the refrigerant opportunity:
Save energy and the environment

Ozone depletion and global warming rank high among the unintended changes brought about by human activities since the Industrial Revolution. Evidence suggests that recent accelerated warming of the Earth’s surface is the result of increased concentrations of heat-trapping “greenhouse” gases, such as carbon dioxide, which in turn are attributed to the combustion of fossil fuels. [1]

Scientific discussions about the “complex interrelationship between ozone depletion and climate change” [2] almost invariably lead to debate about the refrigerants used in HVAC systems. At issue is the tradeoff between the environmental impacts of hydrofluorocarbons (HFCs) versus those of hydrochlorofluorocarbons (HCFCs), which the Montreal Protocol has slated for phaseout in developed countries. On the one hand, the ozone depletion potential (ODP) of HFCs is negligible compared to that of HCFCs; yet chemically, HFCs are greenhouse gases. HFCs also are thermodynamically slightly less efficient than their HCFC counterparts “given idealized equipment design, so the same amount of cooling may require more electricity and thereby [cause] the indirect release of more CO2 in generating that electricity.” [3]

The refrigerant selection dilemma is reflected in the U.S. Green Building Council’s LEED Green Building Rating System®, which promotes green building practices. Credit toward certification can be quickly earned by choosing not to use HCFCs. But that decision also can make it more difficult to conserve energy.

This EN examines the basis for refrigerant-related credits in the current LEED rating system and what the USGBC is doing to resolve the refrigerant debate.

LEED–NC and refrigerants

The LEED rating system (Table 1, p. 2) grades building performance based on metrics for sustainability in six categories, including energy use and protection of the atmosphere. Having satisfied the prerequisites in a category, a building earns “extra” credit (awarded as points) for exceeding the minimum requirements. The more points a building earns, the higher (and more prestigious) its level of certification—and the greater the potential economic and environmental benefits.

LEED–NC Version 2.1 assesses the performance of new construction and major renovations. The “Energy and Atmosphere” (EA) category awards one point for ozone protection and up to ten points for optimized energy use—but only after the project satisfies the prerequisites (see inset) for commissioning, energy performance, and reduction of chlorofluorocarbons (CFCs).

**EA Prerequisite 3.** The objective of the “CFC Reduction in HVAC&R Equipment” prerequisite is to reduce ozone depletion. Satisfying this requirement is comparatively easy for a newly constructed building with a dedicated HVAC system because systems that use CFCs are no longer manufactured in developed countries.

For an extensive renovation that reuses existing HVAC equipment, compliance requires comprehensive conversion or replacement of all CFC equipment—usually within one year of the project’s completion. This requirement can pose two challenges if the building is served by a central or district cooling facility. First, the project team typically isn’t empowered to promise and implement a CFC changeout plan for the cooling facility. Second, chillers are costly and long-lived. If the existing CFC machines aren’t already at the end of their service life, it may not be economically feasible to replace or convert them.

It’s possible to receive a conversion-phaseout extension of several years under a LEED Credit Interpretation Ruling (CIR). However, the project team must document a satisfactory phaseout plan and provide a letter of...
commitment from the owner. Otherwise, the building is not eligible for LEED certification.

**EA Credit 4.** The “Ozone Protection” credit prohibits the use of HCFCs in base-building HVAC systems. As in EA Prerequisite 3, if the building is served by a central plant, the prohibition extends to that facility as well. In other words, a new or renovated building presently does not receive credit for ozone protection if the central plant serving it contains HCFC chillers.

Although it represents only one of LEED–NC's 69 points, earning EA Credit 4 makes it more difficult to increase energy savings by using higher efficiency HCFC equipment and thereby help earn more of the available points under EA Credit 1, “Optimize Energy Performance.” The global warming potential of HFCs is significantly higher than that of commonly used HCFCs (Table 2), prompting some stakeholders to contend that making high-efficiency HCFC equipment ineligible for Credit 4 reduces the potential benefit to the environment.

