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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 hydrochlorofluoro-carbons (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 CO_2 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

Prerequisites for LEED–NC's Energy and Atmosphere credits

Fundamental building systems commissioning. Verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.

Minimum energy performance. Design the building to comply with ASHRAE/IESNA Standard 90.1–1999 (without amendments) or the local energy code, whichever is most stringent.

CFC reduction in HVAC&R equipment. [Reduce ozone depletion via] zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phaseout conversion. [4]

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.[1] 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

[1] Reva Rubenstein, Ph.D. (chair); David Didion, D.Eng., PE; and Jeff Dozier, Ph.D. Their biographies are included in Appendix A of the TG's final report.

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Table 1. Overview of LEED rating products

LEED rating product		Targeted projects				
Identifier	Current version, (status)	Type	Applicability	Target audience	Rating levels (points required)	When to use it for building certification
LEED–NC	Version 2.1 (v2.2 in public comment period; v3.0 in development)	New construction, major renovations	Construction affects > 50% of occupants	Owners	Certified (26–32 pt) Silver (33–38 pt) Gold (39–51 pt) Platinum (52–69 pt)	One-time event with option to recertify ongoing building performance under LEED–EB
LEED–EB	Version 2.0 (released Oct 2004)	Existing buildings	Construction affects < 50% of occupants	Owners	Certified (32–39 pt) Silver (40–47 pt) Gold (48–63 pt) Platinum (64–85 pt)	Initial certification of existing buildings, which lasts 5 years Ongoing recertification of buildings already certified under LEED–NC or –EB[a]
LEED–CI	Version 2.0 (released Nov 2004)	Commercial interiors	Tenant spaces in office, retail, and institutional buildings	Tenants	Certified (21–26 pt) Silver (27–31 pt) Gold (32–41 pt) Platinum (42–57 pt)	One-time event
LEED–CS	In development	Core and shell	Building core, shell, and site selection; excludes tenant fit-out	Developers	To be determined	To be determined
LEED–ND	In development	Neighborhood development	Urban revitalization, neighborhood/ community planning	Developers, consumers, policymakers	To be determined	To be determined
LEED–H	In development	Homes	Residential dwellings	Owners, developers	To be determined	To be determined

[a] To maintain LEED–EB certification, a recertification application must be filed at least once every 5 years; however, tying recertification to annual performance reviews, annual budget planning, or space leasing contracts can enable more timely improvement of building upgrades, operations, and maintenance programs.

Table 2. **100-Year ODP and GWP values for several common refrigerants**[a]

Refrigerant	ODP	GWP	Application
CFC-11[b]	1.0	4,680	Centrifugal chillers
CFC-12[b]	1.0	10,720	Chillers, refrigerators
HCFC-22	0.04	1,780	Air conditioning, chillers
HCFC-123	0.02	76	CFC-11 replacement
HFC-134a	$<1.5 \times 10^{-5}$	1,320	CFC-12 or HCFC-22 replacement
HFC-407C	$\sim 10^{-5}$	1,700	HCFC-22 replacement
HFC-410A	$<2 \times 10^{-5}$	1,890	Air conditioning

[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

environment, it neither encourages nor rewards them for doing so:

> 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]

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.

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 *($LCGWI_d$)*:[2]

$$A \times LCGWI_d + B \times LCODI \leq C$$

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 $LCGWI_d$ 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:

$$LCGWI_d = \frac{GWP_r \times R_c \times (L_r \times life + M_r)}{life}$$

$$LCODI = \frac{ODP_r \times R_c \times (L_r \times life + M_r)}{life}$$

where,

$LCGWI_d$ = life-cycle direct global warming index, equivalent lb CO_2/ton-yr

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

GWP_r = global warming potential of refrigerant, $0 < GWP_r < 12{,}000$ lb CO_2/lb_r

R_c = refrigerant charge, lb refrigerant/ton of cooling capacity

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

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

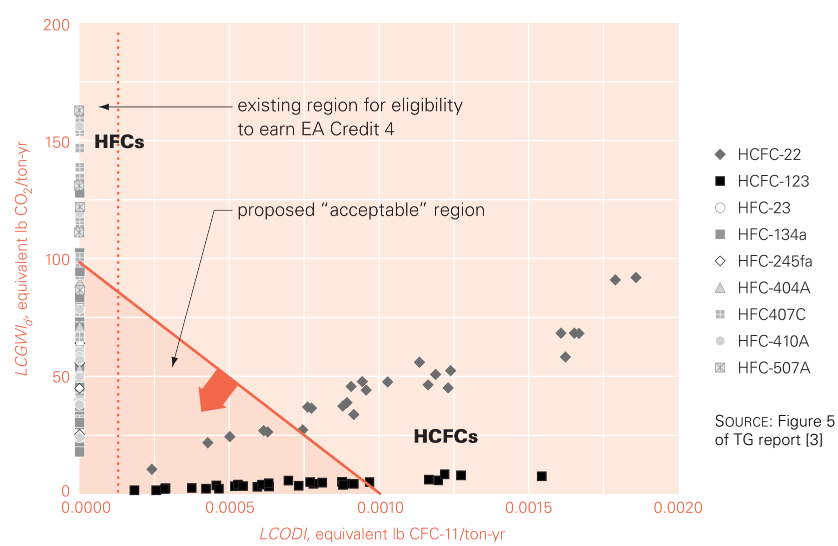
M_r = end-of-life loss, % of charge (proposed default: 3%)

ODP_r = ozone depletion potential of refrigerant, $0 < ODP_r < 0.2$ lb CFC-11/lb_r

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]

[2] "Direct impacts" refer to leaked gases that cause ozone-depleting chemical reactions in the stratosphere or that warm the atmosphere by absorbing heat emitted from the Earth's surface. *Indirect* impacts of global warming already are addressed in EA Credit 1, so the task group focused its attention on *direct* impacts.

