Energy Recovery Ventilation

Introduction

An emphasis on energy conservation resulted in tighter buildings with minimum amounts of fresh air being heated or cooled and brought into air-conditioned spaces. However, the combination of "tight" buildings with little or inadequate fresh air ventilation produced an indoor environment with relatively high levels of chemical contaminants, bacteria, fungi and dust, etc., than outdoor ambient air. Studies have showed that level of contaminants in the indoor air can be sometimes several times higher than outdoor air. This combined with the fact that people tend to spend 90% of their time indoors, either at work or at home, revealing that major source of exposure to airborne contaminants for human beings is from indoors.

Most of the pollutants that we find indoors can be sourced to commonly found items around us. Sulphur, nitrogen dioxide, carbon monoxide produced by combustion and emission, high pollen counts, pesticides, chemical compounds, all contribute to outdoor pollution. Indoor air will contain all of the pollutants of the outdoor air as well as those generated indoors by the occupants and their activities. The indoor air contaminants which can be hazardous to health include Environmental Tobacco Smoke, formaldehyde, radon, asbestos, VOCs emitting from solvents, paints, varnishes, carpets causing long term and short term illnesses. Biologicals like bacteria, viruses, fungus due to presence of high humidity, directly affect the health of the occupants. Odors and dust can cause significant discomfort, feelings of unpleasantness.

In work places, "Sick Building Syndrome (SBS)" is a term that has been used to for long time to describe the presence of acute non-specific symptoms in the majority of the people, caused by buildings with an adverse indoor environment. Standard and regulations are already in place to tackle the issues. However, there is a lack of awareness in the indoor environment at homes, especially in Asia region. At home, people on average spend 8 hours in the bed room to sleep which help people to rehabilitate, conserve energy and consolidate memory. During sleep, human exhale CO_2 and give off a wide range of 'bio-effluents'. These bio-effluents include gases, odors, particulate, bacteria, viruses, etc., together with CO_2 are built up in space if the room is poorly ventilated.

Fig.1 shows time dependency of CO_2 concentration in typical small sleeping room ($V = 21m^3$) during 8-hours long sleep of one person for different ventilation flow rates with initial CO_2 concentration of 400 ppm (same as outdoor). It shows that the indoor CO_2 concentration can reach up to 5000 ppm if there is no air exchange between indoor and outdoor. If the building is follow the tight building standard with air leakage of less than 0.5 l/s, the indoor CO_2 concentration can also reach to 4000 ppm.

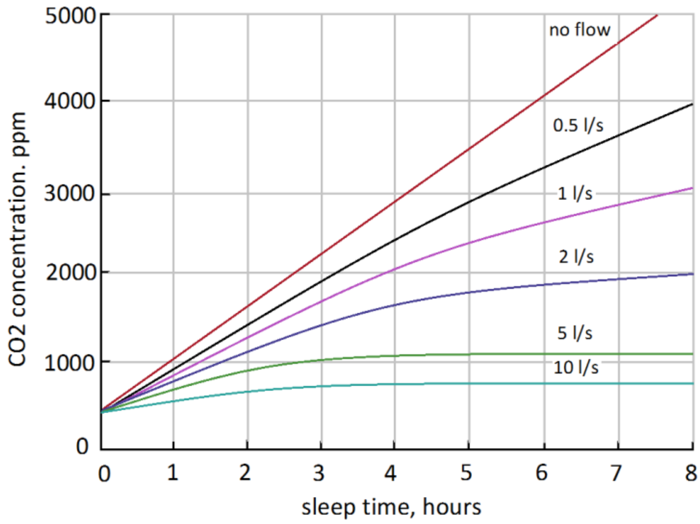

Fig. 1 CO_2 build up during sleep for a bed room with volume of 21m^3

Table 1 provides the relation between CO_2 level and its effect to human health. High-level CO_2 concentration would be dangerous and harmful with a cluster of complex symptoms that include irritation of the eyes, blocked nose and throat, headaches, dizziness, lethargy, fatigue, irritation, wheezing, sinus congestion, dry skin, skin rash, sensory discomfort from odors, and nausea. Even though the symptoms are usually disappear within a few hours, a more serious long term damaging effect on health may arise, typically the legionnaires' disease. The economic consequences of building related illnesses due to poor indoor are enormous.

