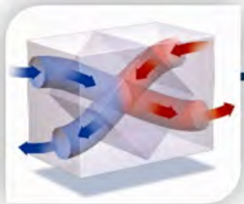

Chapter 3

Heat recovery Ventilators

Introduction

All buildings must be ventilated as required by the applicable building code. There are many ways in which a multi-unit residential building (MURB) can be ventilated, but for buildings attempting to achieve low thermal energy demand (TEDI), heat recovery on ventilation air is essential. For MURBs, this is often through individual suite energy or heat recovery ventilators (ERV/HRV), however, central or floor by floor ventilation systems with heat recovery are also possible. HRVs are self-contained ventilation systems designed to provide outdoor air to spaces, but also to temper that air via heat exchanger, which transfers heat from outgoing exhaust air to the incoming outdoor air. **Figure 3.1** shows a diagram of a typical HRV. Energy recovery ventilators (ERVs) are similar, but they also recover latent energy from exhaust air, as well as managing humidity.

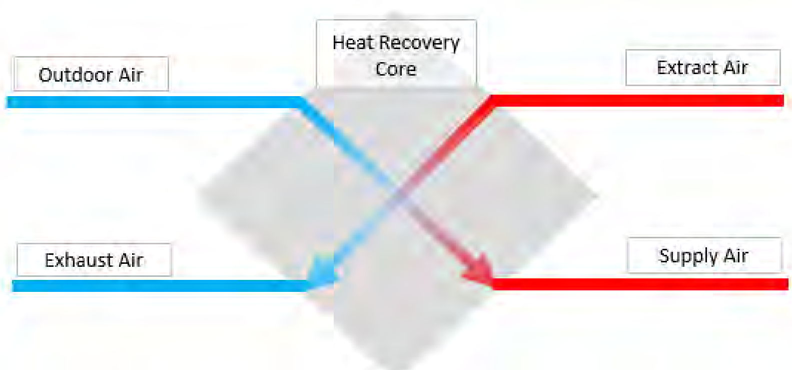

Figure 3.1: Typical HRV Schematic

HRVs directly reduce a suite or building's overall heating energy demand due to the tempering of incoming air. They also consume energy due to the fans (typically two), which are built-in and serve as drivers of supply and exhaust flows. Additional energy consumption by HRVs includes the potential requirement for preheat coils to prevent frost from building up within the unit. Preheat may be required when outdoor conditions are below the manufacturer's recommended operating limits of the unit. However, the overall net effect is a reduction in energy consumption because the savings in heating energy is typically significantly higher than the losses due to fans and auxiliary coils.

This section provides a brief overview of HRV rating methods and direction on how to properly represent HRVs in whole building energy modelling software depending on its rating method and software capabilities, with the goal of representing their benefit as accurately as possible.

Overview of Standards

The selection of an HRV for a design requires understanding of the requirements of the project as well as various key characteristics of the units under consideration. Various standards and certifications have developed out of a need to be able to compare HRVs in a fair way. There are various certifications and testing methodologies available, but the following are the main standards referenced in North America:

- **ANSI/AHRI Standard 1060-2014: Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment**
  - AHRI is typically used for commercial units with flows from 50 to 5,000 cfm.
  - This standard can be used to rate stand-alone cores such as heat pipes or self-contained units like HRVs.
- **CAN-CSA C439-2014: Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy Recovery Ventilators**
  - The CSA standard is the main rating methodology in North America, serving as a basis for both EnergyStar and the HVI rating systems.
  - This standard can be applied to packaged units only, but the standard applies to units of any size.
- **Home Ventilation Institute (HVI) Publication 920: Product Performance Certification Procedure Including Verification and Challenge**
  - Uses CSA C439 as a basis for its methodology.
  - Applies to packaged products intended for residential occupancy only.
- **EnergyStar**
  - Uses CSA C439 as a basis for its methodology.
  - Applies to packaged units up to 500 cfm.
  - Introduces some additional requirements such as minimum efficiency and fan power limits.
- **Passive House**
  - Proprietary methodology developed for use in the Passive House program.
  - Includes additional requirements such as minimum efficiency, fan power limits, supply air temperature limits and bypass requirements.
  - Metrics measure drop-off in air temperature leaving the unit, instead of uplift in air temperature leaving the unit. All of the other standards use uplift.

