Public Review Draft

Interim Report on the Treatment by LEED of the Environmental Impact of HVAC Refrigerants

Phase 1: Centrifugal Water Chillers

January 17, 2004

LEED TECHNICAL AND SCIENTIFIC ADVISORY COMMITTEE

U.S. GREEN BUILDING COUNCIL
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PREFACE

P.1 This report has been prepared under the auspices of the US Green Building Council's LEED Technical and Scientific Advisory Committee (TSAC), in response to a charge given TSAC by the LEED Steering Committee in to review the atmospheric environmental impacts arising from the use of halocarbons as refrigerants in building heating, ventilating, and air conditioning (HVAC) equipment. To undertake this assignment, the TSAC impaneled an *ad hoc* HCFC Task Group (HCFC TG), consisting of Dr. Reva Rubenstein (Chair), Dr. David Didion, PE, and Dr. Jeff Dozier; biographical data on the TG appears in Appendix C of this report.

P.2 TSAC has developed a nine-step process for preparing positions on technical issues, and one of the most important elements of this process is obtaining input from the various stakeholders on an issue. It is as part of this public input process that this draft is being released for public review, with the following objectives:

- to share the analytical methodologies being used.
- to indicate how the analysis is likely to be applied to LEED, and
- to receive public comment on the work to-date.

P.3 The universe of HVAC equipment types and the refrigerants they use is diverse and complex. In an effort to obtain public input at an earlier stage of this work, this draft is focused only on the refrigerants used in centrifugal water chillers. Subsequent phases of the work will expand the methodologies proposed to the other major classes of HVAC equipment and the refrigerants used in them.

P.4 It is anticipated that once the public comment on this draft is received, the work of the HCFC TG will continue. It is hoped that the public comment will identify new sources of data, new or different methods of analysis, and possible new interpretations of the analytic findings. This input will be seriously considered by the HCFC TG and TSAC as the assessment of this issue is finalized.

P.5 The technical analysis provided by TSAC will ultimately be submitted to the LEED Steering Committee, who will make any policy determinations for LEED that need to be made as a result of the technical analysis. The suggestions for policy directions made in this report are solely for the purpose of indicating possible interpretations and applications of the technical findings, as a guide for the Steering Committee's policy decisions.

P.6 TSAC wishes to express its sincere appreciation to the members of the HCFC TG for their diligent work. The technical analysis in this report is largely the work product of the HCFC TG. Some of the context and interpretations of the findings are the work product of the TSAC. Specific authorship attribution is given in Section 7 of this report.

Malcolm Lewis, TSAC Chair

EXECUTIVE SUMMARY

E.1 This report addresses the tradeoff between ozone depletion and global warming caused by anthropogenic release of refrigerants commonly used in HVAC systems. As a starting point for the analysis of this issue, we have focused on centrifugal water chillers using HCFC-123 and HFC-134a. Specifically it evaluates the relative environmental impacts from a chlorine-based halocarbon (HCFC-123) and one without chlorine (HFC-134a). The analysis in this Phase One report focuses solely on this subset of the entire population of HVAC equipment types and refrigerants. It is anticipated that similar methodologies will be applied to the refrigerants in other HVAC products in subsequent phases of this effort.

E.2 The ozone-depletion potential (ODP) of HCFC-123 is rated to be 1.2 % of that of CFC-11, which is banned under the Montreal Protocol. HFC-134a has almost zero ozone-depletion potential, but the global warming potential of HFC-134a is 17× that of HCFC-123, leading to a *direct* global warming mechanism when the compound leaks into the atmosphere. Moreover, HFC-134a is a slightly less efficient refrigerant than HCFC-123, so the same amount of cooling requires more electricity and thereby causes the *indirect* release of more CO_2 in generating that electricity. Therefore, HCFC-123 causes more ozone depletion than HFC-134a, but HFC-134a causes more global warming than HCFC-123.

E.3 An objective and complete comparison between ozone depletion and global warming is beyond this report's scope, indeed beyond the current state of knowledge. To try to assess the relative differences in operating chillers, we model ozone depletion and global warming caused by operating prototypical chillers, and we compare those values with total U.S. emissions of ozone depleting and greenhouse gases. Our finding is that a chiller using HCFC-123 contributes about the same proportion of US ozone depletion, as the added proportion of US global warming caused by a chiller using HFC-134a. This would appear to support leaving the LEED E&A Credit 4 as it is.

E.4 Version 2.1 of the LEED rating system awards one proscriptive credit for avoiding the use of any chlorine-containing refrigerants in buildings. It also awards credits for varying amounts of energy savings cost, hence rewarding the use of a more efficient, refrigerant. The apparent intent was that some refrigerants (e.g. HCFC-123) would earn an added energy credit for being more energy-efficient, and some refrigerants (e.g. HFC-134a) would earn an added credit for reduced ODP impacts. However, because the energy usage of a chiller as a proportion of the total building energy consumption is small, the energy-efficient HCFC-123 chiller does not contribute a whole LEED point's worth of benefit. On the other hand, since the HCFC credit is a proscriptive credit rather than a performance credit, the credit is still earned even if its comparative contribution to reduced ozone depletion is small. This would appear to support a change in the LEED credit structure to remedy this imbalance.

E.5 While the existing credit structure may have been reasonable in light of the information available to the USGBC at the time of LEED's creation, it is our judgment that on balance the technical analysis performed herein suggests that some adjustments may be appropriate. We therefore recommend a change in LEED Version 2.2 along the lines of the change described below, for consideration by the LEED Steering Committee and other relevant LEED committees:

Change the ODP credit (Energy & Atmosphere Credit 4) from a proscriptive credit to a performance credit based upon the refrigerant "ODP x Life Cycle Emission", normalized to a "per ton of cooling capacity" basis. This has the advantage of retaining LEED's intent to reduce the impact of ozone depleting chemicals, while improving the way it addresses the issue. Although more work is needed to confirm this, it is likely that using this approach both HCFC-123 and HFC-134a chillers would get the credit, but that equipment using refrigerant combinations with higher ODP impacts would not.

E.6 Further, to improve the way LEED addresses global warming and ozone depletion, we recommend that the framers of Version 3.0 of LEED consider the following concepts:

- Consider giving explicit credit to the combined *direct plus indirect* emissions of global warming gases, expressed in terms of CO2 per ton of cooling capacity, or some equivalent performance metric.
- Because of the wide range of GWP and ODP ratings among halocarbons, consider establishing linear scales for both global warming and ozone depletion, similar to the current energy point system.
- Consider giving credit for reducing the impacts of the non-refrigeration applications using halocarbons in buildings (e.g. building materials, such as insulation).

E.7 The other specific application recommendation relates to *LEED for Existing Buildings (LEED-EB).* HCFC-123 has become a key replacement for CFC-11 because it can replace CFC-11 in new and existing chillers without extensive modification of equipment or equipment rooms. This has particular significance for *LEED for Existing Buildings*, where it makes sense to encourage the retrofitting of existing chillers by replacing CFC-11 with HCFC-123, which has 80× less ozone depletion potential (ODP) and 38× less global warming potential (GWP) than CFC-11. Approximately 50% of the water chillers in existing buildings still use CFC-11 as refrigerant, so this is an important impact. Thus, we recommend that the LEED Steering Committee and other relevant committees consider structuring the E&A Credit 4 in LEED-EB so that it provides a point for replacement of CFC-11 with HCFC-123 in existing chillers.

1.0 INTRODUCTION

1.1 As the scientific community discovers new environmental problems, the desire to live with a minimal impact on our environment becomes more complex. Some choices have inherent environmental tradeoffs. Technologies, materials, or practices designed to ameliorate one problem may exacerbate another.

1.2 To make matters worse, the political recognition that one pollutant represents a societal threat, as compared to another, is not always timely. Such is the case with ozone depletion and global warming. While the legal protection of the ozone layer is well in place throughout most of the international community, via the Montreal Protocol, the same nations lack agreement that global warming is a comparable threat. Therefore, the current regulatory program to protect stratospheric ozone was established without consideration of any impact on global warming.

1.3 On the other hand, many governments, non-governmental organizations, and companies *do* believe the evidence of the magnitude and consequences of global warming is compelling enough to warrant action. Among them, the U.S. Green Building Council targets energy efficiency and alternative transportation, among other environmental benefits, in its LEED™ standards (Leadership in Energy and Environmental Design).