Table 1 Relation between CO2 level and its effect to human health

350-450ppm	Normal background concentration in outdoor ambient air
350-1,000ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000-2,000ppm	Complaints of drowsiness and poor air.
2,000-5,000 ppm	Headaches, sleepiness and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
5,000	Workplace exposure limit (as 8-hour TWA) in most jurisdictions.
>40,000 ppm	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma, even death.

There are two basic solutions to mitigate the unacceptable levels of pollutants in the air-conditioned space: addressing the source of pollution (*source control*) and addressing the level of contaminants in the air (*dilution*). Source control, though the preferred approach, may not be often practical as they are pollutant specific and may include use of low formaldehyde emitting materials, banning of cigarette smoking, prevention of radon entry through sealing of foundations, eliminating use of asbestos and storing of paints and chemicals outside the occupied space. Controlling relative humidity will prevent microbial contamination.

On the other hand, dilution of contaminant concentration within the air-conditioned space can be accomplished by passive or active ventilation.

- Passive ventilation refers to air exchanged through doors, windows or other openings by natural forces. In most air-conditioned buildings, however, these openings have to be minimized in order to save energy.

- Active ventilation uses the same principles of natural ventilation combined with mechanical assistance and control where the pollutants in the source rate are constant and the pollutants concentration in the air-conditioned space is inversely proportional to the ventilation rate.

For hot and humid climate, increasing ventilation rate impose substantial cooling load on Air-Conditioning and Mechanical Ventilation (ACMV) systems as majority of the energy is consumed on the treatment of outside air. Energy Recovery Ventilation (ERV) systems can recover cooling energy from the exhaust airstream and transfer it to the intake airstream, saving energy and improving humidity control as well. The magnitude of these benefits varies depending on climate, but hot and humid regions like Southeast Asia are ideal places for ERV system applications.

Types of Energy Recovery Ventilation

Ventilation systems that transfer both sensible and latent heat (total enthalpy) are referred to as ERV, while those that only transfer sensible heat are called Heat Recovery Ventilation (HRV). ERV can transfer both sensible and latent heat. Sensible heat refers to the heat content of the air itself, which can be measured with a standard temperature sensor. Latent heat is the amount of energy that is required to evaporate water into water vapor (humidity) and is required to remove that water from the water vapor via condensation. Latent heat can be measured by a wet-bulb thermometer. Both ERV and HRV can remove the heat but HRV does not have the ability to modify humidity levels. Common ERV devices include enthalpy wheels and fixed-plate heat exchangers.

Enthalpy wheels: An enthalpy wheel is composed of a matrix of heat and moisture adsorbing material, like a desiccant, which rotates between the incoming outside air and outgoing exhaust air ducts (Figure 1).

Figure 2 Mechanics of an enthalpy wheel.

In the cooling season, as the wheel rotates, it removes water vapor from the moist outside air and transfers it to the dry, conditioned exhaust air that is leaving the building. Simultaneously, the wheel pre-cools the hot incoming outside air and transfers that heat to the cool, conditioned exhaust air. By pre-cooling and dehumidifying the hot, humid intake air, the enthalpy wheel reduces the load on the refrigerant compressor, saving electrical energy. Under part-load conditions, the wheel speed can be reduced, or a bypass duct can be employed to lessen the load on the fans and reduce energy consumption. Enthalpy wheels can have total effectiveness values as high as 75 percent or more, but proper cleaning and maintenance (at least once a year) are essential to ensure that the enthalpy wheels don't become fouled, as this can reduce heat transfer efficiency and increase the pressure drop in the ductwork.