KEY METRICS

When comparing the standards, it is important to understand that there are differences in terminology for the key metrics involved. The terms *efficiency* and *effectiveness* are used throughout these standards. Both are an attempt to measure the *useful* heat transfer provided by the HRV as a fraction of the theoretical maximum energy that can be extracted. The higher the efficiency, the more energy is recovered and used to temper incoming air. The differences arise in what is included in the theoretical maximum energy that can be extracted and what is considered useful heat. **Table 3.1** summarizes the differences between how the terms are used in each standard. HVI's Sensible Recovery Efficiency (SRE) and Passive House's Efficiency are the metrics most applicable to energy modelling and are referenced later in this chapter.

Table 3.1: Summary and Comparison of Key Metrics

Metric	HVI/CSA	PH	AHRI
Theoretical Energy Available	Difference in temperature between air extracted from space and incoming outdoor air		
Effectiveness	Includes air leakage, cross contamination and fan power (Apparent Sensible Recovery Effectiveness: ASRE)	n/a	Includes air leakage, cross contamination and fan power. Fan power is not accounted for in stand-alone cores.
Net Effectiveness	n/a	n/a	Removes effects of cross contamination, but still includes fans, if present.
Effectiveness (Low Temperature Rating)	Includes air leakage, cross contamination, fan power and defrost/bypass effects	n/a	n/a
Efficiency	**Removes effects of air leakage, cross contamination, defrost and supply fan power. (Sensible Recovery Efficiency: SRE)**	**Includes air leakage, cross contamination and fan power**	n/a

The metrics are derived from measurements taken at particular temperatures and flows. It is important to use the metric measured at the flow closest to the design flow rate of the HRV being modelled. For example, HVI often provides efficiency values for a range of flows, in contrast to Passive House efficiencies, which are always provided at a specific flow rate. For a multi-speed unit, this would be a calculated flow rate, dependent on the minimum and maximum flows. This calculated value is not directly an average, so this can make comparisons between Passive House and other ratings difficult for multi-speed units. See the Passive House documentation for details (PHI, 2009).

The largest difference between Sensible Recovery Efficiency (SRE) and Apparent Sensible Recovery Effectiveness (ASRE) (from **Table 3.1**) is the inclusion of supply fan heat effects, leakage and cross contamination. A comparison of the differences between SRE and ASRE for several hundred HRVs from the HVI product database is shown in **Figure 3.2**. There is a strong relationship between SRE/ASRE difference and fan power, as would be expected.