1.4 The specific issue addressed in this report is a tradeoff between ozone depletion and anthropogenic global warming in the choice of refrigerants. The chlorine-based halocarbon refrigerants (e.g., HCFC-123) often represent the most efficient working fluids for the air conditioning industry, but their ozone-depleting effect is slightly more than 1% of that of CFC-11, no longer produced under the terms of the Montreal Protocol. The main alternative compound (HFC-134a) has virtually no effect on stratospheric ozone, but it is slightly less efficient, thereby requiring more power and thus more carbon dioxide emission for the same amount of cooling, and is itself a greenhouse gas. As a result, the LEED Steering Committee charged its Technical Scientific Advisory Committee with the following tasks:

> ***"To review 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. The review should consider:***
>
> - ***The direct effect of leaked halocarbons on the atmosphere (including but not necessarily limited to ozone depletion and global warming potential).***
> - ***The indirect effects on the energy efficiency of equipment in operation and the consequential effects on atmospheric emissions and impacts (including but not necessarily limited to global warming potential)."***
>
> ***[see Appendix D for full text of charge].***

1.6 Current Status

1.7 The current version 2.1 LEED rating system [1] considers the negative impact that a halocarbon has on the ozone layer if it contains chlorine. As a simplified environmental

rating system, it awards one point, under Energy & Atmosphere (E&A) Credit 4, for the use of HFCs in lieu of HCFCs in building fire suppression and refrigeration systems. To address global warming, the sliding scale for energy savings allows for additional points under E&A Credit 1 if one refrigerant system is more efficient than another. The LEED credit system implicitly assumes that designers thereby have the ability to make a trade-off between global warming impact and ozone depletion impact as they select the HVAC refrigerant type.

1.8 Significance

1.9 This current LEED standard recognizes the merit of a reduction of a building's contribution toward global warming. If a more efficient HCFC refrigeration system is selected over an HFC system, LEED credits might be earned for the efficiency benefits but not earned for the ozone depletion implications. In the case of the HCFC-123 and HFC-134a centrifugal water chiller systems, where the HCFC system achieves a greater efficiency only at the environmental price of using chlorine, an inevitable environmental conflict exists. Is there a way to establish a quantitative relationship between these two systems' *total environmental impact*, and should the assignment of LEED credits be revised? This issue, therefore, is the focus of the study, and while it does not propose a definitive solution in a hard and fast quantitative measure between the two refrigerants, it does spell out the various specifics that may enable the USGBC to improve its rating system over time.

2.0 REFRIGERANT TYPES

2.1 Usually when a fluid substance is called a "refrigerant" it is meant to refer to the working fluid that flows through a machine that is designed to pump heat from a lower temperature to a higher temperature. The overwhelming majority of such machines operate on the vapor compression cycle principle and the fluids that have been found to meet all the necessary criteria for a stable, safe, inexpensive, efficient performance are mostly in the halogen family. This means they are hydrocarbons (usually of the methane and ethane base) with some of the hydrogen atoms replaced by fluorine, chlorine. bromine or iodine atoms. [A notable exception to this family is ammonia. However the safety issues severely limit its use in commercial buildings.] The issue of environmental impact suggests a categorization of this family of chemicals into categories as follows: CFC, HCFC, HFC, and a non-halogen refrigerants group called Natural Refrigerants.

2.2 <u>CFC (ChloroFluoroCarbon)</u>
A molecule of one or two carbons, with <u>all</u> of the hydrogen atoms replaced by either a chlorine or a fluorine atom. They are extremely stable and as a result most of the refrigerants developed prior to the ozone crisis were of this group. However their stability property gives it a very long atmospheric life, allowing it to make its way to the stratosphere where it breaks up and the free chlorine atoms reduce the amount of ozone. Manufacture of these chemicals is now banned in those countries that signed the Montreal Protocol. Significant amounts are still manufactured in some countries that did not sign the protocol.

2.3 <u>HCFC (HydroChloroFluoroCarbon)</u>
A molecule of one or two carbons, with <u>some</u> of the hydrogen atoms replaced by either a chlorine or a fluorine atom. Typically these refrigerants are designed to be sufficiently stable

within the machine but have a relatively short atmospheric life, which minimizes their damage to the ozone layer. Nevertheless, they are scheduled to be banned in the future, so that even those refrigerants in this group that have a short enough atmospheric life that they do negligible ozone damage are to be eliminated. Such is the case of the example studied in this report, HCFC-123.

2.4 HFC (HydroFluoroCarbon)

A molecule of one or two carbons, with some of the hydrogen atoms replaced by fluorine atom. This molecule typically has a negligible impact on the ozone layer. However, its numerous strong fluorine-carbon bonds absorb infrared radiation while the molecule remains in the lower atmosphere, giving a significant GWP value.

2.5 Natural Refrigerants (CO_2, H_20, NH_3, HC, Air)

Five refrigerants, arbitrarily grouped under this title in the early 1990's, because they are virtually environmentally benign to the atmosphere. They were and are used as refrigerants in various applications but all have significant limitations for buildings. There is a strong movement in Europe to expand their areas of application.

2.5.1 CO_2 (carbon dioxide) Currently being considered for automotive air conditioning, however it is inherently inefficient for building applications. Also it operates at a pressure of 100 atmospheres which may raise safety concerns.

2.5.2 H_20 (water) Used for making ice for some limited industrial applications. Machine size per unit capacity is of an order of magnitude larger than current building machinery, because of its very low vapor pressure.

2.5.3 NH_3 (ammonia) Widely used in industrial applications. Excellent thermodynamic performance. Building codes apply strict limitations because it is rated as toxic and flammable.

2.5.4 HC (hydrocarbons) Propane and butane are good refrigerants, thermodynamically, however their
flammability limits capacity for inside buildings to be not much larger than a home refrigerator.

2.5.5 Air Inherently inefficient compared to current air conditioners. Being considered in Europe for railway air conditioning.

2.6 Other Building Applications.

Halocarbons are also used in buildings for applications other than machinery working fluids in cooling equipment. In particular, they are found in the cells of foamed insulation and in fire fighting systems (as a replacement for halon). Since these fluids are of the same chemical family as the machinery fluids they are also referred to as refrigerants in this report. The one difference is that for the fire fighting fluids, at least, only the direct effect needs to be considered for ODP and GWP ratings. Although the primary focus of this TSAC assessment

is for actual refrigeration applications, the impacts of the non-refrigeration applications in buildings should not be ignored by LEED.

3.0 MARKET DISTRIBUTION FOR VARIOUS REFRIGERANT TYPES AND HVAC EQUIPMENT TYPES

3.1 The LEED Credit E&A 4 applies to all types of HVAC systems, including unitary (direct expansion package rooftop equipment, split system, through-the-wall, and heat pumps) and water chillers (centrifugal, reciprocating, screw, and absorption). The focus of discussion of the impact of this credit has been upon centrifugal water chillers, and that is where this first phase analysis has concentrated. However, it is important to realize that there is significantly more unitary HVAC equipment specified and installed than water chillers, both in terms of number of units and total amount of refrigerant charge [6]. Thus, it will be essential that the analysis of these issues ultimately assess unitary equipment as well. However, as the starting point for the analysis of the HVAC refrigerant issue, we have focused on centrifugal water chillers using HCFC-123 and HFC-134a. Thus, the analysis in this Phase One report focuses on this subset of the entire HVAC equipment / refrigerant population. It is anticipated that similar analysis methodologies will be applied to the refrigerants in other HVAC products in subsequent phases of this effort.

3.2 It should be noted that "HCFC-123 [has become] a key replacement for CFC-11 due to its similar properties to CFC-11, which permit it to replace CFC-11 in new and existing chillers without extensive modification of equipment or equipment rooms [6, p120]." This has particular significance for *LEED for Existing Buildings*, where it makes sense to encourage the retrofitting of existing chillers using CFC-11 to HCFC-123, which is significantly better in terms of its ODP impact (80x) and its GWP impact (38x) than CFC-11. Approximately 50% of the stock of water chillers in existing buildings still use CFC-11 as refrigerant [6, p 108], so this is an important impact. 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.

