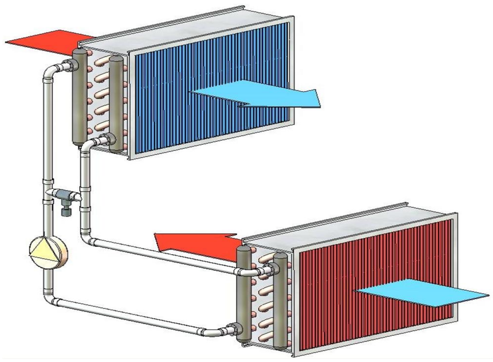

Fig. 9 – Run-around system.

Generally, it refers to any intermediate stream used to transfer heat between two streams that are not directly connected for reasons of safety or practicality. It may also be referred to as a run-around loop, a pump-around coil or a liquid coupled heat exchanger. A typical run-around coil system comprises two or more multi-row finned tube coils connected to each other (Fig. 9) by a pumped pipework circuit. The pipework is charged with a heat exchange fluid, normally water, which picks up heat from the exhaust air coil and gives up heat to the supply air coil before returning again. Thus heat from the exhaust air stream is transferred through the pipework coil to the circulating fluid, and then from the fluid through the pipework coil to the supply air stream.

4.5. Comparison Air-to-Air Heat Exchangers

A variety of devices are available which facilitate air-to-air heat exchange (Table 1), these include: Plate Heat Exchangers, Heat Pipe, Rotary Heat Wheel and Run-Around Coil (S.E.A.I., 2010).

Table 1
Comparison of the different types of Air-to-Air Heat Exchangers (S.E.A.I., 2010)

	Plate Heat Exchanger	Heat Pipe	Rotary Heat Wheel	Run-Around Coil
Heat recovery effectiveness, [%]	50...80 % Sensible only	45...65 % Sensible only	50...85 % Sensible 50...85 % Latent	50...65% Sensible only
Temperature range, [ºC]	–60…800	–40…40	–55…800	–45…500
Typ. pressure drop, [Pa]	150…300	150…500	100…300	150…500
Typ. face velocity, [m/s]	1.0…5.0	2.0...4.0	2.0...5.0	1.5...3.0
Air flow arrangements	Counter-Flow Cross-Flow	Counter-Flow Parallel-Flow	Counter-Flow Parallel-Flow	Not Applicable
Cross-leakage, [%]	0...5	0	1...10	0
Modulation control	By-pass damper	Tilt angle down to 10% of maximum	Wheel speed or by-pass damper	Pump speed control or by-pass valve
Equipment size range	25 l/s and up	50 l/s and up	25...35,000 l/s	50 l/s and up
Plant life expectancy, [Yrs]	25...30	15...20	15	20...30
Payback period, [Yrs]	0.7	1.3	0.7	1.2
Advantages	- No moving parts. - Low pressure drop, but can be selected for high pressure differentials. - Easily cleaned. - Plate material can be selected to suit a wide range of applications. - Relatively high heat transfer efficiency. - Extensively used in residential and commercial applications.	- Few moving parts (except tilting mecha-nism). - High pressure differentials between air streams is possible. - Relatively space efficient - no external power requirements - fully reversible - easy cleaning.	- Relatively high heat transfer efficiency. - Low pressure drop. - Easily cleaned. - Compact large sizes. - Matrix material can be selected to suit a wide range of applications. - Capability of recovering sensible and latent heat.	- Flexibility (air streams can be separated). - No risk of cross-contamination. - Suitable for retro-fit to existing ductwork systems. - Standard, well proven coil technology. - Relatively space Efficient.

Table 1 (Continuation)

Disadvantages	- Some risk of cross-contamination. - Air streams must be adjacent. - Sensible heat transfer only.	- Few suppliers. - Air streams must be adjacent. - Some risk of cross-contamination (depends on construction quality). - Sensible heat transfer only.	-Cross contamination between air streams. - Air streams must be adjacent. - Fan location is important. - Large space required to accom-modate the wheel. - Regular maintenance is required. - Large surface area to volume of matrix makes it susceptible to corrosion.	- Two stage heat transfer leading to inefficiencies. - Predicting performance requires accurate analysis. - Sensible heat transfer only. - Relatively low heat transfer efficiency. -Filtration required to protect coils.

The actual level of heat recovery will depend on the type of heat recovery device selected and the temperature difference between the supply and extract air streams. All heat recovery devices create a resistance against which a fan has to operate (pressure drop). This causes the fan to work harder to maintain the flow rate, so increasing electricity consumption. Where an intermediate circulating fluid is used, there is the additional consideration of the electrical consumption of the circulating pump and the losses from the interconnecting pipework.

5. Conclusions

Findings from literature review shown that there are different of heat recovery types such as fixed plate, heat pipe, rotary wheel and run-around units utilized to recover energy loss. In Table 1, the efficiency, advantages and disadvantages of various types are summarized.

For natural or passive ventilation heat pipe recovery has been used since no moving part is required in this system. For mechanical ventilation, researchers tend to integrate heat pumps, the so-called *mechanical ventilation heat pump recovery*, while rotary wheel recovery has widely been used in desiccant dehumidification to recover heat and moisture. Many theoretical and experimental works in literature have been conducted for integrating heat recovery system with natural ventilation, mechanical ventilation, dehumidification systems and air conditioning.

The amount of energy saved by installing a heat recovery device is equal to the energy recovered less the extra energy used in operating pumps, fans, etc. The final decision on installing heat recovery systems depends on economic viability. As the cost of electric energy is greater than the cost of fossil fuels, the heat recovery device will need to recover enough energy to economically justify its inclusion, while delivering a reasonable payback period (Table 1).

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SISTEME MECANICE DE VENTILAŢIE CU RECUPERAREA CĂLDURII PENTRU PROIECTE DE RENOVARE ŞI PENTRU CLĂDIRI NOI

(Rezumat)

Calitatea aerului din interior este important pentru sănătatea umană, deoarece ne petrecem mai mult de 80% din timp în interiorul clădirii. O izolare etanşă, prea multă umiditate, precum şi alţi factori pot duce la un aer nesănătos în casa noastră sau la locul de muncă, provocând o serie de probleme de sănătate. În lumea de azi, conştientă de importanţa energiei, reglementarea privind performanţa termică a clădirilor a creat nevoia de sisteme de ventilaţie mai eficiente pentru a minimiza pierderile de căldură şi consumul inutil de energie. De asemenea, a devenit tot mai evident faptul că metodele de ventilaţie tradiţionale, cum ar fi deschiderea unei ferestre sau utilizarea unui ventilator, nu oferă o ventilaţie adecvată. Un sistem de ventilaţie adecvat proiectat şi instalat este soluţia de control a umidităţii şi va contribui la asigurarea unui mediu interior sănătos pentru ocupant. Această lucrare studiază sistemele de recuperare a căldurii/energiei în clădire şi tipuri de dispozitive de recuperare a căldurii/energiei. Aceste sisteme de ventilaţie mecanică folosesc ventilatoare pentru a menţine un flux cu viteză redusă de aer proaspăt din exterior în casă (aer admis) în acelaşi timp cu evacuarea unei cantităţi egale de aer viciat din interior (aer evacuat).