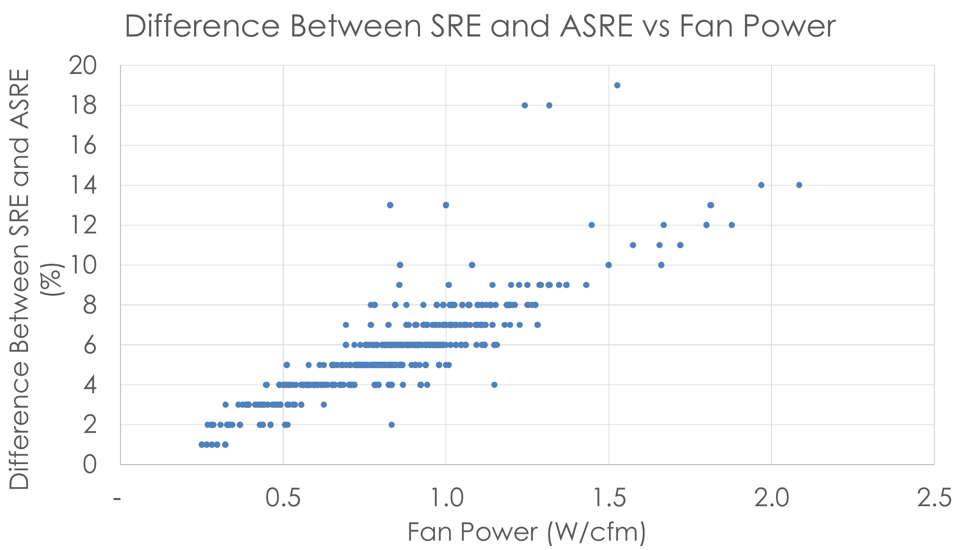

Figure 3.2: Effects of Fan Power on SRE vs ASRE

Third Party Methodologies

Methodologies for interpreting HRV ratings and modelling HRVs vary. Moreover, additional requirements related to HRVs that are not directly related to a particular HRV rating methodology may also be required in projects. For example, the supply air temperature for Passive House is not allowed to drop below certain comfort limits. There is also a requirement that HRV effectiveness be derated by 12% if the unit is not an officially certified Passive House HRV.

PHIUS (the Passive House Institute of the US) studied HRV ratings in the context of Passive House in the report "PHIUS Technical Committee ERV/HRV Modeling Protocols" (PHIUS, 2015). The intent was to find a more equitable representation of HVI rated HRVs for the North American industry. The report recommends to manually adjust for fan power using HVI rated conditions for efficiency (not effectiveness). This means that the effects of leakage and cross contamination are not accounted for and the effect of fan heat is approximated. This is generally a good approach, but the PUIUS method is specifically designed to recreate a Passive House rating for use in the Passive House software only.

While the above methods may not be ideal representations of HRVs in actual operation, they are required to support specific methodologies like Passive House, and are to be used in conjunction with specific tools that support these methodologies and associated assumptions.

Recommended Methodology

There are various methodologies and standards with different terminology and focus. This can lead to significant confusion and controversy relating to which one is "best". Fundamentally, all of the examined standards provide useful information when used with understanding of its context and when trying to answer the question "How will this HRV impact my building's energy consumption?" The primary goal, when trying to answer this question, is to accurately model the energy impacts of the HRV on the design. In order to do this, all of the energy-related impacts should be represented.

At first it may appear that the ASRE is the most desirable metric because it includes as many "real world" effects as possible. There are several problems with this approach. Leakage of air into the HRV and transfer of heat through the HRV casing affect the temperature of air being provided to the space, however, they occur at the expense of additional load on the space itself. This leads to no overall net savings in heating energy so it is not appropriate to include this in a metric designed to help asses overall energy consumption. Cross contamination between supply and exhaust flows does lead to a net reduction in energy consumption because the air would otherwise leave the building and be lost. However, allowing "credit" for this in a metric endorses energy savings at the cost of air quality.

The recommended approach is to use the SRE for energy modelling exercises. However, this is not without issues because supply fan power is not included in the SRE. Fan power directly offsets heating load, at the cost of Energy Use Intensity (EUI), which is a real and necessary impact that should be accounted for in an energy model. Fan power should be modelled directly, if possible, or the SRE can be adjusted to account for fan power. A description of the potential adjustment is included later in this chapter.

CONTEXT IS KEY

The various rating methodologies differ in their intent, context and assumptions, so it is a challenge to use them for fair comparisons between HRVs. However, they all provide metrics useful for judging real-world annual energy use when used in their intended way. Fundamentally, the different methodologies are all "correct" for their given contexts. The key is to use them appropriately.

When comparing HRVs it is important to understand if a particular metric gives "credit" for one effect or another (poorly performing fans, leakage, etc.), but when judging its impact on a building, what matters most is that the metric is used correctly in the tool. The challenge is that different energy modelling tools make different basic assumptions and have different defaults, which can make accurately using the available metrics a challenge. Several key points should be understood:

1. Energy modelling software will either assume a location for the fans in a heat recovery device or start with a default fan arrangement. These assumptions and/or defaults may not match the actual fan placement of the HRV in question. The energy modeller must understand these differences and adjust for them if necessary.

