

Heat Recovery Ventilation for Energy-Efficient Buildings: Design, Operation and Maintenance

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Abstract: Since the 1990s, many efforts have been intensified to fight global warming and energy crisis. Considering that the building sector is responsible for about 40% of the EU energy use and 36% of CO₂ emissions, many sustainable concepts have been revived from the past, a number of new innovative technologies have been invented, and new construction standards and policies have been implemented.

Sustainable architecture offers tailor-made solutions to minimize the negative environmental impacts of buildings without compromising its users' comfort. According to studies, humans spend about 90% of their live-time indoors; indoor air quality has a major effect on human health. Hence, bringing fresh air into all habitable areas without letting the warm/cool air escape has become a priority.

If properly operated and maintained, heat recovery ventilation (VHR) in energy-efficient buildings leads to an increased filtration and removal of micropollutants, and an overall improvement of the indoor air quality, thus generating more comfort and less health-related problems. A systematic case study in Italy is used in this research providing evidences of the effectiveness of mechanical ventilation heat recovery systems. This paper discusses a case with a combination of poor design, operation and maintenance to answer the questions of: what are the concerns about potential failures that are associated with these systems; and are there any cons in the technical aspects of a mechanical heat recovery ventilation system?

Keywords: Passivhaus, Energy efficiency, HVAC, Indoor air quality, Sustainable architecture.

I. INTRODUCTION: INDOOR AIR QUALITY AND OCCUPANT'S HEALTH

According to the United States Environmental Protection Agency (EPA), indoor environments can be much more polluted than outdoors even in large metropolitan areas (EPA, n.d.). Many people are at high health risks in their own homes due to the extensive exposure of indoor pollutants. In developed and temperate countries, it is estimated that individuals spend 70% of their live-time in their private homes, 20% in buildings, and 10% working outside or in transport (as cited in BenGhida, 2016). It was estimated that indoor pollutants are 1,000 times more likely to be inhaled by occupants than comparable outdoor pollutants due to improperly air ventilation and air renewal (California Air Resources Board, 2005).

On the other hand, indoor air emissions have a direct economic impact on cities and countries, e.g. California loses more than \$45 billion a year in direct medical expenses and worker productivity and efficiency (Ibid).

Besides radon, which is the natural undetectable radioactive gas that accumulates in enclosed spaces (BenGhida, 2016), building materials and furnishings, appliances, human activities, tobacco smokes, pets, devices for combustion, chemical products, air conditioning and ventilation systems are the main man-made sources of high indoor levels of air pollutants. These indoor contaminants can be found at very high rates in energy efficient buildings where airtightness is very important (Arundel et al., 1986). Humidifiers are usually used not only for minimization of adverse health effects but also to increase indoor comfort conditions and building durability. If not properly maintained and sterilized these humidifiers will have a negative effect, first, on the occupants due to microbial contamination, and second, on the building structure due to fungal growth or mite infestation (Arundel et al., 1986).

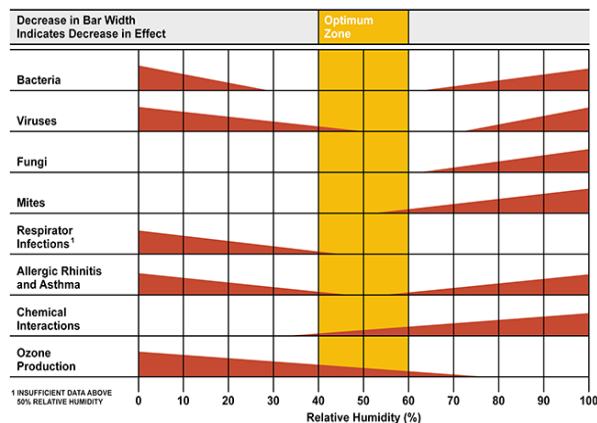


Figure 1. Optimum relative humidity range for minimizing adverse health effects (Arundel et al., 1986)

Figure 1 shows the optimum relative humidity (RH) zone for minimizing adverse health effects related to the indoor relative humidity. Most biological and chemical aspects increase in severity below 40% and/or above 60% (fig.1). Mortality due to influenza and respiratory diseases might be decreased in regions with low RH during winter seasons by increasing it (Arundel et al., 1986).