Fixed-plate heat exchangers: Unlike enthalpy wheels, fixed-plate heat exchangers don't employ any moving parts. By driving intake and exhaust air through an alternating series of parallel plates that are separated and sealed, heat is effectively transferred between the two airstreams (Figure 3). Fixed-plate heat exchangers are available in a number of different configurations and can be made to transfer moisture as well as heat by using semipermeable materials to separate the airstreams.

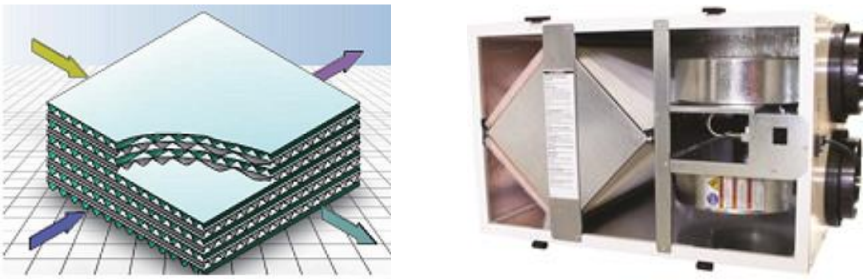

Figure 3 Configuration of a fixed-plate heat exchanger.

The total energy effectiveness of plate heat exchangers varies from unit to unit based on several factors such as size and configuration etc., but it's possible to find units with effectiveness values that are comparable to those of enthalpy wheels. Additionally, because no moving parts are involved, fixed-plate heat exchangers may be able to save additional energy when compared with an enthalpy wheel while also yielding lower maintenance costs. It is also important to maintain a clean air supply when using a fixed-plate heat exchanger for good performance. Table 2 provides an overall comparison of the two types ERVs

Table 2 Comparison of the two types of ERVs

	Rotary Wheel	**Fixed Plate**
Airflow arrangement	Counter-flow/Parallel-flow	Counter-flow/ Parallel-flow/Cross-flow
Air treatment range, m^3/h	85 and higher	85 and higher
Typical effectiveness	Sensible (50-80%) Total (55-85%)	Sensible (50-80%) Total (55-85%)
Allowable face velocity m/s	2.5 to 5	0.5 to 5
Typical design velocity m/s	2.5 to 5	1 to 5
Pressure drop, pa	62 to 250.	5 to 500
Typical design pressure drop	62 to 250	25 to 375
Temperature range, ^0C	-57 to 94	-57 to 800
Advantages	• Compact large sizes • Low pressure drop • Matrix material can be selected to suit a wide range of applications	• No moving parts • Low pressure drop • Easily cleaned • Lower cost • Core can be selected to suit a wide range of applications • Extensively used in Residential and Commercial applications
Limitations	• Cross-contamination possible • Cold climates may increase maintenance requirements • Large space required to accommodate the wheel • Large surface area to volume of matrix makes it susceptible to corrosion	• Cross-contamination possible
Cross-leakage	1 to 10%	0 to 5%
Control	Wheel speed control, or bypass dampers over full range	Bypass dampers and ducting

Fixed Plate ERV System Design and Installation

The correct size, type and number of ERV units required for any area is determined by three factors: the room size, its use and location, Table 3 shows recommended air change rates per hour for different required room ventilation needs.

Table 3 recommended air change rates per hour for different required room ventilation needs

Residential		**Offices**	
basements	3-4	Business offices	6-8
bedrooms	5-6	Lunch break rooms	7-8
bathrooms	6-7	Conference rooms	8-12
Living rooms	6-8	Medical procedure offices	9-10
Kitchens	7-8	Copy rooms	10-12
Laundry rooms	8-9	Main computer rooms	10-14
Restaurants		**Public Buildings**	
Dining areas	8-10	Hall ways	6-8
Food staging	10-12	Retail stores	6-10
Kitchens	14-18	Foyers	8-10
Bars	15-20	Churches	8-12
		Restrooms	10-12
		Auditoriums	12-14