2. The impacts of defrost and other control methods, such as summer bypass, will not already be accounted for by default in an energy model, so the energy modeller must implement these effects separately. Modelling controls separately is desirable because they can vary between projects even with identical HRVs. The details of how this is done depends on the software.

3. When modelling a heat recovery system using an hourly simulation program such as EnergyPlus or eQuest, the energy modeller must determine if an adjustment to efficiency is required. The flow charts in **Figure 3.3** and **Figure 3.4** provide a more detailed description of this process, but the modeller must do one of the following:

    - Ensure that modelled fan placement matches the HRV's design,

    - Adjust the effects of fan heat on the airstream of the modelled HRV to match the effects of the fans in the actual HRVs, and

    - Adjust the efficiency up or down appropriately so that when/if the energy model adds fan heat, the overall efficiency matches the HRV's rated efficiency.

4. Use the efficiency metric measured at the design flow rate of the HRV if available.

5. Fan power is not included in an AHRI rating for a stand-alone core regardless of the use of effectiveness or efficiency.

6. HVI/CSA's effectiveness and low temperature rating efficiency are similar in that they both take into account defrost cycling time. These values should not be used directly because defrost and its effect on heat recovery is modelled explicitly elsewhere through bypass controls, pre-heat coils or other software-dependent approaches.

The following flow-charts (**Figure 3.3** and **Figure 3.4**) demonstrate the recommended approach to HRV modelling when HVI/CSA and AHRI metrics are available. These flow charts apply to projects pursuing conventional high performance building targets. If a project is pursuing Passive House certification, then the Passive House metrics and methodology must be used.

