INTRODUCTION

Air handling devices of any form will have some amount of air leakage. Since most air handling devices include a fan, the device (air handling unit, fan coil etc.) will see the largest pressure differential of any part of the HVAC system and hence potentially the highest leakage rate.

Air leakage is an energy penalty for the building. It is important enough that energy compliance documents such as ASHRAE Standard 90.1 – Energy Standard for Buildings Except Low-Rise Residential Buildings have leakage requirements for ductwork, however, there are currently no leakage requirements for air handling devices. This document will review common leakage criteria and make recommendations on specifying leakage rates.

In addition to air leakage, most air handling devices have some form of temperature gradient across the unit casing that leads to a parasitic energy loss or gain. Studies have shown that cabinet leakage losses are three to five times greater than thermal heat gain or loss through the cabinet.

INFILTRATION AND EXFILTRATION

Figure 1 shows a typical make-up air handling unit (AHU) with no return fan. The pressure curve shows how the unit is both positively and negatively pressurized with respect to its surroundings. Between the inlet and the fan, the cabinet is negatively pressurized and outdoor air is leaking in (infiltration). By the inlet of the fan, there is -2.4” w.c. pressure differential across the cabinet.

Beyond the fan, air is positively pressurized and is leaking out (exfiltration). In this example, at the discharge of the fan the pressure differential is +2.6” w.c.

Both leakage directions are problematic. In the case of negative pressurization, unconditioned and unfiltered air enters the unit and is delivered to the building. Leakage on the positive pressure side results in air that has fan work and psychrometric work being lost and not delivered to the building. This can be a significant operating cost.
IMPACT OF LEAKAGE ON OPERATING COST

Analysis by Price on a 100% gas heat make-up air unit compares the 4% (of supply air volume) infiltration and thermal loss of a standard unit with the 1% leakage rate for a 10,000 cfm high performance unit located in Chicago. The 75% reduction in infiltration results in a $500 annual savings.