4.0 DIRECT AND INDIRECT EFFECTS OF CHILLERS ON OZONE DEPLETION AND GLOBAL WARMING

4.1 To compare the environmental impacts on global ozone and climate of two widely used refrigerants, the hydrochlorofluorocarbon HCFC-123 ($CHCl_2CF_3$) and the hydrofluorocarbon HFC-134a (CH_2FCF_3), in medium-capacity water chillers, we adapted a simple model based on one developed for EPRI [2]. The impacts occur through two mechanisms: *direct* impacts from the leakage of gases that deplete ozone or warm the atmosphere through their absorption of the earth's thermal emission, and *indirect* impacts, which occur through the amount of electricity consumed as a function of the chiller's operating efficiency (the lower the chiller's efficiency, the more electricity is consumed and consequently the more CO_2 emissions are generated. The quantities calculated and compared are an environmental warming index (*EWI*) expressed in kg/yr of CO_2 equivalent and an

ozone depletion index (*ODI*) expressed in kg/yr of equivalent CFC-11 (CCl_3F). The models for these calculations are as follows:

The direct environmental warming index, which simulates the refrigerant escaping to the atmosphere during both annual operations and disposal at the end of a chiller's life, is:

$$EWI_d = \frac{GWP}{L} \times \left[\underbrace{\left(Q \times R_C \times L_A \times L \right)}_{\text{(operating)}} + \underbrace{\left(Q \times R_C \times L_D \right)}_{\text{(disposal)}} \right] \tag{1}$$

The ozone depletion index, which likewise includes both annual operations and disposal, is:

$$ODI = \frac{ODP}{L} \times \left[\left(Q \times R_C \times L_A \times L \right) + \left(Q \times R_C \times L_D \right) \right] \tag{2}$$

The indirect environmental warming index, based on CO_2 emitted in producing the energy to operate the chiller, is calculated using:

$$EWI_i = EFL \times Q \times P \times \sum_j f_j \times CDF_j \tag{3}$$

Table 2 presents the notation and the values used in the model.

Table 2. Notation and input values

Symbol	Description	HCFC-123	HFC-134a
CDF	CO_2 produced per kilowatt-hr power generated (kg CO_2/kWhr), dependent on fuel source *j*.	0.610	0.610
EFL	Equivalent full load of chiller operation (hr/yr).	1500	1500
f_j	Fraction of power generated with fuel source *j*.	1.0	1.0
GWP	Global warming potential of a compound released into atmosphere (kg CO_2 equivalent/kg compound).	76	1320
L	Chiller lifetime (yr).	30	30
L_A	Annual loss/leakage rate, including both operating and intermittent losses (%/yr).	0.01	0.01
L_D	Sum of initial and disposal loss/leakage rate, one-time events per chiller (%).	0.022	0.022
ODP	Ozone depletion potential of a compound released into atmosphere (kg CFC-11 equivalent/kg compound).	0.012	0.000014
P	Chiller performance (kW/ton).	0.509	0.533
Q	Nominal chiller capacity (tons).	450	450
R_C	Specific refrigerant charge fraction (kg/ton).	0.774	1.232

4.2 The Carbon Dioxide Factor, *CDF*, is the conversion factor for determining the amount of CO_2 released into the atmosphere from the electric power plant. Of course this factor varies with the type of plant (i.e., coal, gas, hydropower, etc.). For this study, we use the national weighted average value, as determined by the U.S. Department of Energy and Environmental Protection Agency [3]. Using this average dictates a value of 1.0 for the *f* factor and no summation, Σ, is required.

4.3 Values for the Global Warming Potentials, *GWP*, are the latest 100-year integration period values [4].

4.4 The average chiller life, *L*, of 30 years was selected based on discussions with engineers of various manufacturers [5].

4.5 The annual refrigerant loss rate, L_A, has been decreasing significantly over the past decade due to manufacturer's awareness of environmental concerns. The latest chiller design standard of zero loss has been modified to the more realistic value of 1% per year. This value has been used in other analyses of ozone depletion in the past few years [4].

4.6 Similarly, the loss, L_D, which accounts for refrigerant escaping during the installation and removal of the machine at the beginning and end of its life, is assumed to be 2% of the total charge.

4.7 *ODP* values were taken from reference [4].

4.8 The power values, *P*, required to meet the chiller capacity assumed were determined by the methodology illustrated in the Appendix.

4.9 We chose the average capacity *Q* on the advice of three industry sources who agreed that 450 tons was a likely median for the range of centrifugal water chillers sold in the U.S. for buildings applications. This may seem a bit too large from an average building size, but we reasoned that since screw compressor chillers are now competing up to the 300 ton range, the 450 ton number was more representative for centrifugal chillers. The capacity value has no influence on the efficiency value in the theoretical archetypical model, so it is not pertinent, per se, in the indirect impact calculation.

4.10 *Q* does affect the absolute values of the annual equivalent full load operation hours. While this can vary widely dependent on climate and designer's sizing calculations, there is no reason to think the one refrigerant system would have a run time that would differ significantly from the other, so the relative differences should not differ. A review of several power plants' data and discussions with other experts who had to make the same estimate showed that most agreed that 1500 hours was a reasonable number for a national average for *EFL*.

4.11 The typical average charge values, R_C, for each chiller were taken from reference [6].

4.12 Of the input values for our analysis, only four parameters (*GWP*, *ODP*, *P*, R_C) vary with the type of refrigerant used and thus have an effect on the relative impact of the different chillers. However, the assumption that the refrigerant losses, L_A and L_D, are equal probably underestimates the direct global warming impact of HFC-134a, because the HCF-134a vapor pressure is higher than that of HCFC-1213 so any opening or disconnecting of

the respective machines would result in more losses due to this higher pressure. Unfortunately no field data could be found to quantify the differences.

4.13 Environmental Impact Results

Table 3 shows the calculations, from Equations (1) through (3) in the previous section, of the direct and indirect environmental warming impacts, as well as the impact on the ozone depletion. It is interesting to note that, while the indirect environmental warming impact is considerably greater than the direct (in part due to the long life of the chiller), the direct and indirect differences between the refrigerants are similar. The important point is that while the HCFC-123 has more of an impact on ozone, HCF-134a has more of an impact on global warming. Since there is no method by which these two differences can be equated to each other, we examine their respective impacts as part of the overall chemical impact of CO_2 and CFC-11 equivalents.

Table 3. Model calculation results, per chiller

	HCFC-123	HFC-134a	Difference	
EWI_d (kg CO_2 equiv.)	284	7,855	7,571	direct Environmental Warming Index, including annual operation & disposal
EWI_i (kg CO_2 equiv.)	209,425	219,299	9,875	indirect Environmental Warming Index, CO_2 emitted producing energy for chillers
EWI_{total}	202,709	227,154	**17,445**	$EWI_d + EWI_i$
ODI (kg CFC-11 equiv.)	0.04486	0.00008	**-0.04478**	Ozone Depletion Index, including annual operation and disposal

4.14 Total annual U.S. emission of global warming substances is 5.22×10^{12} kg CO_2 equivalent [7]. The total U.S. emission of ozone depleting chemicals is 5.75×10^{6} kg CFC-11 equivalent [8]. Using these values as the denominators for the ratios of the respective refrigerants, Table 4 shows the results. Of course all the values are small, because the one chiller's worth of impact is tiny compared to the U.S. total. However, as a fraction of the U.S. total, the environmental impacts of the differences between refrigerants are only about a factor of 2 different (note bold values), which we deem to be essentially equal given the levels of uncertainty of the impact data. This means that the amount of damage done to the ozone layer resulting from the use of one HCFC-123 chiller is approximately the same as the amount of damage done to global warming by the use of one HFC-134a chiller of the same capacity. This measure may form a basis for considering the relative impact of one refrigerant to another.

Table 4. Fractional impact of one chiller within U.S. total (nano-units)

	HCFC-123	HFC-134a	Difference
EWI_d	0.0545	1.51	1.45
EWI_i	40.1	42.0	1.89
EWI_{total}	40.2	43.5	**3.34**
ODI	7.80	0.0145	**–7.79**

5.0 CHILLER ENERGY USAGE IMPACT ON BUILDING ENERGY USAGE

5.1 One of the apparent rationales in the LEED structure for E&A Credits 1 and 4 is that there is a trade-off between energy performance and ozone depletion performance that is essentially equivalent: choose an HFC-134a chiller and earn the E&A Credit 4; choose an HCFC-123 chiller and earn an extra efficiency point under E&A Credit 1. It seems appropriate to examine the validity of this trade-off.