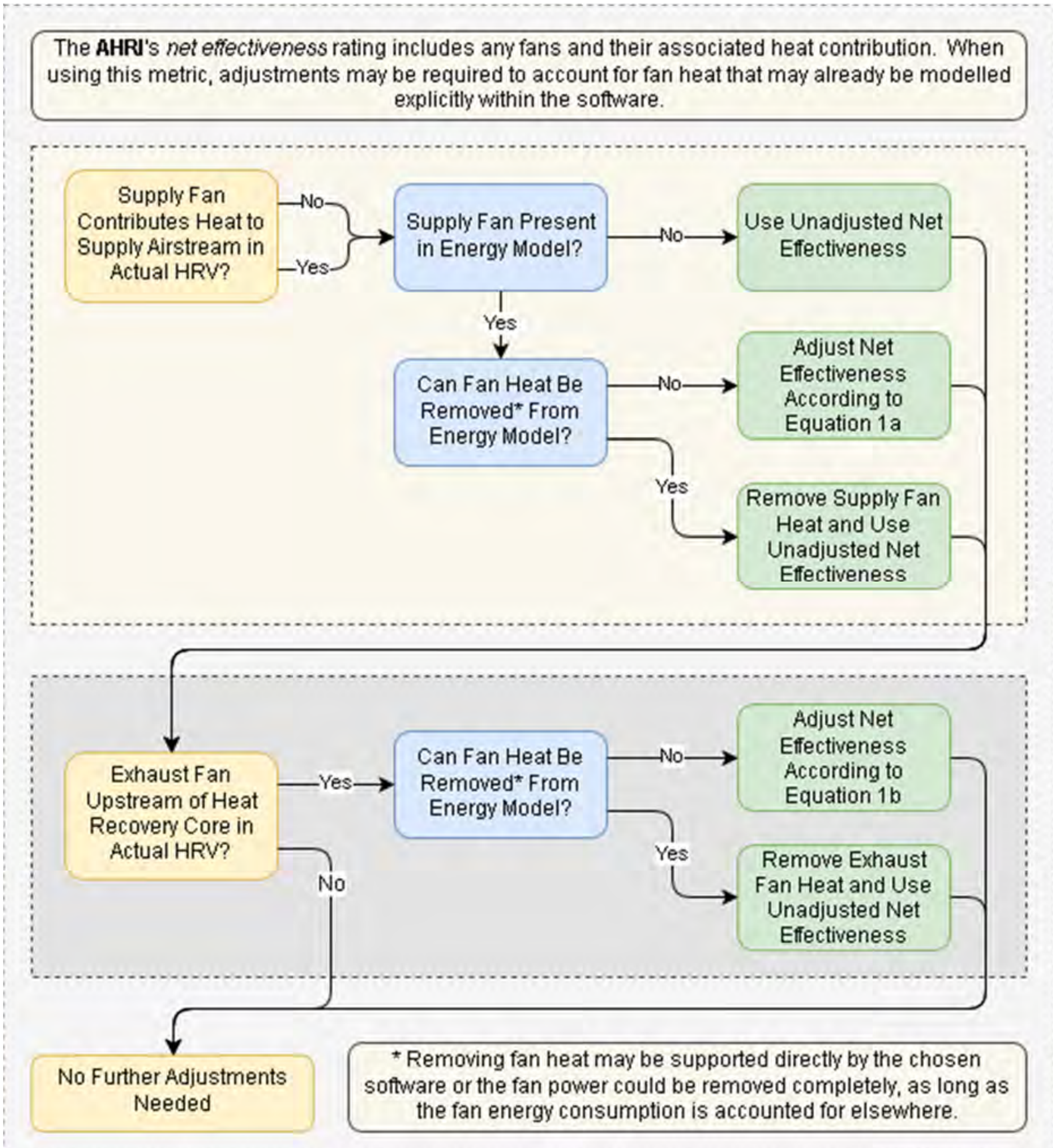

Figure 3.3: HRV Modelling Flow Chart (AHRI)