Table 3: Heat Loss and Infiltration Cost

<table>
<thead>
<tr>
<th>Temp Range DB (°F)</th>
<th>Number of Occurances (hr)</th>
<th>Load (Btu/h)</th>
<th>Cost</th>
<th>Heat Load (Btu/h)</th>
<th>Cost</th>
<th>Heat Load (Btu/h)</th>
<th>Cost</th>
<th>Heat Load (Btu/h)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>95-100°F</td>
<td>1</td>
<td>3483</td>
<td>$0.02</td>
<td>14652</td>
<td>$0.10</td>
<td>536</td>
<td>$0.00</td>
<td>3663</td>
<td>$0.03</td>
</tr>
<tr>
<td>90-95°F</td>
<td>47</td>
<td>2709</td>
<td>$0.89</td>
<td>18180</td>
<td>$5.98</td>
<td>417</td>
<td>$0.14</td>
<td>4545</td>
<td>$1.50</td>
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<tr>
<td>85-90°F</td>
<td>119</td>
<td>1935</td>
<td>$1.61</td>
<td>12564</td>
<td>$10.47</td>
<td>298</td>
<td>$0.25</td>
<td>3141</td>
<td>$2.62</td>
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<tr>
<td>80-85°F</td>
<td>347</td>
<td>1161</td>
<td>$2.82</td>
<td>8568</td>
<td>$20.81</td>
<td>179</td>
<td>$0.43</td>
<td>2142</td>
<td>$5.20</td>
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<tr>
<td>75-80°F</td>
<td>576</td>
<td>387</td>
<td>$1.56</td>
<td>5238</td>
<td>$21.12</td>
<td>60</td>
<td>$0.24</td>
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<td>$5.28</td>
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<tr>
<td>70-75°F</td>
<td>658</td>
<td>242</td>
<td>$0.97</td>
<td>2484</td>
<td>$11.44</td>
<td>37</td>
<td>$0.15</td>
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<tr>
<td>65-70°F</td>
<td>594</td>
<td>726</td>
<td>$2.63</td>
<td>3255</td>
<td>$11.79</td>
<td>112</td>
<td>$0.40</td>
<td>814</td>
<td>$2.95</td>
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<tr>
<td>60-65°F</td>
<td>886</td>
<td>1209</td>
<td>$6.53</td>
<td>5425</td>
<td>$29.31</td>
<td>186</td>
<td>$1.01</td>
<td>1356</td>
<td>$7.33</td>
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<tr>
<td>55-60°F</td>
<td>586</td>
<td>1693</td>
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<tr>
<td>50-55°F</td>
<td>601</td>
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<td>335</td>
<td>$1.23</td>
<td>2441</td>
<td>$8.95</td>
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<tr>
<td>45-50°F</td>
<td>603</td>
<td>2661</td>
<td>$9.78</td>
<td>11935</td>
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<td>409</td>
<td>$1.51</td>
<td>2894</td>
<td>$10.97</td>
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<tr>
<td>40-45°F</td>
<td>455</td>
<td>3144</td>
<td>$8.72</td>
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<td>558</td>
<td>$3.51</td>
<td>4069</td>
<td>$22.95</td>
</tr>
<tr>
<td>30-35°F</td>
<td>814</td>
<td>4112</td>
<td>$20.41</td>
<td>18445</td>
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<td>633</td>
<td>$3.14</td>
<td>4611</td>
<td>$22.89</td>
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<tr>
<td>25-30°F</td>
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<td>4596</td>
<td>$16.31</td>
<td>20615</td>
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<td>$2.51</td>
<td>5154</td>
<td>$18.29</td>
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<tr>
<td>20-25°F</td>
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<td>5079</td>
<td>$9.73</td>
<td>22785</td>
<td>$43.62</td>
<td>781</td>
<td>$1.50</td>
<td>5696</td>
<td>$9.91</td>
</tr>
<tr>
<td>15-20°F</td>
<td>334</td>
<td>5563</td>
<td>$11.33</td>
<td>24965</td>
<td>$50.82</td>
<td>856</td>
<td>$1.74</td>
<td>6239</td>
<td>$12.71</td>
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<tr>
<td>10-15°F</td>
<td>127</td>
<td>6047</td>
<td>$4.68</td>
<td>27125</td>
<td>$21.01</td>
<td>930</td>
<td>$0.72</td>
<td>6781</td>
<td>$5.25</td>
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<tr>
<td>5-10°F</td>
<td>75</td>
<td>6531</td>
<td>$2.99</td>
<td>29295</td>
<td>$13.40</td>
<td>1005</td>
<td>$0.46</td>
<td>7324</td>
<td>$3.35</td>
</tr>
<tr>
<td>0-5°F</td>
<td>57</td>
<td>7014</td>
<td>$2.44</td>
<td>31465</td>
<td>$10.94</td>
<td>1079</td>
<td>$0.38</td>
<td>7866</td>
<td>$2.73</td>
</tr>
<tr>
<td>-5-0°F</td>
<td>31</td>
<td>7498</td>
<td>$1.42</td>
<td>33635</td>
<td>$6.36</td>
<td>1154</td>
<td>$0.22</td>
<td>8409</td>
<td>$1.59</td>
</tr>
<tr>
<td>-10-(-5)°F</td>
<td>28</td>
<td>7982</td>
<td>$1.36</td>
<td>35805</td>
<td>$6.11</td>
<td>1228</td>
<td>$0.21</td>
<td>8951</td>
<td>$1.53</td>
</tr>
</tbody>
</table>

Additional energy losses can occur from the non-productive fan work. For VAV systems, the fans will operate at a higher flow rate to offset the air loss. For constant volume systems, the supply air volume will not be delivered (due to leakage losses) or, more likely, the system flow rate will be increased to offset the losses thus increasing the fan work. Increasing the supply airflow to offset the leakage will result in an additional $120/year penalty. The costs of air leakage in an AHU are significant and should be minimized.

Systems that exhibit infiltration (negative pressure units) have air leaking into the supply air system that may not be filtered or conditioned. For critical applications (e.g., healthcare) infiltration can be a major concern.
CABINET CONSTRUCTION

To minimize cabinet leakage, the following practices are employed:

- Minimize wall deflection to L/240. Walls that flex create leaks. The most common method for fiberglass insulated units is to increase the outer casing steel gauge. For larger units, deeper walls (2 to 4 inches thick) are used to minimize deflection. More recently, many manufacturers have moved to injected foam cabinet construction which is extremely rigid.