With the provided guidelines, the following formula can be used when using air change rates:

$$Quantity\ of\ fresh\ air(m^3/h) = Air\ change\ rate \times Room\ volume(m?)$$

Four-step process can be used to calculate the total m^3/h:

1. Use the above *Air Changes per Hour Table* (or local standards) to identify the required air changes needed for each room.
2. Calculate the volume of the room ($Length \times Width \times Hight$).
3. Multiply the volume of the room by the required room air changes.
4. Sum the m^3/h of all rooms to obtain the total flow required.

If number of people is known such as bedrooms, the ventilation rate for the room can also be calculated based on the number of people in the room:

$$Quantity\ of\ air\ (m^3/h) = Number\ of\ people \times Rate/person\ (l/s) \times 3.6$$

The total flow required is obtained by sum the m^3/h of all rooms. A common practice for ventilation rate is *6 l/s* per person.

Fixed plate ERVs are generally well-built and well-designed pieces of equipment. However, there are some issues in the installation need special attention:

- Separate the duct system for ERV from the existing ductwork to avoid the problems associated with system control on airflow and pressure differences.
- Separate the ERV inlet and exhaust from each other and the rest of the home's ductwork to avoid cross contamination and moisture problems.
- Separate bathrooms to avoid moist air back into the house, it is recommends that bathrooms be equipped with independent exhaust fans and vents.

Following checklist can be used to help building owners and contractors understand the requirements for a quality ERV installation.

- Select an ERV with a good and a recognized recovery performance rating for local conditions.
- ERV ventilation system ducting should be completely separated from the ACMV system.
- The system has filters installed on both the intake and exhaust sides.
- Use separate ducting for kitchen and bathroom exhaust fan.
- Install multiple supply vents and a central exhaust.
- Design control system for dedicated volume and continuous operation.
- Use plain controls that consumers can easily access and understand.
- Provide a full range of airflows.
- Separate the intake and exhaust terminals outside to prevent air stream crossover.
- Seal and insulate all ductwork, and test for leakage.
- Measure ERV airstreams to ensure airflow through the ERV is balanced.
- Ensure all controls work as intended.
- Provide a maintenance plan with a schedule for changing the ERV filters, cleaning the outside air intake screen, and removing and cleaning the core regularly.

ERV System Control

Depending on the installation and ERV model, several parameters may need to be measured by sensors in ERV systems, including temperature, humidity, pressure and/or CO_2. The sensors are connected to controllers which has specific set point value. The control system also includes relays and transducers, switchers, regulators and timers to adjust fan speeds and air flow rates in ducts etc. the main control board may be located on the ERV itself and/or in the rooms. For multi-zone implementation, the main ERV control board is usually placed adjacent to the ERV and several terminal controllers are placed near the room thermostats. The operating controls may include several of the following functions.

- ***Low speed control***: To ensure the removal of indoor pollutants and the supply of fresh outdoor air, an ERV should be operated on low speed continuously based on the pre-set schedule, especially in airtight rooms and rooms with normal indoor pollutant levels. Under most circumstances, low-speed operation will meet the ventilation needs and will be more effective than intermittent high-speed operation.
- ***Time scheduling***: An intermittent exchange mode setting that automatically turns on the ERV at low speed for specified intervals. Operating in intermittent exchange mode may be appropriate when pollutant sources are low, the house is not overly airtight, or the occupants are away from room for extended periods. Sometimes, other provisions for ventilation can be arranged to turn off the ERV, such as opening doors and windows.
- ***High speed control***: Under certain conditions, the ventilation rate may need to be increased from low-speed operation. Depending on the installation, a high-speed cycle is triggered manually or by a timer, or other controls. High-speed operation is often

needed when: 1) using paints, solvents, cleaning products and other household chemicals; 2) the room air seems stale or contains odors; 3) there are many people in the room, such as during a party or meeting. Frequent or even continuous high-speed operation may be desirable during the first year after renovation to exhaust the moisture and pollutants being released by new building materials.