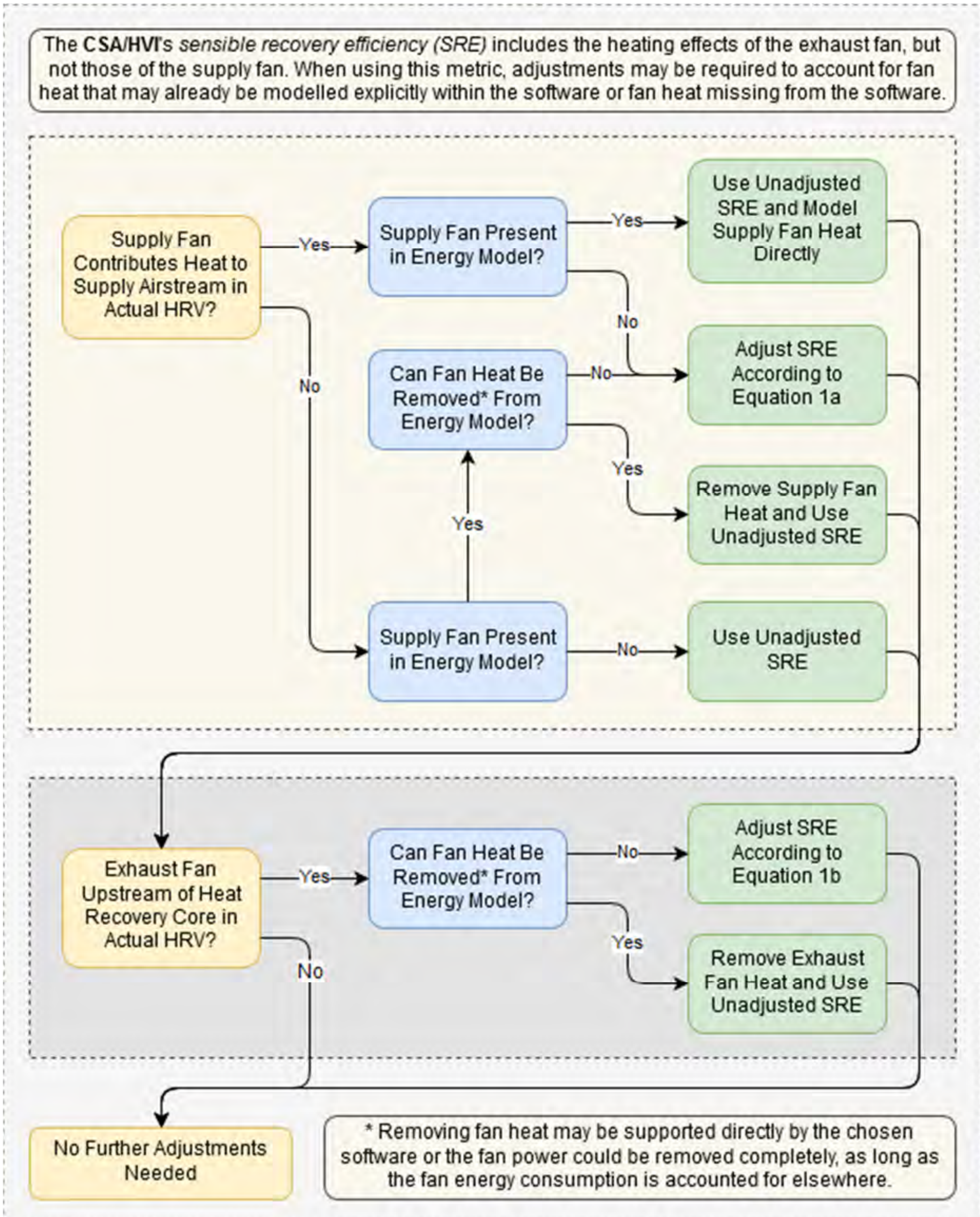

Figure 3.4: HRV Modelling Flow Chart (CSA/HVI)

The following equation can be used to adjust the rated efficiency. The constants shown here are the combinations of conversions of units and the rated difference in temperatures required by the methodology in question. More details about the derivation of these formulas can be found in **Appendix B**.

$$\varepsilon_{Adjusted} = \varepsilon_{Rated} \pm A_{SF} - A_{EF} \quad \text{(Equation 1)}$$

Where A_{SF} is the adjustment for the supply fan and A_{EF} is the adjustment for the exhaust fan. A_{SF} will be positive in cases when the energy modeller is trying to add the effects of fan heat and negative when trying to remove the effects of fan heat. In order to decide, the energy modeller must understand the software being used and whether fan heat is already accounted for in the energy model. The end goal is to account for fan heat fairly, in the appropriate place and only once. A_{EF} will always be negative or zero because the metric being adjusted will already include the effects of the exhaust fan.

$$A_{SF} = \pm \frac{\left(\frac{W_{SF}}{cfm}\right)}{12.5497+\left(\frac{W_{EF}}{cfm}\right)} \quad \text{(Equation 1a)}$$

$$A_{EF} = 0.07968 \times \varepsilon_{rated} \times \left(\frac{W_{EF}}{cfm}\right) \quad \text{(Equation 1b)}$$

$$W_{SF}\ and\ W_{EF} = Rated\ power\ consumption\ of\ the\ supply\ and\ exhaust\ fans\ respectively.$$

$$cfm = Rated\ flow\ rate\ of\ unit\ in\ cubic\ feet\ per\ minute$$

$$\varepsilon_{rated} = Rated\ efficiency\ as\ a\ fraction\ (SRE\ for\ CSA/HVI)\ or\ net\ effectiveness\ (AHRI)$$

The fan powers in the equations above should be considered zero if the fan motor is not in the same airstream as the fan itself. If one motor serves two fans, the entire fan power should be allocated to the appropriate airstream. There is a small difference between calculating the effects of the supply and return fans individually or together. However, this difference is small, and decreases as fan power decreases, so is not considered here.

Adjusting efficiency using Equation 1 brings the SRE metric closer to the ASRE metric. The remaining differences are primarily due to leakage and cross contamination. **Figure 3.5** shows the differences between the adjusted SRE and ASRE versus unadjusted SRE for several hundred HRVs from the HVI database. Most HRVs have 2-4% difference after adjustment. The more efficient units differ by at most 2%. Several outliers are present. These represent HRVs with particularly inefficient fans or HRVs where the fan arrangement is not typical.