- Seal all joints.

- Seal all penetrations such as wiring and piping penetrations.

- Use doors with gasketed frames. The doors should open against air pressure.

Generally, the smaller the unit the higher the leakage rate relative to supply air flow rate. However, since the unit is small, the absolute leakage has a minor impact on overall operating cost.
DOOR ORIENTATION

Door orientation has a major impact on cabinet leakage. A door should open against the pressure gradient. This means the larger the pressure differential, the greater the force pressing the door against its seal. A door that opens with the pressure gradient is being forced away from its seal. (A door that opens with the pressure gradient can be a safety risk as it will be pushed towards the person if the unit is operating.)

Almost every AHU will have both negative and positive sections (see Figure 1) so both inward and outward swinging doors should be employed to provide the lowest leakage rate possible. While this is quite common on high-end custom AHUs, it is rare on rooftop units. Inward swinging doors require clearance on the inside and can often require a longer section to function. For example, an inward swinging door in the inlet of a fan will require space so the door can swing clear of the fan isolation base.

Using doors that do not open against pressure will make it difficult if not impossible to maintain high performance leakage rates.

LEAKAGE CRITERIA

For North America, most specifications follow the SMACNA standards for duct leakage. However there currently is no leakage standard for air handling products (Europe has EN1886 which has a leakage component).

This leaves the specifier responsible for defining the leakage criteria. The manufacturers that can actually provide leakage data also define the method in which the data is presented. There is also no third-party validation of leakage data. The following are some common methods to define leakage criteria:

Leakage Rate as a Percentage of Supply Airflow

One of the most common methods of defining leakage criteria is to base it on a percentage of supply airflow at a given static pressure. Units shall have a leakage rate not to exceed 1% of supply airflow rate at 8” w.c.

This form of specification speaks to the quality of cabinetry expected on a project and not to the leakage rate expected from the actual unit. For example, the unit is not likely operating at 8” w.c. and whether it is operating at negative pressure or positive pressure is more important. Even if the supply fan was selected to operate at 8” w.c. it is unlikely that any part of the AHU casing will experience the full 8” w.c. It will likely be split to part of the unit in negative and part of the unit in positive (See Figure 1).

From the manufacturer’s point of view, supply air flow rate is not directly connected to cabinet surface area. For the same airflow rate the cabinet area could easily double depending on the components in the airstream. For example, maintaining the same absolute leakage rate on an AHU that is 20 feet long compared to a unit that is only 10 feet long (for the same airflow and static pressure) is problematic.

Leakage Rate Based on Design Static Pressure

A few custom AHU manufacturers provide leakage data in the form of percent supply airflow based on a multiplier of design static pressure. Units shall have a leakage rate not to exceed 1% of supply airflow at 1.5 times the static pressure.
Some care should be taken on the definition of static pressure. Most would assume static pressure means the supply fan total static pressure (5” w.c. in the above example) but it is often interpreted as meaning 1.5 times the largest pressure differential (positive or negative) experienced by the AHU. In the example above, the highest will be 1.5 x 2.6” w.c. = 3.9” w.c. This is actually less than the supply fan design total static pressure of 5” w.c.

**EN1886 Leakage Standard**

EN1886 is a standard that covers many aspects of AHU construction. Section 5 covers casing air leakage. The standard sets criteria for the AHU and based on the level the unit can achieve a class is assigned. This allows the specifier to define the level of performance for the project.

The standard covers both negative pressure only AHUs and combination positive and negative pressure AHUs. The class levels are set by the amount of acceptable leakage for a given area.

For units that only see negative pressure, the test is performed at 400 Pa (1.6” w.c.). Table 1 shows the classes and the leakage rates for negative pressure only units.