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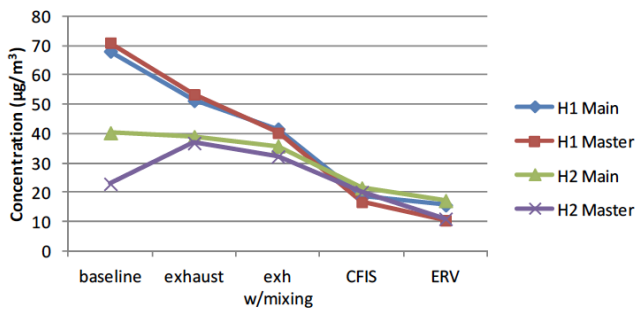


Figure 2. Formaldehyde concentration by ventilation system type (Rudd and Bergey, 2013)

Figure 2 shows indoor formaldehyde concentration measurements in the main and master zones in two different houses during baseline test and four different ventilation systems.

An Energy Recovery Ventilator (ERV) acts exactly as an HRV while keeping some of the indoor air moisture. The selection choice between an HRV or an ERV depends on four factors: 1) the climate, 2) the number of house users, 3) the specific personal needs (e.g. health conditions), 4) and the house size and volume. The ERV system gives an optimum result for formaldehyde abatement, however, it is important to mention that Rudd and Bergey did their experiment with different air changes per hour for the five ventilation systems (Rudd and Bergey, 2013).

II. HOW DOES A HEAT RECOVERY VENTILATOR WORK?

HRV units (air-to-air heat exchanger) provide continuous clean, fresh, and filtered air from the outdoor to the living indoor and exhaust stale air from high moisture spaces: kitchens, laundries, and bathrooms (fig.3).

Up to 95% of exhaust air heat can be recovered by transferring it to the incoming air (depends of HRV model and brand). Indoor comfort is ensured by smart sensors that monitor the relative humidity and supplied air that adjust automatically the indoor air quality with minimum heat loss. Depending on installed windows quality, air permeability of the architectural project and climate zone, HRV can save up to 30% in heat energy (Manz et al., 2000; Juodis, 2006).

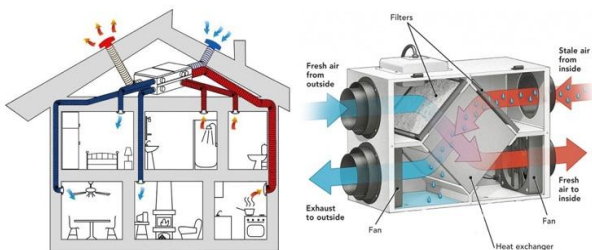


Figure 3. Heat energy ventilator

The HRV also known as the heat recovery air exchangers are equipped with two continuously running fans. The first one expels indoor stale air (saturated with smells, smoke, pollutants, etc.), and the second one supplies fresh filtered outside air. The fresh new air and expelled stale air never come into contact with each other; the air is not recycled. This technology captures heat or cooled energy and recycles it; it does not generate it. It can recover heat during winter or cool during summer from the expelled stale air, and

transfers it to the fresh incoming filtered air. The available HRV with cross-flow in the Italian market has a varying yield between 70-95% satisfying the actual EU ventilation standard for single family dwellings EN 13141-7: 2010.

A frost protection control is activated when the outdoor temperature is below the freezing point 0 °C to prevent the freezing off the heat exchanger core; the HRV is put on a standby mode. The antifreeze solution transfers the warm air towards the core, and the damper closes off the cold airstream. If the outdoor temperature rises again, the unit returns to its normal working mode. The frost protection control prevents the heat exchanger core from freezing

There are two types of HRV (fig.4):

- ✓ Centralized heat recovery ventilator (ducted): requires an adequate ducting for air distribution installation. It ventilates the whole house.
- ✓ Decentralized heat recovery ventilator (monobloc): designed to be installed directly in the wall or in a glass in contact with the outside. Ventilate the one single space or room.



Centralized HRV



Decentralized HRV

Figure 4. Centralized (Ducted) HRV vs Decentralized (monobloc) HRV

Filters, as well as the exterior vents, should be removed and cleaned four times per year on a regular basis.