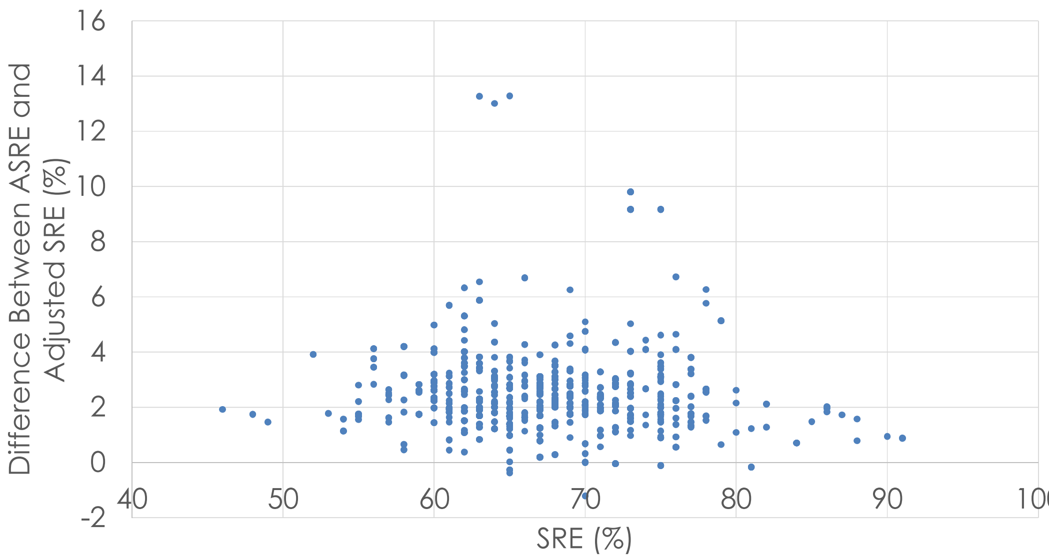

Figure 3.5: Difference between Adjusted SRE and ASRE versus SRE

The primary differences between metrics are due to fans, leakage and cross contamination. Fan heat is accounted for in the energy model or adjusted using Equation 1, air leakage from the room into the HRV will not affect energy use in reality and cross contamination is energy savings at the expense of air quality.

Fans

A key difference between the standards is the assumption of when/if fan energy is "useful". In the Passive House method, all fan heat (supply and exhaust) is assumed to contribute to offsetting heating loads. This may or may not be appropriate for a given project. In the other methodologies, the supply fan contributes to heating during heating season, but applies a penalty during cooling season. Also, if the exhaust fan is upstream of the heat recovery core, its impact will be included in the effectiveness, while if it is downstream it will not.

In all methodologies that include fan power, inefficient fans can inflate the results. Passive House is the only method to also limit fan power as a requirement to meeting the standard. Passive House requires that HRVs not exceed 0.45 Wh/m^3 (~0.26 W/cfm) at the tested flow rate. By limiting fan power, Passive House reduces the heating effects of low-efficiency fans. In any methodology, the fan power must be considered due to its effect on overall energy consumption.

Defrost

Defrost strategies can play an important role in a heat recovery system for Canadian climates. All heat recovery devices have a low limit on their operating temperatures, meaning they will automatically shut off or take some action to prevent damage due to frost or low temperatures. The minimum operating temperature differs between units, with higher efficiency units typically having lower minimums. The defrost strategy can significantly impact thermal energy demand in a building because the measures taken to mitigate frost will often reduce heat recovery effectiveness or temporarily disable heat recovery completely. The following are common strategies for frost control in HRVs:

- **Bypass:** Internal or external to the HRV, a bypass system will allow outdoor air to be supplied without it passing through the heat recovery core. This ensures that ventilation air is provided, but provides no heat recovery. This method will put all ventilation air heating load directly onto the mechanical system and could also lead to comfort issues when cold air is introduced directly into the heated space.