**Table 1: EN1886 Leakage Class for Negative only AHUs**

<table>
<thead>
<tr>
<th>Leakage Class</th>
<th>Max. Leakage rate (L/\text{m}^2) (cfm/100ft²)</th>
<th>Filter Class (EN779)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A</td>
<td>3.96 (77.9)</td>
<td>G1-4</td>
</tr>
<tr>
<td>A</td>
<td>1.32 (26.0)</td>
<td>F5-7</td>
</tr>
<tr>
<td>B</td>
<td>0.44 (8.67)</td>
<td>F8-9</td>
</tr>
</tbody>
</table>

Table 2 shows the classes and leakage rates for units that experience both negative and positive pressures. The positive pressure section is tested at 700 Pa (2.8” w.c.) and the negative pressure section is tested at 400 Pa (1.6” w.c.).

The advantage of the EN standard is that there are procedures that everyone can follow so the results are consistent. As well, the product can be third-party verified. The main issues are that even the highest level of performance is not very stringent and the standard is not used in North America. If the specifier chooses to use the standard, it could be requested as follows:

*All air handling units shall meet EN1886 Class B for leakage.*

**SMACNA Standard**

SMACNA has set leakage criteria in their HVAC Air Duct Leakage Test Manual. Figure 4-1 in their manual is based on:

\[
CL = \frac{F}{p^{0.65}}
\]

Where;

- **CL** is the duct class
- **F** is the leakage rate in cfm/100ft²
- **p** is the duct static pressure in inches w.c.

![Figure 5 - SMACNA Leakage Class Curve](image)

While the standard was developed for field installed ductwork, it can also be applied to AHUs. The leakage class is based on the average leakage per 100 ft² of cabinet for a given static pressure. The higher the static pressure or the larger the unit (more surface area), the more leakage can be expected in a given class.

This is one of the best methods for establishing leakage criteria. It is the method the specifier will likely use to rate the ductwork and it is straightforward for the equipment manufacturer to follow.
To convert from leakage as a percent of supply air at a given static pressure to the SMACNA method requires estimating the size of a typical AHU (to obtain the surface area) and assuming 500 fpm air velocity through the tunnel to obtain a supply air flow rate. With these assumptions, a Class 6 SMACNA unit will be approximately 1% supply air volume at 8” w.c.

**LEAKAGE TEST SPECIFICATION**

Since there are no third-party verifications for cabinet leakage ratings in North America, a leak test is sometimes requested by the specifier for critical applications. While it is possible to ask for an in-situ leakage test, it is very rare. It is very difficult to set up the test and ship the necessary equipment to the site. The norm is to require the test to occur at the factory. This has the advantage that if there is an issue, it can be resolved in the factory, prior to shipping. The test may or may not be witnessed by the owner or their representative. When the test is not witnessed, an officer of the manufacturer should sign off on the results.

On a project with multiple air handling products it is typical to only test a few sample units and not every single unit. Often the specification will read that the owner will select a sample unit to be tested. The first step in a leakage test is to establish the leakage criteria. In addition, a few key parameters can greatly affect how the test is to be performed:

- Does the unit have both positive and negative pressure sections?
- Does the unit have shipping splits?
- Is the unit a dual path energy recovery unit?

**Positive and Negative Pressure Testing**

The common methods are discussed above. Any manufacturer set up to perform cabinet leakage tests can follow all the criteria. How the criteria will be interpreted is critical, in particular, how to deal with positive and negative leakage sections. Most AHU layouts are either all negative (fan is the last component in the airstream) or a combination of negative and positive sections (fan is in the middle of the AHU). An all negative unit is straightforward; it is tested under negative pressure according to the chosen criteria.

A negative and positive section AHU requires more planning. It can be expected that the construction (i.e. the door swings) will be different between the two sections so it is not appropriate to perform just one (positive or negative) test as the test will not be valid for how the unit will operate.

EN1886 requires the two sections of the AHU to be tested separately. This is the best procedure. Where the specifier uses a criterion of a specific leakage rate at a given static pressure or the SMACNA leakage class system, the tests should be performed at these conditions regardless of fan static pressure design condition.