5.2 Market data indicate that HCFC-123 chillers are at most 12% more efficient than HFC-134a chillers. The annual cooling energy usage represents 10.6% of a building's total annual energy usage [11, p1-10]. Applying the 12% efficiency factor to the 10.6% of building energy yields an improvement of 1.3% of total annual building energy usage. The structure of LEED E&A Credit 1 provides for one additional LEED point for every 5% improvement in the energy performance of the building. Thus, it would take four times the energy savings that the chiller is likely to produce to earn an added LEED point under this credit, so it appears that the energy efficiency improvement of an HCFC-123 chiller (as compared to an HFC-134a chiller) would not by itself result in a building earning an extra LEED point under E&A Credit 1.

5.3 Based upon this analysis, we conclude that the "energy vs. ozone trade-off" concept does not in fact yield an equivalent treatment of the two refrigerant types in terms of the potential impact on LEED points earned.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

6.1 An objective scientific comparison between global warming and ozone depletion is extremely complex, and will only come from a full understanding of all interacting pathways and the effects on economic activities, human health, and terrestrial and oceanic ecosystems. Therefore, any quantitative credit scheme addressing both must involve some subjectivity, at least where the final credit values are concerned. However, there is no reason that every environmental parameter cannot be considered qualitatively and determined if it is applicable for rating. There is enough scientific evidence that global warming is a problem that a rating scheme of some sort should be devised.

6.2 The current LEED rating system does consider refrigerants' contribution to ozone depletion. However, it does not consider *direct* emissions that contribute to global

warming. It only considers the *indirect* contribution through energy performance. As Table 3 shows, the direct emission of HFC-134a is only 4% of the chiller's contribution to global warming, but Table 4 shows that more than 40% of the difference between the refrigerants' contribution to global warming stems from direct emissions.

6.3 When direct effects are combined with the indirect effects and compared with the direct ozone damage (note bold numbers of Table 4), it is apparent that the different halocarbons used in a chiller can do as much relative environmental damage via global warming as ozone depletion. This, it appears that the current scheme that trades off points for avoiding ozone depletion or conserving energy adequately captures the state of the science. This would appear to support leaving the LEED E&A Credit 4 as it is.

6.4 However, the relative magnitude of the impacts (which are roughly equivalent environmentally) is not reflected in the energy efficiency credit scale of E&A Credit 1, with the result that the HCFC-123 chiller would not receive a full point's worth of energy efficiency credit, even though the alternative HFC-134a chiller would receive a full point under E&A Credit 4 for reduced ozone depletion. This would appear to support the need for a change in the LEED credit structure to remedy this imbalance.

6.5 While the existing credit structure may have been reasonable in light of the information available to the USGBC at the time of LEED's creation, it is our judgment that on balance the technical analysis performed herein suggests that some adjustments may be appropriate.

Recommendations

6.6 We therefore recommend a change in LEED Version 2.2 along the lines of the change described below, for consideration by the LEED Steering Committee and other relevant LEED committees:

> Change the ODP credit (Energy & Atmosphere Credit 4) from a proscriptive credit to a performance credit based upon the refrigerant "ODP x Life Cycle Emission", normalized to a "per ton of cooling capacity" basis. This has the advantage of retaining LEED's intent to reduce the impact of ozone depleting chemicals, while improving the way it addresses the issue. Although more work is needed to confirm this, it is likely that using this approach both HCFC-123 and HFC-134a chillers would get the credit, but that equipment using refrigerant combinations with higher ODP impacts would not.

6.7 Further, to improve the way LEED addresses global warming and ozone depletion, we recommend that the framers of LEED Version 3.0 consider the following concepts:

- Consider giving explicit credit to the *direct plus indirect* emissions of global warming gases, expressed in terms of CO2 per ton of cooling capacity, or some equivalent performance metric.
- Because of the wide range of GWP and ODP ratings among halocarbons, consider establishing linear scales for both global warming and ozone depletion, similar to the current energy point system.

- Consider giving credit for reducing the impacts of the non-refrigeration applications using halocarbons in buildings (e.g. building materials, such as insulation).

6.8 The other specific application recommendation relates to *LEED for Existing Buildings (LEED-EB).* HCFC-123 has become a key replacement for CFC-11 because it can replace CFC-11 in new and existing chillers without extensive modification of equipment or equipment rooms. This has particular significance for *LEED for Existing Buildings*, where it makes sense to encourage the retrofitting of existing chillers by replacing CFC-11 with HCFC-123, which has 80× less ozone depletion potential (ODP) and 38× less global warming potential (GWP) than CFC-11. Approximately 50% of the water chillers in existing buildings still use CFC-11 as refrigerant, so this is an important impact. Thus, we recommend that the LEED Steering Committee and other relevant committees consider structuring the E&A Credit 4 in LEED-EB so that it provides a point for replacement of CFC-11 with HCFC-123 in existing chillers.

7.0 AUTHORSHIP AND ACKNOWLEDGEMENTS

7.1 AUTHORSHIP

7.2 This report represents the work product of a team. The underlying technical analysis of atmospheric impacts was performed by the HCFC Task Group. The applications to LEED were authored by TSAC. The conclusions and recommendations were a group effort. In an effort to give credit where it is due, and to make clear that certain extensions from analysis to application were made not by the scientists but by the TSAC members, the summary below of authorship indicates who authored each section of the report. Those sections not listed below were mixed authorship.

TSAC HCFC Task Group

Reva Rubenstein, Ph.D., Chair
David Didion, D.Eng., P.E.
Jeff Dozier, Ph.D.

Sections 1, 2, 4, 6.1-6.3, 7.4, Appendices A and B (partial).

TSAC:

Malcolm Lewis, D.Eng., P.E., Chair
Nigel Howard, LEED Director

Preface, Sections 3, 5, 6.4-6.6, 6.8, 7.2, Appendix B (partial)

7.3 ACKNOWLEDGEMENTS

7.4 Drs. Didion and Dozier would like to recognize the contributions made to the concepts presented in this report by Dr. Reva Rubenstein, Mr. Nigel Howard, and Dr. Malcolm Lewis. Dr. Rubenstein and Mr. Howard were full participants in the discussions held during the spring and summer of 2003, and Dr. Lewis made valuable modifications to the report in early 2004.. Neither the problem nor the solution would have been as proposed without their thoughts and guidance.

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APPENDIX A: CHILLER MODEL AND SENSITIVITY RESULTS

A.1 The most influential piece of data for determining the indirect impact on GWP is the chiller performance rating, which is defined as the ratio of power in (kW) to capacity (ton). For the determination of these values for both the HFC-134a and HCFC-123 chillers, we use the NIST Standard Reference Database 49 [9]. Known as CYCLE-D, this database was developed specifically for the comparison of refrigerants and refrigerant mixtures performance within the vapor compression cycle without the encumbrances of specific hardware specifications. The program consists of a simulation of the vapor compression cycle that can call upon the NIST Reference Database 23:REFPROP, a program that contains the world's most authoritative thermophysical properties of refrigerants [10]. Results on the evaluations of HFC-134a and HCFC-123 are presented in the following pages. The state numbers in the data sheets (1 thru 11) are presented pictorially in the subsequent schematic and thermodynamic diagrams. The performance factor of kW/ton, which is the practical term generally used in the U.S. industry, is not printed out explicitly. The more academic term is COP, which is the inverse of this term but in like dimensions (i.e., kW/kW). The mixed dimension of kW/ton refer to the electric power in (kW) to the design capacity, where 1ton equals 12000Btu/hr. Thus the kW/ton was determined manually by dividing the value of total power (listed in the fourth line from the bottom) by the assigned system cooling capacity (fifth line from the top) of 450 tons. In this case the total power and the compressor power were assumed to be the same since there is no reason to expect the auxiliary powers (e.g., fans, controls, etc.) to be different in two machines under consideration. Note that since this performance factor is, in effect, the inverse of the efficiency then the lower the numerical value of kW/ton the higher the efficiency. Dividing the power data, from the two tests below, by the assumed capacity value of 450 tons yields the final results of 0.509 kW/ton for HCFC-123 and 0.533 kW/ton for HFC-134a.