### Enter: TSAC and the HCFC task group

Endeavoring to resolve what has become a divisive issue, USGBC’s LEED Steering Committee charged the Technical and Scientific Advisory Committee (TSAC) in September 2001:

To review all of the atmospheric environmental impacts arising from the use of halocarbons in HVAC equipment and recommend a basis for LEED credits that gives appropriate credit to the alternatives. [3]

TSAC undertook this assignment by forming an ad hoc HCFC task group (TG) of respected and highly credentialed technical experts. Following a prescribed nine-step process, the TG prepared a report that synthesizes input from stakeholders and advises two approaches (interim and long-term) for awarding LEED credits that deal with the atmospheric effects of commonly used refrigerants.

In their analysis, the TG considered past and present models of centrifugal water chillers and unitary equipment, as well as CFCs (already banned by the Montreal Protocol), HCFCs (scheduled for phaseout), and HFCs. The final report, *The Treatment by LEED of the Environmental Impact of HVAC Refrigerants*, was issued in September 2004, and subsequently approved by the LEED Steering Committee and the USGBC board. [3]

As a result of their review, the TG concluded that although the existing LEED rating structure presumes that designers can select a refrigerant by assessing the total impact on the environment,
Table 2. 100-Year ODP and GWP values for several common refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>ODP</th>
<th>GWP</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC-11(^a)</td>
<td>1.0</td>
<td>4,880</td>
<td>Centrifugal chillers</td>
</tr>
<tr>
<td>CFC-12(^b)</td>
<td>1.0</td>
<td>10,720</td>
<td>Chillers, refrigerators</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>0.04</td>
<td>1,780</td>
<td>Air conditioning, chillers</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>0.02</td>
<td>76</td>
<td>CFC-11 replacement</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>&lt;1.5 × 10(^{-5})</td>
<td>1.320</td>
<td>CFC-12 or HCFC-22 replacement</td>
</tr>
<tr>
<td>HFC-407C</td>
<td>&lt;1 × 10(^{-5})</td>
<td>1.700</td>
<td>HCFC-22 replacement</td>
</tr>
<tr>
<td>HFC-410A</td>
<td>&lt;2 × 10(^{-5})</td>
<td>1,890</td>
<td>Air conditioning</td>
</tr>
</tbody>
</table>

\(^a\) Data source: Table 1 of [3]
\(^b\) Banned by the Montreal Protocol in developed countries, but still used in the chillers of many existing buildings

For ozone depletion (LCODI) and direct global warming (LCGWId):\(^2\)

\[
A \times LCGWId + B \times LCODI < C
\]

where \(A = 1\), \(B = 100,000\), and \(C = 100\)

When graphed (Figure 1), the proposed “acceptable” region under the diagonal line reflects the USGBC’s policy of limiting eligibility for credit to the top 25 percent of the market and on the TG’s evaluation of a uniform random sample of the various HVAC equipment types and refrigerants available.

As proposed, eligibility for EA Credit 4 requires that the combined value of LCGWId and LCODI (including constants \(A\) and \(B\)) is less than \(C\). Initially set at 100, the value of \(C\) could be adjusted to reflect improvements in equipment performance.

The following equations calculate the refrigerant’s lifetime performance, normalized per ton of cooling capacity and per year of equipment life:

\[
LCGWId = \frac{GWP \times R_c \times (L \times life + M_r)}{life}
\]

\[
LCODI = \frac{ODP \times R_c \times (L \times life + M_r)}{life}
\]

where,

\(GWP\) = life-cycle direct global warming index, equivalent lb CO2/ton-yr

\(LCODI\) = life-cycle ozone depletion index, equivalent lb CFC-11/ton-yr

\(ODP\) = ozone depletion potential of refrigerant, 0 \(<\) \(ODP\) < 0.2 lb CFC-11/lb

\(R_c\) = refrigerator charge, lb refrigerant/ton of cooling capacity

\(L\) = refrigerant leakage rate, % of charge/yr (proposed default: 1%)

\(life\) = equipment life, yr (proposed default: 30)