III. BALANCING THE HEAT RECOVERY VENTILATOR

HRVs are designed to maintain a quasi-neutral indoor pressure by creating an equal balance between the incoming and outgoing air. However, the balance might not be reached in these cases:

- ✓ The HRVs are improperly regulated which creates a negative indoor pressure similarly to an unregulated exhaust fan, which on its turn can cause appliances combustion and inefficiency of the ventilation system
- ✓ There is a stack effect
- ✓ The HRV is ducted to an existing HVAC ductwork
- ✓ Radon gas mitigation fan
- ✓ Existing exhaust fans (e.g. WC fans)
- ✓ Doors and windows opening
- ✓ Natural gas appliances that pull indoor air for combustion

IV. ADVANTAGES AND DISADVANTAGES OF MECHANICAL HEAT RECOVERY VENTILATOR UNITS

Table 1 presents the most important pros and cons of an HRV use and installation in residential buildings.

Table 1. Pros and cons of heat recovery ventilator units

Advantages	Disadvantages
Maximum energy efficiency thanks to heat recovery systems: Up to 95% recovery (depends on HRV model installed)	Works efficiently in well-insulated and airtight buildings
Compact in size of the main control unit	Larger encumbrance of the insulated air supply/exhaust pipes, and air distribution ducts
Rapid initial investment amortization (in extreme climates)	Important initial investment
Can be used for heating and cooling	Filters need to be cleaned every 3 months (or replaced)
Reduction or elimination of chiller, piping, technical center, chimney, etc.	-
Static or dynamic management of overpressure or depression in every individual space.	-
Reduction of connected load and consumption (kW) for heating and cooling	-
Continuous clean, fresh, filtered air supply: elimination of irritants, allergens and air pollutants	-
Moisture control: mold formation prevention	-
Maintain comfortable constant temperature	-
Children and elderly well-being	-
Indoor acoustical comfort (silent)	-
Smart management: sensors constantly monitor the relative humidity and adjust the supplied air volume/air flow	-
Reduce greenhouse gas emissions	-

V. COST-EFFECTIVENESS OF AN HRV

To simplify the comparison, I will use an average electricity price for Italian household consumers (taxes included) of 0.2067 €/kwh which was determined for the first half 2018, as provided by Statistics Explained from the European Union portal (Eurostat, 2018). Obviously, the Italian market is much more open and competitive and offers many solutions and opportunities to spend less. An annual energy consumption comparison of different household appliances with a standard HRV is shown in Table 2. The selection of the heat recovery ventilator system depends on the number of house occupants, climate, and the volume size of the house to be ventilated. Thus, the energy consumption of an HRV varies from 50Watt to 100Watt and even more for bigger houses. The costs vary from €10,300 to €12,100 for an HRV unit and its full installation inside a 100m² house. The Law no. 190 of December 23, 2014 encourages the use of new technologies towards energy conservation and energy efficiency in buildings; it is possible for home owners to get a 50% tax deduction and in some circumstances, it can reach up to 65%.

It is important to mention that the recovered thermic watts are much higher than the consumed electrical watts, and of course it is much cheaper to heat dry air than humid air.

Table 2. Comparison of annual energy consumption of the HRV unit vs household appliances

Designation	Watt	Estimated use	Yearly consumption [kwh]	Annual cost [€]
20-Watt LED Bulb	20	4 hours/day	29.2	6.03
Hairdryer [With only 1 speed]	2800	2 hours/month	67.2	13.89
Fan [with 4 # speed]	180	8 hours [speed 2]/6months	64.4	13.31
Combi fridge-freezer	200	Continuously	201	41.55
LED TV	60	4hours/days	54	11.16
HRV	50-100	Continuously [~75Watt]	~657	135.80

VI. CONCLUSIONS

Providing clean and fresh indoor air into our homes is essential for a healthy livable environment. Controlled mechanical heat recovery ventilation do not only provide clean and fresh air but it also contributes to the building's energy efficiency and global warming mitigation. With the "2015 Stability Law", the Italian government is working to build a healthier and more sustainable country, encouraging the population to use the latest buildings cutting-edge sustainable technologies. Disadvantages outlined in this paper are almost negligible in comparison with the huge benefits that the HRVs are bringing to homeowners. The initial investment cost of an HRV are worthy for a healthy family. However, this is not a ready-to-use high-tech technology; because the study, installation and calibration of HRVs must be done by professionals. Any oversizing, negligence, or misuse can compromise the efficiency of the system and affect negatively the house user's health.

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¹Known as the 2015 Stability Law, for documented expenses related to the interventions referred to in Article 16-bis, paragraph 1 of the Decree of the President of the Republic December 22, 1986, n. 917