A.2 Modeling an archetypical chiller that focuses on the relative performance of the refrigerant still requires some minimum input about the systems components and operating conditions; particularly those that would affect the thermodynamic state of the fluid at key positions within the system (e.g., at the compressor entrance). The respective evaluations required the data from the table below as input. These data were obtained from the references listed.

Cycle-D Operating Conditions

	HFC-134a	HCFC-123	Reference
Condenser temperature	96°F	96°F	5
Evaporator temperature	43	43	5
Subcooling	8	8	5
Superheat	2	2	Calculated
Motor efficiency	0.96	0.96	5
Compressor efficiency	0.82	0.82	5
Capacity	450 tons	450	5

A.3 Certainly the most influential operating condition on performance is the evaporator temperature; followed closely by the condenser temperature. The water chiller refrigerant values chosen, 43°F and 96°F, respectively, were recommended as the typical test

conditions for laboratory rating conditions. The analysis below applies the CYCLE-D model to HCFC-123 and HFC-134a, respectively.

Refrigerant HCFC-123

Input data:

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Refrigerant and weight composition
R123   1.00;
System cooling capacity (Tons)   =450.00
Compressor isentropic efficiency =   .820
Compressor volumetric efficiency =  1.000
Electric motor efficiency        =   .960
Pressure drop (in sat. temp.) (F): in the suction line   =   .0
                                   in the discharge line =   .0
Evaporator: dew-point temp.    (F) =  43.0     Superheat (F) =  2.0
Condenser: bubble-point temp.  (F) =  96.0    Subcooling (F) =  8.0
Effectiveness of the llsl heat exchange =  .00

Parasitic powers (kW): indoor fan  =  .000      outdoor fan  =  .000
                       controls    =  .000


----------------------THERMODYNAMIC CYCLE RESULTS----------------------

    STATE                 T       P      H        V          S        XQ
                         (F)    (psi) (Btu/lb) (ft3/lb)  (Btu/lb F)

 1  Compr. shell inlet  45.0     6.2    96.6   5.57E+0    .19560   1.000
 2  Cylinder inlet      47.4     6.2    96.9   5.60E+0    .19636   1.000
 3  Cylinder outlet    109.4    19.3   106.2   1.97E+0    .19930   1.000
 4  Condenser inlet    109.4    19.3   106.2   1.97E+0    .19930   1.000
 5  Cond. sat. vapor    96.0    19.3   103.9   1.92E+0    .19522   1.000
 6  Cond. sat. liquid   96.0    19.3    32.1   1.12E-2    .06611    .000
 7  Condenser outlet    88.0    19.3    30.2   1.11E-2    .06254    .000
 8  Exp. device inlet   88.0    19.3    30.2   1.11E-2    .06254    .000
 9  Evaporator inlet    43.0     6.2    30.2   7.93E-1    .06351    .141
10  Evap. sat. vapor    43.0     6.2    96.2   5.54E+0    .19497   1.000
11  Evaporator outlet   45.0     6.2    96.6   5.57E+0    .19560   1.000

    Work =   9.61 Btu/lb   Qevap =  66.40 Btu/lb   Qcond =  76.01 Btu/lb
                           COPc  =   6.910         COPh  =   7.910
    Two-phase glide:  evaporator =    .0 F     condenser =    .0 F
    Condenser superheat          =  13.4 F     P(3)/P(2) =   3.11
    Liquid line subcooling due to llsl heat transfer     =    .0 F
    Suction vapor superheat due to llsl heat transfer    =    .0 F
    Volumetric capacity:   cooling                 heating
       @ vol. eff. = 1.00      11.9 Btu/ft3            13.6 Btu/ft3
```

```
---------------------COMPRESSOR AND SYSTEM RESULTS----------------------

Compressor power      = 229.027 kW
Compressor COP: COPc  =   6.910                        COPh =   7.910
                  cfm =   7585.                       cfm/ton =   16.86

Refrigerant mass flow rate  =****** lb/h       Total power = 229.027 kW
Cooling capacity: evaporator=5400.000 kBtu/h      system   =5400.000
kBtu/h
Heating capacity: condenser =6181.514 kBtu/h      system   =6181.514
kBtu/h
      System COP: COPc,sys  =   6.910             COPh,sys =   7.910
```

Refrigerant HFC-134a

```
Input data:
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Refrigerant and weight composition
R134a  1.00;
System cooling capacity (Tons)   =450.00
Compressor isentropic efficiency =   .820
Compressor volumetric efficiency =  1.000
Electric motor efficiency        =   .960
Pressure drop (in sat. temp.) (F): in the suction line   =   .0
                                   in the discharge line =   .0
Evaporator: dew-point temp.    (F) =  43.0     Superheat (F) =  2.0
Condenser: bubble-point temp.  (F) =  96.0    Subcooling (F) =  8.0
Effectiveness of the llsl heat exchange =  .00

Parasitic powers (kW): indoor fan  =  .000      outdoor fan  =  .000
                       controls    =  .000


---------------------THERMODYNAMIC CYCLE RESULTS----------------------
```

	STATE	T (F)	P (psi)	H (Btu/lb)	V (ft3/lb)	S (Btu/lb F)	XQ
1	Compr. shell inlet	45.0	52.7	109.6	9.06E-1	.22259	1.000
2	Cylinder inlet	46.9	52.7	110.1	9.11E-1	.22342	1.000
3	Cylinder outlet	112.5	130.6	120.0	3.85E-1	.22658	1.000
4	Condenser inlet	112.5	130.6	120.0	3.85E-1	.22658	1.000
5	Cond. sat. vapor	96.0	130.6	115.8	3.63E-1	.21901	1.000
6	Cond. sat. liquid	96.0	130.6	43.7	1.37E-2	.08933	.000
7	Condenser outlet	88.0	130.6	40.9	1.35E-2	.08427	.000
8	Exp. device inlet	88.0	130.6	40.9	1.35E-2	.08427	.000
9	Evaporator inlet	43.0	52.7	40.9	1.73E-1	.08590	.181
10	Evap. sat. vapor	43.0	52.7	109.2	9.01E-1	.22172	1.000
11	Evaporator outlet	45.0	52.7	109.6	9.06E-1	.22259	1.000

```
     Work =  10.41 Btu/lb   Qevap =  68.71 Btu/lb   Qcond =  79.13 Btu/lb
                            COPc  =   6.600         COPh  =   7.600
     Two-phase glide:  evaporator =    .0 F     condenser =    .0 F
```

```
     Condenser superheat          =  16.5 F     P(3)/P(2) =   2.48
     Liquid line subcooling due to llsl heat transfer     =    .0 F
     Suction vapor superheat due to llsl heat transfer    =    .0 F
     Volumetric capacity:   cooling                 heating
        @ vol. eff. = 1.00      75.4 Btu/ft3            86.8 Btu/ft3

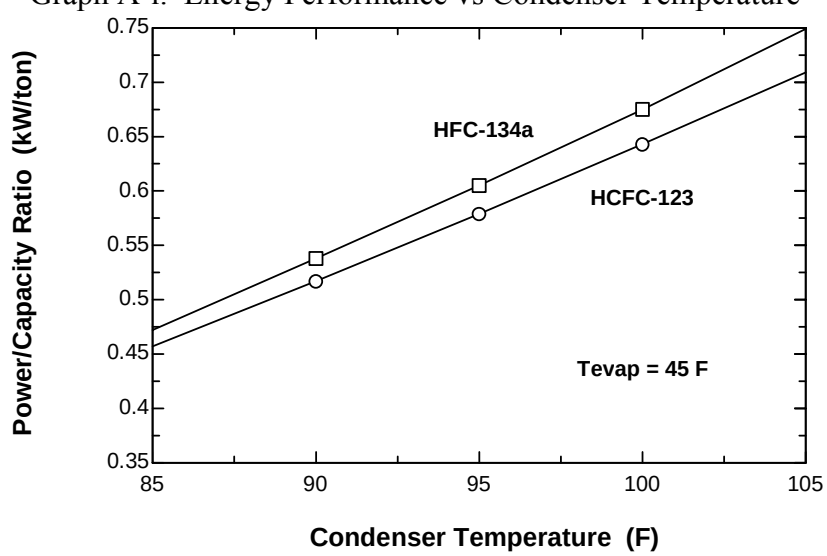

 ---------------------COMPRESSOR AND SYSTEM RESULTS-----------------------

 Compressor power      = 239.773 kW
 Compressor COP: COPc  =   6.600                       COPh =   7.600
                   cfm =   1193.                      cfm/ton =   2.652