\(M_r\) = end-of-life loss, % of charge (proposed default: 3%)

Rather than single out any particular refrigerant, this proposal focuses on the environmental impacts of specific combinations of HVAC equipment and refrigerant. Given the current rate structure, which precludes additional credits and fractional points, the TG believes this approach “is a more technically robust approach to considering refrigerant alternatives and that it will encourage LEED users to evaluate both critical atmospheric effects.”\(^3\)

Figure 1. Proposed concept for earning EA Credit 4

TG’s conclusions

To arrive at a more comprehensive and quantitative comparison of the atmospheric effects of refrigerants, the TG adapted a simple model to calculate performance-based life-cycle indexes for ozone depletion (LCODI) and direct global warming (LCGWId).\(^2\)

Observing that “there is enough scientific evidence that global warming is a problem,” the TG proposed a concept to replace the existing ozone-only assignment of LEED credits.

From LEED (Version 2.1) does not currently consider direct global warming effects of refrigerants from release into the atmosphere.

… If a more efficient refrigeration system is selected, LEED credits might be earned for the energy benefits in EA Credit 1, but not earned in EA Credit 4 if the refrigerant depletes ozone, even slightly. Therefore, if a cooling system achieves greater efficiency only at the environmental price of using a chlorine-containing refrigerant, an inevitable environmental conflict exists. [3]

Rather than single out any particular refrigerant, this proposal focuses on the environmental impacts of specific combinations of HVAC equipment and refrigerant. Given the current rate structure, which precludes additional credits and fractional points, the TG believes this approach “is a more technically robust approach to considering refrigerant alternatives and that it will encourage LEED users to evaluate both critical atmospheric effects.”\(^3\)
Future versions of LEED, the TG noted, could include separate credits for ozone depletion and global warming, which would consider all emissions of ozone-depleting substances and greenhouse gases—not just those from refrigerants.

**Putting the approach into practice.** How might a designer use these calculations to determine whether a particular combination of equipment and refrigerant will be eligible for EA Credit 4 under the TG proposal?

As an example, consider a new centrifugal chiller with a refrigerant charge of 3.3 lb of HCFC-123 per ton of cooling. From Table 1 of the TG report, we find that $ODP_r = 0.02$ and $GWP_r = 76$ for HCFC-123. When coupled with the proposed defaults for critical leakage rates and refrigerant charge ...

$$L_r = 1\%$$
$$l_{life} = 30 \text{ years}$$
$$M_r = 3\%$$

... this provides enough information to determine the life-cycle index values for global warming and ozone depletion:

$$LCGWId = \frac{76 \times 3.3 \times (0.01 \times 30 + 0.03)}{30} = 2.7588$$

$$LCODI = \frac{0.02 \times 3.3 \times (0.01 \times 30 + 0.03)}{30} = 0.000726$$

Using these index values and the proposed criterion, we find that the direct atmospheric impact of this particular chiller/refrigerant combination is low enough to earn EA Credit 4 (i.e., results in a value less than $C$, which is 100):

$$1 \times 2.7588 + 100,000 \times 0.000726 = 75.4$$

Table 3 compiles similar examples for several common HVAC refrigerants. In each case, the index values for ozone depletion and global warming are based on the largest refrigerant charge evaluated by the task group. Apart from CFC-11, only HCFC-22, with a direct atmospheric impact of 3179, is ineligible for EA Credit 4 (given the refrigerant charges and TG-proposed defaults listed in Table 3).

**What happens next?**

The LEED Steering Committee and the USGBC Board already have incorporated the proposed concept for EA Credit 4 (renamed as “Refrigerant Selection”) in the initial public draft of LEED–NC Version 2.2, which was released in December 2004. In addition, Version 2.2 proposes the following formula “for projects with multiple units of building-level HVAC and refrigeration equipment” [6]:

$$\frac{\sum (LCGWId + LCODI \times 10^5) \times Q_{unit}}{Q_{total}} \leq 100$$

where,

- $LCGWId = LCGWId$
- $LCODI = LCODI$
- $Q_{unit} = \text{cooling capacity of an individual HVAC or refrigeration unit, tons}$
- $Q_{total} = \text{total cooling capacity of all HVAC or refrigeration equipment, tons}$

This formula makes it possible to demonstrate (for example) that a building with HCFC-22, HFC-134a, and HCFC-123 equipment is eligible for EA Credit 4.