If the leakage rate criteria is based on a multiplier of fan static pressure design condition (see above), then the pressure seen in the given section (positive or negative) should be used to set the level and not the total static pressure supplied by the fan. For the example shown in Figure 1 and a criteria of 1.5 times rated static pressure, the target static pressures would be 3.6” w.c. for the negative section and 3.9” w.c. for the positive section.
**Shipping Splits**

In cases where the AHU is too large to ship or there are site conditions that require the unit to arrive in smaller sections for placement, the unit will be built in sections that need to be bolted together. Units with splits will impact any leakage test. The set up for the leakage test will be more complex because the unit will need to be assembled. A major challenge is that it is typical to caulk or gasket the sections together to obtain the best seal. Once caulked, it is very difficult to disassemble a unit without damage.

Since caulking cannot be used for a leakage test, the test may need to be performed by section or some other form of temporary sealing at the split joints may be required.

**Dual Path Energy Recovery Unit Leakage Test**

Dual path energy recovery units can be very complex to test for leakage. Careful planning and clear understanding of the test criteria is important. Each individual air path can be negative only (as shown in Figure 7) or a negative and positive arrangement.

The pressure differential across the center wall that separates the two airstreams will depend entirely on the unit configuration. While it can be assumed that the two air paths will be separated when a plate or heat pipe energy recovery device is used, an enthalpy wheel will NOT separate the two air paths. There is no way to test the center wall leakage integrity when a wheel is used other than to block out the wheel section.

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**Figure 7 - Typical Dual Path Energy Recovery Unit**

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**PRICE CUSTOM ROOFTOP UNIT LEAKAGE TESTING**

Price has performed extensive testing on its cabinet construction. This data correlates well with actual leakage tests performed on customer units. Negative pressure units typically have lower leakage rates than positive pressure units as the data below demonstrates. As mentioned previously, doors are the major leakage issue. Price offers both standard and low leak doors to provide two levels of leakage performance.
Standard Door Construction

The figures below show positive and negative leakage performance for our standard door construction units both as a percent of supply airflow and as a SMACNA leakage class. The specifics of the actual AHU design can influence the unit leakage performance but in most cases Price can offer 1% of supply airflow at 8 inches w.c. in either positive or negative configuration with standard door construction. In the SMACNA leakage class system, Price can offer Class 6 with standard door construction.
Low Leak Door Construction

The figures above show positive and negative leakage performance for our low leak door construction units both as a percent of supply airflow and as a SMACNA leakage class. The specifics of the actual AHU design can influence the unit leakage performance but in most cases Price can offer 1% of supply airflow at 10 inches w.c. in either positive or negative configuration with low leak door construction. In the SMACNA leakage class system, Price can offer Class 3 negative pressure and Class 6 positive pressure with low leak door construction.
LEAKAGE RATING RECOMMENDATIONS

Since there are no industry test standards for reference, the responsibility falls on the specifier. Some reference to leakage rates is strongly recommended. Price recommends either the SMACNA leakage class or leakage rate as a percent of supply air volume.

The following specification language is offered to assist the specifier.

Unit shall meet or exceed leakage Class 6 (CL = 6) [Class 3 negative pressure] as based on the SMACNA test method. Manufacturer shall provide test data confirming cabinet construction can meet the requirement.

Or

Units shall have a leakage rate not to exceed 1% of supply air volume at 8” w.c. [10” w.c.] static pressure in either positive or negative pressure tests. Manufacturer shall provide test data confirming cabinet construction can meet the requirement.

Unit or witness tests have a cost impact to the project and should only be considered for critical applications. If the project does require unit performance testing the following can be included:

Prior to shipment, the manufacturer shall test one unit of the owner’s choice. The results shall be signed by an officer of the company. If the unit fails to meet the design criteria, the unit shall be repaired and retested. In addition, the owner shall select one other unit and it shall be tested.

Or

Prior to shipment, the manufacturer shall test one unit of the owner’s choice. The test shall be witnessed by the owner or their representative and the results shall be signed by an officer of the company. The cost of travel for the test shall be included in the equipment price. If the unit fails to meet the design criteria, the unit shall be repaired and retested. In addition, the owner shall select one other unit and it shall be tested.