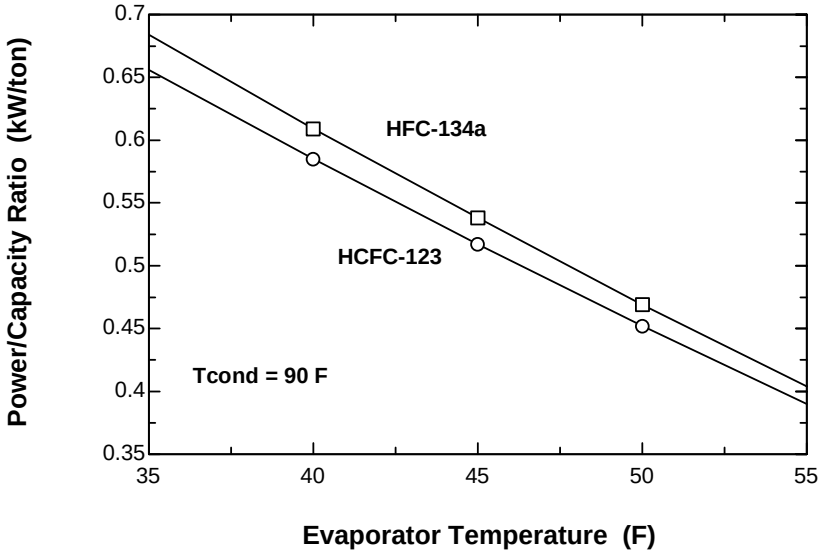
 Refrigerant mass flow rate  =****** lb/h       Total power = 239.773 kW
 Cooling capacity: evaporator=5400.000 kBtu/h      system   =5400.000
kBtu/h
 Heating capacity: condenser =6218.181 kBtu/h      system   =6218.181
kBtu/h
       System COP: COPc,sys  =   6.600             COPh,sys =   7.600
```

A.4 As can be seen from the graphs below, the performance of both chillers is sensitive to the source and sink temperatures. However, what is important for a relative comparison is that the respective performances are approximately the same over the entire range of likely water chiller operating temperatures. That is, the HCFC-123 is always more energy efficient than the HFC-134a.

Graph A-l. Energy Performance vs Condenser Temperature



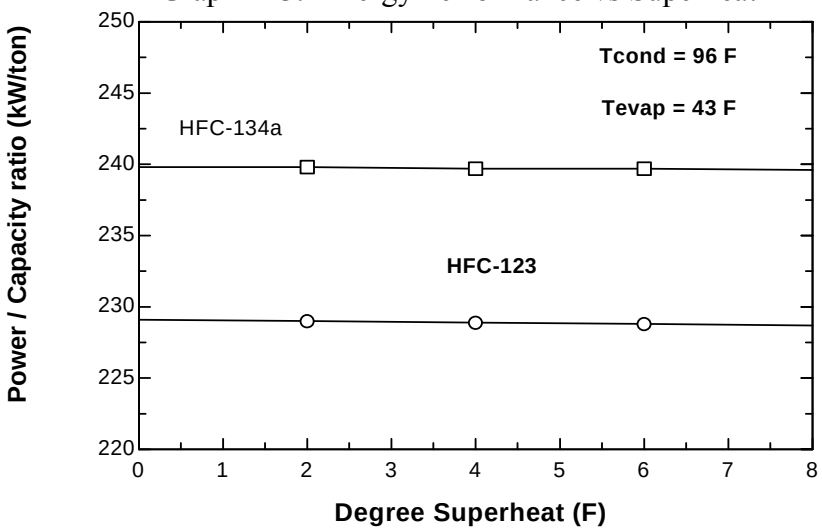
Graph A-2. Energy Performance vs Evaporator Temperature



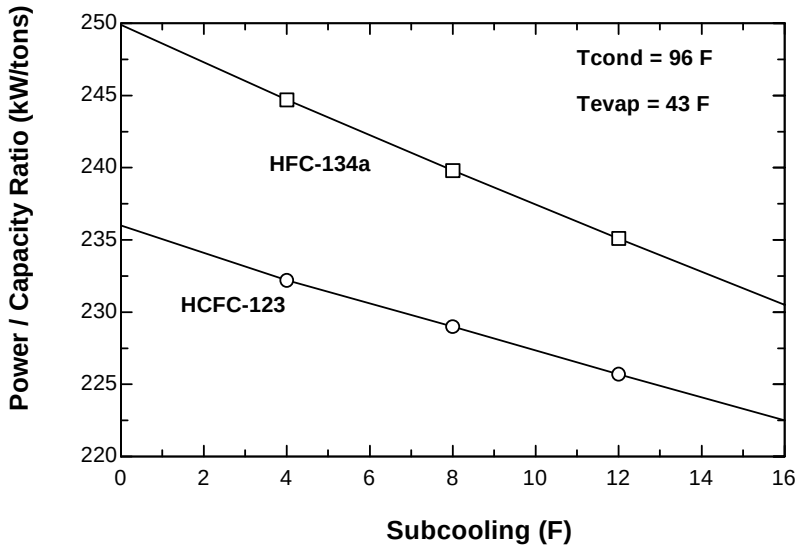
A.5 The other operating conditions that influence the chiller's performance are the condenser's subcooling, which is beneficial, and the superheat entering the compressor, which is detrimental.

A.6 As can be seen from the graphs below the superheat selection has insignificant effect on either refrigerant's performance. The subcooling does have some effect and the performance of HFC-134a appears to be approaching HCFC-123 but not before the atmospheric temperature (ultimate sink) is reached and not before the size of the heat exchanger becomes unreasonably large. Thus, here again the HCFC-123 energy performance is superior to that of HFC-134a.

Graph A-3. Energy Performance vs Superheat



Graph A-4. Energy Performance vs Sub-Cooling



A.7 The motor and compressor efficiency values are typical of what is currently used. There is no reason to think that their values would be different for one refrigerant to the other. Therefore, a change in either of these hardware values would not really affect the relative performance of one system versus the other.

APPENDIX B: A POSSIBLE RATING METHODOLOGY

B.1 The lack of a direct relationship between the Global Warming Potential (GWP) and the Ozone Depletion Potential (ODP) creates a challenge in developing a rating system that allows the two environmental factors to be considered together, as they should be in evaluating the environmental impact of an HVAC system. For the case of the GWP/ODP impact of centrifugal water chillers, one possible methodology is presented here for purposes of discussion.

B.2 To begin, consider all the refrigerants that might be part of a building's design or operation. Their applications in the building might include maintaining comfort conditions (e.g., heating, cooling, dehumidifying), insulation foaming agent, fire protection, etc.[1] A partial list of such refrigerants is presented in Table B-1 below.

Table B-1. Refrigerants' ODP and GWP Data per Molecule[2]

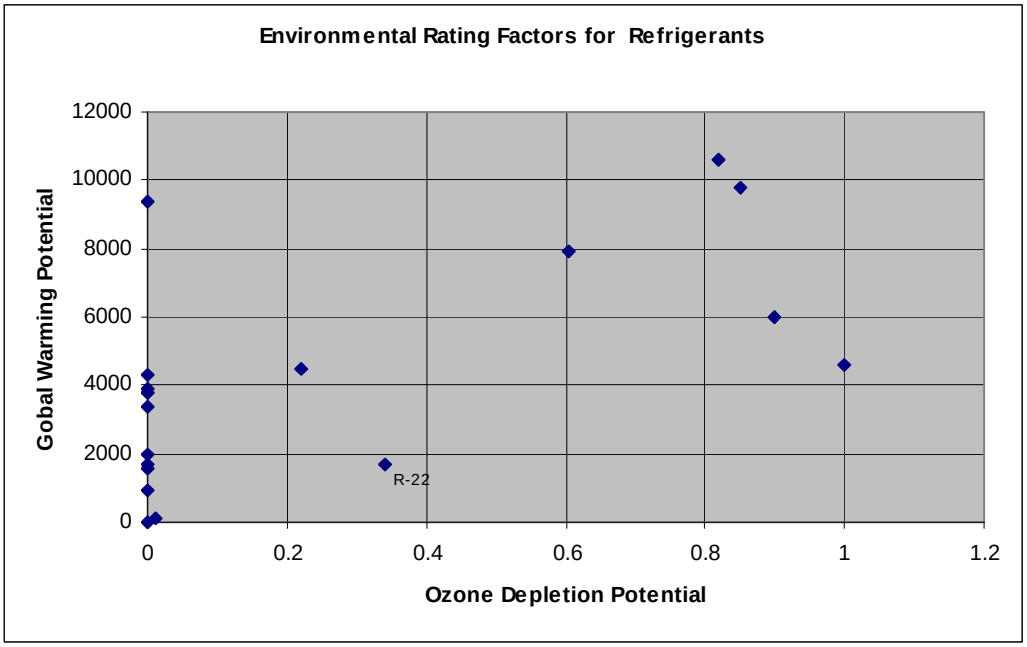
Refrigerant	ODP	GWP	Application
HFC-23	0	14800	low temperature refrigeration
CFC-12	0.82	10600	freezers, chillers, air conditioners
CFC-114	0.85	9800	centrifugal chillers
HCF-236fa	0	9400	fire systems
CFC-500	0.605	7900	centrifugal chillers
CFC-11	1	4600	centrifugal chillers
CFC-502	0.221	4500	freezers
HFC-143A	0	4300	mixture component
HFC-507A	0	3900	freezers
HFC-404a	0	3800	space conditioning
HFC-227ea	0	3800	fire systems
HFC-125	0	3400	mixture component
HFC-410A	0	2000	air conditioning
HFC-407C	0	1700	Drop-in replacement for HCFC-22
HCFC-22	0.34	1700	freezers, chillers, air conditioning
HCF-134a	0	1600	CFC-12 replacement
HFC-245fa	0	950	foaming agent for insulation
HCFC-123	0.012	120	CFC-11 replacement

B.3 A scatter plot of this data using the axes of GWP and ODP shows the wide range of variation in these data for various refrigerants, as shown in Graph B-1 on the next page. It must be noted that these data are on a "per molecule" basis, and do not reflect the comparative quantities of refrigerant charge needed for an HVAC application. They also do not reflect the *direct* and *indirect* GWP impacts as a result of leakage and energy efficiency, respectively.

[1] For purposes of comparing the relative impact of various uses of refrigerants in building products, it is instructive to note that a typical residential refrigerator has ~2 lbs of refrigerants embodied in its foam insulation, and ~6 ounces of refrigerant in its refrigeration compressor.

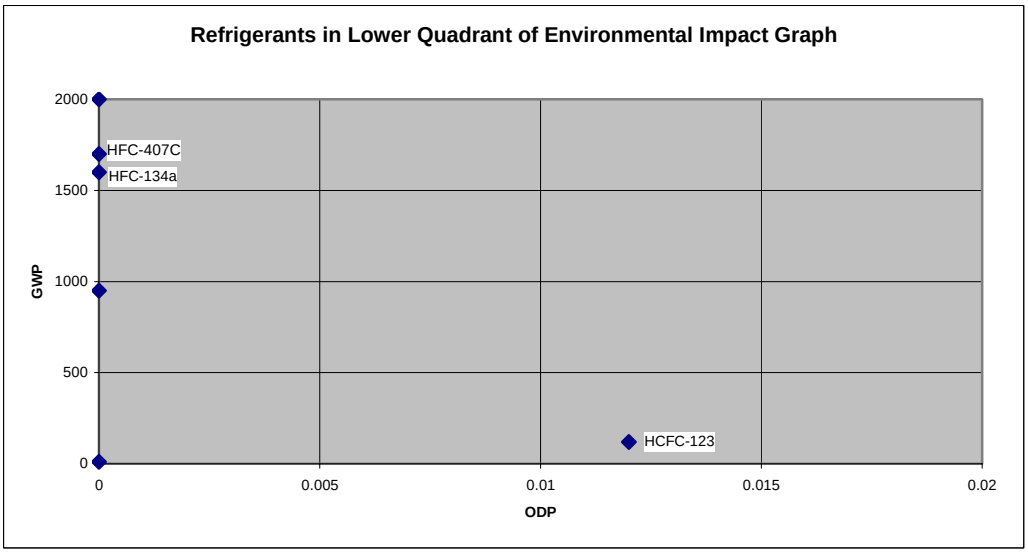
[2] Note that these molecular data do not reflect the relative impacts of these refrigerants in actual HVAC applications, as that must factor in the relative quantity of charge and lifecycle emissions; see discussion later in this Appendix.

Graph B-1. GWP vs ODP for Various Refrigerants (Molecular Values).



B.4 Graph B-2 shows this same data, but just for the refrigerants down near the origin of the graph, as it appears in Graph B-1 that there are a number of refrigerants with almost the same ODP and relatively close GWP. The analysis in Section 4 of this report demonstrates that HCFC-123 and HFC-134a are of approximately of the same environmental impact, for different reasons, but that analysis is based upon the actual applications in HVAC equipment. That analysis takes into account variations in quantity of charge, operating pressure, leakage, and energy efficiency that each refrigerant has in specific HVAC equipment, which these molecular data do not.

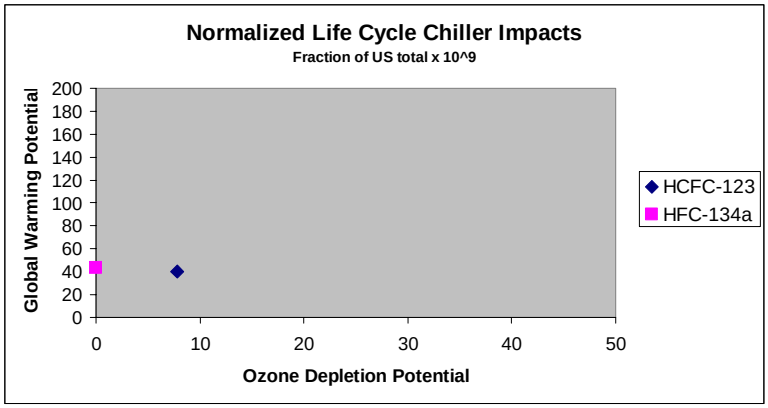
Graph B-2. GWP vs ODP for Refrigerants with Lower Molecular Environmental Impacts.



B.5 This molecular methodology, when based on GWP and ODP as exemplified here, has the inherent limitation of considering only the *direct* effect of the refrigerant. The use of GWP and ODP as a scale evaluates "environmental damage per molecule" and since one refrigerant may require more molecules than another to perform the same cooling task, it is necessary to consider the quantity of the refrigerant needed per unit of cooling output. To properly represent the total environmental impacts of the HVAC applications, the *indirect* effect, which is the dominant one, must also be taken into account. For chillers, that translates to GWP and ODP per unit of cooling capacity.