Official public release of LEED–NC Version 2.2 is anticipated by fall 2005, following balloting of the USGBC membership. Rather than postpone implementation until then, a January 2005 administrative credit

### Table 3. Direct atmospheric effects calculated for several common refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Leakage rate $L_r$, %/yr</th>
<th>Charge $R_c$, lbf/ton</th>
<th>End-of-life loss $M_r$, %</th>
<th>Equipment life, yr</th>
<th>Fixed inputs $b$</th>
<th>Outputs (life-cycle indexes)</th>
<th>Combined index value $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC-11 $^a$</td>
<td>1.0</td>
<td>2.4</td>
<td>3.0</td>
<td>30</td>
<td>1.0, 4,680</td>
<td>0.0264</td>
<td>123.552</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>5.0</td>
<td>4.5</td>
<td></td>
<td></td>
<td>0.04, 1,780</td>
<td>0.0022</td>
<td>979</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>3.3</td>
<td>2.4</td>
<td>3.0</td>
<td>30</td>
<td>0.02, 76</td>
<td>0.000726</td>
<td>2.7588</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>3.3</td>
<td>3.3</td>
<td>3.0</td>
<td>30</td>
<td>1.5 $\times 10^{-5}$, 1,320</td>
<td>0.0000005</td>
<td>47916</td>
</tr>
<tr>
<td>HFC-407C</td>
<td>3.3</td>
<td>2.8</td>
<td>3.0</td>
<td>30</td>
<td>10$^{-5}$, 1,700</td>
<td>0.0000004</td>
<td>61.71</td>
</tr>
<tr>
<td>HFC-410A $^a$</td>
<td>3.5</td>
<td>2 $\times 10^{-5}$, 1,890</td>
<td>0.0000007</td>
<td></td>
<td>72.765</td>
<td>72.8</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Values other than the defaults proposed in the TG report may be used; however, the team or manufacturer must provide persuasive evidence that accounts for leakage that occurs during equipment service.

$^b$ $ODP$ and $GWP$ values shown here are from Table 1 of the TG report [3].

$^c$ $R_c$ values shown here are from Appendix C of the TG report; they represent the largest refrigerant charge evaluated by the HCFC task group. As such, the values shown may be significantly higher than the actual $R_c$ values of many current-production chillers.

$^d$ Using the criterion proposed in the TG report, a particular equipment/refrigerant combination only is eligible for EA Credit 4 if the combined life-cycle index value does not exceed 100.

$^e$ The USGBC estimates that approximately half of the water chillers in existing buildings use CFC-11; the Montreal Protocol bans new CFC production in developed countries.
interpretation ruling (CIR) incorporates the TG proposal as an alternative method to receive a credit in LEED–NC Version 2.0 or 2.1. To earn EA Credit 4 for an HVAC system that uses an HCFC refrigerant, you’ll need to reference the EA C40 CIR (dated January 11, 2005) and document the calculation showing that the combined atmospheric impact is eligible for EA Credit 4.

**Implications for other LEED products**

Thus far, we’ve only looked at how the TG report affects initial certification of new construction and major renovation projects under LEED–NC. The size of the existing building market—which the USGBC estimates as 80 times larger than new construction—makes the atmospheric effects of existing refrigerant/equipment combinations too significant to ignore. [6]

**LEED–EB and EA Prerequisite 3.** Although the Montreal Protocol bans CFC products in developed countries, a 2002 United Nations report estimates that roughly 50 percent of the water chillers in existing buildings still use CFC-11. [7]

With respect to LEED–EB, the TG made this observation:

> The annual volume of refrigerants sold for replacement in existing building equipment is four times that sold for new equipment, so the significance of the existing buildings market cannot be ignored. [3]

EA Prerequisite 3 of LEED–EB reinforces ongoing reductions of ozone depletion by requiring that owners show that base-building HVAC systems do not use CFCs.