- ***Economizer Control***: The CO2 sensor should provide control to ERV outside air damper whenever the fresh air economizer cannot be used. If outside air is suitable for free cooling and there is a demand for cooling the bypass economizer shall have priority.
- ***Maintenance Indicator***: A maintenance light, which comes on automatically when the filters, and possibly other components, need to be cleaned or serviced. In addition, safety control systems are needed to minimize damages in a building and process facilities, by avoiding for example too high pressure in ducts.

Pollutant sensors (CO_2) may also be installed to realize Demand Control Ventilation (DCV). In such scheme, one sensor should be used for each zone of major occupancy or per ERV if a number of ERV serve a large zone. If occupancy density/pattern/usage is different in two adjacent areas, each area should be considered a separate zone. Sensors should be placed so that they can take a representative sample of CO_2 concentrations in each major occupied zone. Sensors can be placed in the space using similar location criteria to thermostats. An addition consideration is that the sensor should not be in a location where people might regularly breathe directly into the sensor. Sensors should be placed 1.5-2 meter above the floor. An alternative location is to place the sensor inside or above the return air grill leaving the space. The sequence of operation for CO_2 based DCV scheme may include

- ***Minimum Position for CO_2 Control***: The system shall be configured to provide a base ventilation rate to the space to control non-occupant related sources in the space. For most applications this base ventilation rate is 20-30% of the Design Ventilation Rate (DVR) for the space. This base level of ventilation should be provided during all occupied hours.
- ***Maximum Position for CO_2 Control***: The maximum position of the damper during CO_2 control should be set to equal the DVR for the space.
- ***Control Range***: The outside fan and air damper will be modulated between the minimum position and the maximum position necessary to provide the DVR to the space based on CO_2 concentrations. It is recommended that a proportional control approach be used to modulate the fan and damper based on CO_2 readings between a lower and upper control limit. This proportional modulation will ensure that 6 l/s per person of outside air is provided at all times based on actual occupancy.
- ***Upper Control Limit***: The proportional control strategy should be designed to position the damper to provide the DVR when the CO_2 levels are equivalent to the equilibrium concentration of CO_2 corresponding to the target l/s per person ventilation rate in the space.
- ***Lower Control Limit***: The proportional control strategy would position the damper in the minimum position until indoor levels exceed a certain CO_2 threshold above outside levels. Typically this threshold should be set at 150 to 200 ppm CO_2 above outside levels of at 400 to 600 ppm.
- ***Multiple Sensors Controlling a Single ERV***: Control should be based on the highest CO_2 concentration measured in all spaces served by the air handler. This can be

accomplished within the programming capabilities of most building control systems. Alternatively, transducers are available that can take in multiple inputs and pass through the highest value.

- ***Sensor Self-Calibration***: All CO_2 sensors are self-calibrating and require no maintenance over their rated life span. The self-calibrating feature used by these sensors is based on the fact that when buildings are unoccupied, inside concentrations of CO_2 will typically drop to outside levels, which are typically around 400 ppm. The CO_2 sensor is programmed to look for these low points that might occur over a 3-week period. If the sensor sees that it is out of adjustment with the lowest concentration measured over three weeks, the sensor automatically adjusts its calibration. To ensure optimum operation of this self-calibration feature, it is highly recommended that the control sequence of the system include a periodic per occupancy purge of the space to ensure that the sensors see true outside/background levels.

Benefits and Applications

The benefits to a building owner of a system with ERV are significant. An ACMV system that utilizes ERV is more energy efficient, improves humidity control, enhances indoor air quality, reduces peak demand charges, etc. These benefits are briefly discussed below.