B.6 The environmental impact of the few refrigerants exemplified were already known from the study in Section 4 of this report and from the knowledge that the alternative to R-22 would require a similar charge per unit capacity in the machine application (i.e., it is a drop-in replacement with little loss in capacity). For chiller systems using different refrigerants the amount of refrigerant for each may differ in order to achieve the same cooling capacity. Thus, a fair comparison would be "damage done per chiller", for a given chiller size, as was shown in Table 4 for the HFC-134a /HCFC-123 comparison in this study. This is shown in the Graph B-3 below for the prototypical 450 Ton chillers used in the analysis. It could be further refined to a basis of "environmental damage per ton of cooling capacity".

Graph B-3. Normalized Life Cycle Chiller Impacts.



B.7 The "refrigerant charge per cooling capacity" is not predictable from data about the physical properties of the refrigerants, so different cooling system types have to be examined on a case-by-case basis. Based on existing systems, average data for each of the refrigerant system types has been, and is being, gathered by the industry and other researchers. It is our opinion that for the relative comparisons that are necessary for this analysis, this average data would be adequate, and it is anticipated that averages will be used in Phase 2 of this work. Ultimately, this approach to rating will require industry to provide these data for the specific cooling equipment models in their product lines, as a basis for evaluating their performance under the proposed approach to LEED's rating of ODP performance.

B.8 Once these data are available, it should be possible to identify groups of HVAC products (combinations of equipment and refrigerants) that fall into regions of total environmental impact (combined GWP and ODP per unit of cooling capacity). It is hypothesized that it will be possible to identify three regions that might correspond to "No Environmental Impact", "Minimum Environmental Impact", and "Significant Environmental Impact." If so, quantifying these categories might lead to a LEED rating scale of zero points for a refrigerant in the 'Significant Impact' zone, one point for one in the 'Minimal Impact' zone, and two points for one in the 'No Impact' zone. Although the 'No Impact' category is not likely to be ever achieved for centrifugal chillers, it allows for the possibility and sets an ultimate goal. The actual development of these regions will, of course, have to wait until the data are available from industry for their HVAC products.

APPENDIX C: BIOGRAPHICAL DATA FOR AUTHORS

HCFC TASK GROUP

Reva Rubenstein, Ph.D, Task Group Chair

Dr. Rubenstein has more than 40 years experience in the technical sciences, including chemistry, public policy, nursing science education, toxicology, and environmental management, and specializes in matters related to the health and environmental impacts of chlorofluorocarbon (CFC) substitutes. She acted as the Science Advisor to the Director of the Stratospheric Protection Division (now Global Programs Division) of the U.S. Environmental Protection Agency (EPA) until her retirement in March 2001. Her duties included analysis of toxicity and exposure reports submitted to the EPA under the Significant New Alternatives Policy (SNAP) program for both new and existing chemical alternatives. During her tenure as Science Advisor and Toxicologist for the U.S. EPA, Dr. Rubenstein served on a variety of honorary committees and won awards for her knowledge and dedication. In 1997, Dr. Rubenstein received the U.S.EPA Bronze Medal for Commendable Service for contributions to the research strategies for protection of stratospheric ozone. Since 1995, she has served as a member of the United Nations Environmental Programme Halon Technical Options Committee. She is also serving a term from 1999 to 2002 as a member of the Halon Alternative Protection Options HAO-AAA Technical Committee, which is responsible for clean agent fire extinguishing systems (NFPA 2001). In 1996, Dr. Rubenstein served as a member of the Committee on Fire Suppression Substitutes and Alternatives to Halon 1301. This committee was a committee of the National Research Council's Naval Studies Board. Dr. Rubenstein was a member of the United States Coast Guard delegation to the Fire Protection Subcommittee of the International Maritime Organization from 1998 to 2000. This subcommittee reports to the Maritime Safety Committee and the Maritime Environmental Protection Committee in furtherance of its responsibility to develop regulations under the Safety of Life at Sea Treaty, (SOLAS).

David A. Didion, D.Eng., P.E.

David Didion is a retired Fellow of the National Institute of Standards and Technology (NIST). He began the refrigeration engineering phase of his career as a project engineer in the Building and Fire Research Laboratory in 1971. By 1974, he had become the leader of the Thermal Machinery Group and began a 10 year program to develop a series of laboratory test methodologies for seasonal efficiency ratings of various vapor compression cycle machines (e.g., air conditioners and heat pumps). These procedures are in use throughout the manufacturing industry, today. In 1981, he started a research program in zeotropic refrigerant mixtures. This program's modeling and laboratory efforts focused on the interaction between the machinery and their working fluids. This work helped point the way for the world-wide industrial effort to develop the new, chlorine-free, refrigerant mixtures that are compatible with the earth's ozone layer. For this 15 year effort, he has received several honors and awards from the U.S. Department of Commerce, the DuPont Corporation, the Air Conditioning and Refrigeration Institute, the American Society of Mechanical Engineers, and the American Society of Heating, Refrigeration, and Air Conditioning Engineers, the U.K.'s Institute of Refrigeration's 2001 Gold Medal, and the International Institute of