> Alternatively, Prerequisite 3 can be met by providing third-party evidence that replacement of existing CFC equipment is not economically feasible—that is, the simple payback of the replacement exceeds 10 years.

“Simple payback” is prescribed as the implementation cost of the replacement divided by the resulting annual cost avoidance for energy plus any difference in maintenance costs. [8] If the simple payback is less than 10 years, then compliance with Prerequisite 3 requires system replacement or conversion.

In addition to the payback analysis, the project team must demonstrate proper handling of CFCs in accordance with the EPA Clean Air Act as well as leakage that is both below 5 percent annually and below the annual volume of refrigerants sold for replacement in existing building equipment. The simple payback of the replacement divided by the resulting annual cost avoidance for energy plus any difference in maintenance costs.

### Table 4. Making an HVAC system eligible for EA Credit 4

<table>
<thead>
<tr>
<th>LEED–NC 2.1 or earlier</th>
<th>LEED–NC 2.2 (first public draft)</th>
<th>LEED–EB</th>
<th>LEED–CI</th>
<th>LEED–CS</th>
<th>LEED–ND</th>
<th>LEED–H</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EA Prerequisite 3</strong></td>
<td><strong>EA Credit 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Specify new equipment that does not use CFCs</td>
<td>• Document HVAC&amp;R equipment does not use HCFCs OR • Cite the EA C40 CIR (dated January 11, 2005) and document that refrigerants in the base-building HVAC&amp;R equipment comply with [\text{LCGWP} + \text{LCODP} \times 10^9 \leq 100]</td>
<td>• Replace or convert all base-building HVAC&amp;R equipment that uses CFCs OR • Show that replacement is not economically feasible via the results of a third-party audit (i.e., simple payback &gt; 10 yr)</td>
<td>• Do not operate base-building HVAC&amp;R equipment that contains HCFCs OR • Verify that refrigerant emissions from base cooling equipment over the performance period are less than 3% of charge per year (Documentation must comply with EPA Clean Air Act, Title VI, Rule 608)</td>
<td>• Same as LEED–NC</td>
<td>• Still under development</td>
<td>• Still under development</td>
</tr>
<tr>
<td>• For major renovations, adopt a replacement/conversion schedule for all existing CFC equipment</td>
<td>• Document that the refrigerants in the base-building HVAC&amp;R equipment comply with [\text{LCGWP} + \text{LCODP} \times 10^9 \leq 100]</td>
<td>• For major renovations, adopt a replacement/conversion schedule for all existing CFC equipment</td>
<td>• Demonstrate an annual refrigerant leakage rate &lt; 5%, and that the leakage over the remainder of unit life will be &lt; 30%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What about LEED–CI? The newly released rating system for commercial interiors, LEED–CI Version 2, provides a standard rating scheme for tenant improvements to new or existing office space. [8] Its point structure is similar to that of LEED–NC. Both standards require zero use of CFCs in HVAC systems under EA Prerequisite 3 … at the base-building level for LEED–NC and within the tenant space for LEED–CI. However, LEED–CI presently omits the point for refrigerant selection/ozone protection (EA Credit 4), whether this will change in the future remains to be seen.

Closing thoughts

Although we devoted our attention exclusively to refrigerants in this article, achieving sustainability through green design requires a much broader view. Success demands that we focus on delivering cost-effective buildings that not only conserve resources and minimize environmental impacts, but that also operate reliably and enhance occupant well-being. We can do much to advance these goals by designing and implementing HVAC systems that use energy judiciously and effectively.

By Chris Hsieh, systems marketing engineer, and Brenda Bradley, information designer, Trane. You can find this and previous issues of the Engineers Newsletter at http://www.trane.com/commercial/library/newsletters.asp. To comment, e-mail us at comfort@trane.com.