- ***Reduce ACMV energy consumption***: ERV systems save energy by reducing the need to cool or heat outside air. Although fan energy consumption tends to remain unchanged or even increase if the ERV system increases drag in the ductwork, the cooling and heating savings generally far outweigh any increase in fan energy consumption.
- ***Reduce peak demand***: HVAC systems are some of the biggest contributors to peak electricity use—times during the day when the utility is required to produce the most energy and when rates are highest. By reducing the need for cooling and heating, an ERV system can help lower a building’s peak demand, thereby lowering your electric bill even further by requiring less power during times when rates are highest.
- ***Improve humidity control***: Because ERV systems are able to pre-dry incoming ventilation air; they can also help to improve humidity control. Improved building and appliance energy efficiency has decreased sensible cooling loads, while latent loads (including occupant respiration and moist ventilation air) have remained essentially the same. ACMV system are now required to remove more latent heat than they were designed for, leading to higher indoor humidity levels. ERV systems can mitigate these conditions, providing a benefit to building operators and occupants alike.
- ***Enhance IEQ***: In some cases, buildings may not be bringing in enough outside air for proper ventilation. By reducing the energy needed by the HVAC system to condition outside air, ERV systems can encourage building operators to increase the amount of outside ventilation air and improve indoor air quality. Additionally, ERV systems can allow building operators to meet updated building codes with a minimal corresponding increase in energy consumption.

ERV systems are well established, and installed costs are relatively stable. However, savings can vary widely depending on the region and the settings used. Costs and savings can vary from site to site based on factors like local climate; the size, type, capacity, and complexity of the ERV unit; and the ACMV system to be installed. Although some rules of thumb exist for estimating installed costs and reductions in HVAC tonnage, these are of limited accuracy. The best way to assess these criteria is to use energy simulation tools like the U.S. Environmental Protection Agency's ERV Financial Assessment Software Tool or vendor-provided calculators. Several studies show favorable economics for ERV systems in a variety of buildings. Simple payback periods for retrofit installations are ranged from two to five years in hot and humid climates. However, ERV installations in new construction projects can yield much shorter payback periods as a result of downsizing the cooling in response to lower ventilation loads. In general, buildings that make the best candidates for ERV systems are distinguished by the following.

- **Moderate to extreme cooling or heating climates**: Given that ERV can reduce the conditioning load from ventilation, buildings in climates where a lot of energy is required to heat or cool the outdoor air stand to benefit the most, whereas those in climates where little conditioning is required or where economizer operation is common will save less. Facilities with large refrigeration loads, such as supermarkets, will also benefit from the reduced humidity load that the display cases would otherwise have to remove.
- **Large ventilation requirements**: Buildings that require large amounts of outdoor air are likely to be good candidates for ERV because they will have correspondingly higher cooling and heating loads due to ventilation. For this reason, buildings that are open for only a few hours per day are unlikely to be good candidates for ERV and might be better off using timers to shut off ventilation fans during unoccupied hours.
- **New construction**: ERV systems can be more easily integrated into new buildings where they can be designed from the beginning to work with the ductwork. Additionally, because ERV systems reduce the cooling and heating load on the ACMV system, much of this equipment can be downsized, yielding lower up-front costs and larger energy savings.
- ***Homes***: ERV system can protect human health with less money spend on energy bills, using less energy to, assure comfort, and protect your property from damage. As air moves through your building, it removes pollutants so that there is always fresh air in living spaces to improved quality of life with a healthy and cozy room climate is guaranteed at day and night. It also protects the living space from mold and bacteria growth.

ERV help maintain a comfortable and healthy home by reducing the temperature and humidity of the fresh incoming air in the hot and humid regions. This is an important energy saving method. It's a healthier and more comfortable alternative to excessively running air conditioning to combat high humidity and temperature generated inside infiltrated through cracks and openings in the buildings. There is no better solution to poor indoor air quality, necessary ventilation and energy efficiency. The ERV offers building owners controlled, measured air-to-air exchange while promoting optimal air quality and energy efficiency.