Refrigeration's highest honor: the Lorentzen Prize. Throughout this period, he has maintained a teaching career in the graduate engineering evening programs at the University of Maryland and Johns Hopkins University, where he is a 'Fellow by Courtesy'. Since his retirement from NIST, in 2002, he has remained active in his field through the continuation of engineering graduate school teaching, as the USA Regional Editor of the International Journal of Refrigeration, and selected private consulting projects in the field of vapor compression cycles and refrigerants. He also remains active member of ASHRAE's Standards Committee 34. This committee determines if a new refrigerant has satisfied all the tests for flammability and toxicity and is thus qualified to be assigned a number (e.g. R-134a, etc.) and a safety rating category.

Jeff Dozier, Ph.D.

Jeff Dozier's research and teaching interests are in the fields of snow hydrology, Earth system science, remote sensing, and information systems. He has pioneered interdisciplinary studies in two areas: one involves the hydrology, hydrochemistry, and remote sensing of mountainous drainage basins; the other is in the integration of environmental science and computer science and technology. In addition, he has played a role in development of the educational and scientific infrastructure. He founded UCSB's Donald Bren School of Environmental Science & Management and served as its first Dean for six years. During that time he inspired and supervised the design of Bren Hall, the first LEED Platinum-award laboratory building. He was also the Senior Project Scientist for NASA's Earth Observing System in its formative stages when the configuration for the system was established. Professor Dozier received his B.A. from California State University, Hayward in 1968 and his Ph.D. from the University of Michigan in 1973. He has been a faculty member at UC Santa Barbara since 1974. He is a Fellow of the American Geophysical Union, the American Association for the Advancement of Science, and the UK's National Institute for Environmental eScience. He is also an Honorary Professor of the Chinese Academy of Sciences and a recipient of the NASA Public Service Medal.

TSAC

Malcolm Lewis, D.Eng., P.E.

Dr. Lewis is President of CTG Energetics, Inc., a consulting engineering firm specializing in mechanical, electrical, and energy systems for buildings and industrial processes. He has over 30 years of experience in engineering design and has been responsible for the design of numerous energy-efficient and "green" facilities. For the US Green Building Council, he has served as a member of the Board of Directors (1997-2002), and is currently a member of the LEED Steering Committee, and is Chair of the LEED Technical and Scientific Advisory Committee (TSAC).

Nigel Howard

Nigel serves as Vice-President for LEED™ & International Programs, US Green Building Council, responsible for LEED and the overall day-to-day management of the USGBC Washington Headquarters office. In this role, he is the Director of the LEED program and headquarters staff and operations, and is the Council's senior spokesperson for LEED. He is also an *ex-officio* member of TSAC. Nigel was formerly Director of the Centre for Sustainable Construction at BRE in the UK. In this capacity he was responsible for 4 teams, the first developing the UK's environmental assessment method BREEAM; the second developing a UK LCA methodology for materials components and buildings and an eco-profiles database and design tool – ENVEST; the third developing and implementing strategic policy initiatives on behalf of UK Government and the fourth developing sustainability assessment methods to take account of environmental, economic and social issues for communities – Cities, Towns, Villages, etc. Nigel is trained as a professional chemist with over 25 years of experience working on aspects related to the energy and environmental impact of buildings.

APPENDIX D. CHARGE TO TSAC.

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LEED v2.0 Energy Credit 4: Ozone Depletion
Charge to TSAC from LEED Steering Committee
Date 21 September 2001

Back Ground

Energy Credit 4 is interpreted by a number of commentators as inconsistent with prevailing scientific views. The basis for concern is that although the Ozone Depletion Potential of commonly used HFC's are not much less than some commonly used HCFC's, the Global Warming Potential of the same HFC's can be significantly higher than that of the same commonly used HCFC refrigerants. By precluding high-efficiency/low ozone depletion HCFC equipment, commentators believe the credit could result in fewer environmental benefits.

In contrast, the USGBC Board ruled that this credit should stay as written two years ago. This decision was made because when LEED is used as a whole system, as intended, Energy Credit 1 appropriately reflects the reduced GWP of more energy efficient buildings and this should more than offset any small increase in the GWP of using an HFC over the life of a building. For example, the Board noted that while Energy Credit 4 is the *only* one of 69 credits that specifically focuses on ozone protection; at least ten other points can be attained directly for energy efficiency and global warming. Additional points minimize energy uses and global warming through transportation options and renewable energy.

Charge to TSAC

The LEED Steering Committee charge the TSAC of USGBC with the following tasks:

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.

The review should consider:

- The direct effect of leaked halocarbons on the atmosphere (including but not necessarily limited to ozone depletion and global warming potential)
- The indirect effects on the energy efficiency of equipment in operation and the consequential effects on atmospheric environmental emissions and impacts (including but not necessarily limited to global warming potential)

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