Figure 1. Proposed concept for earning EA Credit 4



SOURCE: Figure 5 of TG report [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%
life = 30 years
M_r = 3%

[3] USGBC guidelines limit the present credit structure for LEED–NC Version 2 to 69 points; points cannot be added or removed until NC Version 3.

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

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

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

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 317.9, 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 base-building-level HVAC and refrigeration equipment" [5]:

$$\frac{[\Sigma(LCGWP + LCODP \times 10^5) \times Q_{unit}]}{Q_{total}} \le 100$$

where,
$LCGWP$ = $LCGWI_d$
$LCODP$ = $LCODI$
Q_{unit} = cooling capacity of an individual HVAC or refrigeration unit, tons
Q_{total} = 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

	Variable inputs[a]				Fixed inputs[b]		Outputs (life-cycle indexes)		
Refrigerant	Leakage rate L_r, %/yr	Charge R_c, lb/ton[c]	End-of-life loss M_r, %	Equipment life, yr	Ozone depletion potential, ODP	Global warming potential, GWP	Ozone depletion, *LCODI*	Global warming, $LCGWI_d$	Combined index value[d]
CFC-11[e]	1.0	2.4	3.0	30	1.0	4,680	0.0264	123.552	2,763.6
HCFC-22		5.0			0.04	1,780	0.0022	97.9	317.9
HCFC-123		3.3			0.02	76	0.000726	2.7588	75.4
HFC-134a		3.3			1.5×10^{-5}	1,320	0.0000005	47.916	48.0
HFC-407C		3.3			10^{-5}	1,700	0.0000004	61.71	61.7
HFC-410A		3.5			2×10^{-5}	1,890	0.0000007	72.765	72.8

[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.

(continued from inside)

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 EAc40 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

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

	EA Prerequisite 3	EA Credit 4
LEED–NC 2.1 or earlier	• Specify new equipment that does not use CFCs • For major renovations, adopt a replacement/conversion schedule for all existing CFC equipment	• Document HVAC&R equipment does not use HCFCs OR • Cite the EAc40 CIR (dated January 11, 2005) and document that refrigerants in the base-building HVAC&R equipment comply with $LCGWP + LCODP \times 10^5 \leq 100$
LEED–NC 2.2 (first public draft)	• Specify new equipment that does not use CFCs • For major renovations, adopt a replacement/conversion schedule for all existing CFC equipment	• Document that the refrigerants in the base-building HVAC&R equipment comply with $LCGWP + LCODP \times 10^5 \leq 100$ • Provide the refrigerant type and charge per ton of cooling capacity • Provide supporting evidence if using other-than-default values for annual leakage (1%) and end-of-life loss of charge (3%) over an assumed 30-year life
LEED–EB	• Replace or convert all base-building HVAC&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 > 10 yr) • Comply with the refrigerant management and reporting requirements of EPA Clean Air Act, Title VI, Rule 608 • Demonstrate an annual refrigerant leakage rate < 5%, and that the leakage over the remainder of unit life will be < 30%	• Do not operate base-building HVAC&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) • Demonstrate that leakage over the remaining unit life will be < 25%
LEED–CI	Same as LEED–NC	There is no "ozone depletion/refrigerant selection" credit in LEED–CI. Instead, EA Credit 4 rewards the use of "green power."
LEED–CS LEED–ND LEED–H	Still under development	Still under development

30 percent over the remaining life of the unit. These requirements apply whether recertifying a LEED building or initially certifying an existing building.

Calculation details have yet to be published, but it's possible that the annual leakage rate could be determined simply by totaling the amount of refrigerant added to the machine during the course of the year and dividing the result by the total refrigerant charge.

If the measured leakage rate recorded during a performance period (six months, for example), is within the allowable limit and satisfactorily documented, it also *may* be possible to extrapolate the leakage to a year and over the remaining unit life from the values recorded during that period. (For more conclusive information, check the credit interpretation rulings; also watch for publication of the LEED–EB reference guide in 2005.)

LEED–EB and EA Credit 4. Leakage is a significant factor when it comes to determining the atmospheric impacts of a refrigerant. If properly contained, a refrigerant has little *direct* impact on the atmosphere. EA Credit 4 reflects this thinking by allowing HCFC equipment to earn this point if the leakage rate is less than 3 percent annually and less than 25 percent over the remaining life of the unit. Both values can be calculated as described for EA Prerequisite 3.

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. [9] 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. •

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