- **Recirculation:** Exhaust air is recirculated as supply air, warming the heat recovery core and reducing frost. The disadvantage to this method is that there is no ventilation air during recirculation mode. This is a simple method, but there is no heat recovery during recirculation and some codes do not allow ventilation to be stopped in this way.

- **Exhaust Only:** Using this method involves stopping the flow of outdoor air through the heat recovery core, but continuing to exhaust air from the building. This allows the core to warm up without cold outdoor air entering, but means there is no ventilation during this period. It also leads to an imbalance of air pressures within the building, which is undesirable.

- **Outdoor Air Preheat:** Incoming outdoor air is preheated to ensure the air is always above the minimum operating temperature of the HRV. This allows heat recovery and ventilation at all times, but introduces additional heating energy for the preheat coil. This is the optimal method of defrost because the amount of additional heating energy will likely be lower than the amount of heat recovery gained.

It is generally recommended that ventilation is provided continuously for MURBs, therefore, the outdoor air preheat method is generally recommended. Some jurisdictions allow certain exceptions to this and/or include additional requirements. Nevertheless, the energy required to preheat the incoming air is important to consider. **Table 3.2** shows the penalty a building will incur due to preheating the outdoor air up to the low limit of an HRV for typical MURB ventilation rates. When comparing HRVs of similar efficiency, the unit with the lower temperature limit will result in a lower TEDI due to less preheat. It is clear that the penalties can be significant in colder climates so design teams should carefully consider the temperature rating of the project's HRVs.

It is important to understand that ensuring constant ventilation may result in a penalty, but will also ensure that the heat recovery device is available at all times because it would otherwise be bypassed. This can lead to an overall net reduction in TEDI even after the preheat penalty, depending on the efficiency of the HRV and the climates.

The scenarios discussed in this chapter and the next chapter assume that an HRV is rated for operating conditions matching the typical outdoor temperature of that climates, so that preheat is not required. If the unit had a lower limit than this, the penalties in **Table 3.2** would apply to these scenarios as well.

Table 3.2: TEDI Penalty Due to Preheat Coil by Climate Zone

Preheat Coil Setpoint (°C) (HRV Low Limit Rating)	Preheat Coil TEDI Penalty (kWh/m²) by Climate Zone			
	4	5	6	7a
0	0.2	3.9	7.7	14.1
-5	0	1.6	4.0	9.1
-10	0	0.5	2.0	5.6
-15	0	0.1	0.9	3.1
-20	0	0	0.4	1.4
-25	0	0	0.1	0.5

Regardless of the method, the energy impacts of defrost must be included in energy models. The approach varies depending on the software, so the energy modeller must understand the design defrost strategy and how to implement this in the software being used on a project.

HRV Standards in Context

For most projects, there will be no choice in which standard to use. Requirements are imposed by the authority having jurisdiction or by the building rating system being used.

In a design with low thermal demand, the assumptions around which metric to use, and the resulting impact on overall building energy use and TEDI, may not be significant. **Table 3.3** summarizes the effects of modelling HRVs in climate zone 7a using various rating methodologies. The "Max Difference" column shows the maximum difference in TEDI resulting from modelling the HRV for the various methodologies. The Passive House rating, the HVI ASRE rating and Adjusted SRE were modelled in EnergyPlus. Some of the units examined have both Passive House and HVI ratings available.

The differences between the ratings are small and consequently the differences in TEDI are also small. As the efficiency of the units increases and the fan power decreases, potential differences between standards are marginalized for low TEDI buildings.

Table 3.3: Summary of Impact on TEDI of Various Standards

HRV	PH Rating (%)	HVI ASRE Rating (%)	HVI SRE Rating Adjusted using Equation 1 (%)	Total Fan Power (Watts/cfm)	Max Difference in TEDI (kWh/m²) For Climate Zone 7A
1	92	90	88	0.52	1.71
2	84	88	87	0.39	1.74
3	-	83	79	0.88	1.77
4	-	81	76	0.77	2.22
5	-	64	60	1.01	1.86