IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

DYNATEMP INTERNATIONAL, INC AND FLUOROFUSION SPECIALTY CHEMICALS, INC.

Petitioners

v.

R421A LLC d//b/a CHOICE REFRIGERANTS

Patent Owner

Case No. IPR2020-01660

U.S. Patent No. 9,982,179

DECLARATION OF DR. ECKHARD GROLL

I, ECKHARD GROLL, declare:

I. QUALIFICATIONS

1. My name is Eckhard A. Groll, and I am the Reilly Professor of Mechanical Engineering at Purdue University. I was appointed the William E. and Florence E. Perry Head of the School of Mechanical Engineering in 2019. My complete C.V. is attached as Appendix A to this declaration.

2. I have been retained by counsel for Petitioner Dynatemp Refrigerants Company to provide my expert opinion regarding U.S. Patent 9,982,179 ("the '179 Patent"), and to compare the claims to prior patents.

3. I am being compensated for my work in this matter. My compensation in no way depends on the outcome of this proceeding.

4. I received a Pre-Diploma in Mechanical Engineering from the Ruhr-University of Bochum Germany, a Diploma of Engineering in Mechanical Engineering from the Ruhr-University of Bochum Germany, and a Doctor of Engineering in Mechanical Engineering from the University of Hannover, Germany in 1994.

5. I have published extensively, including in the International Journal of Refrigeration, the Journal of Applied Thermal Engineering, the Journal of Energy and Buildings, ASHRAE Transactions and the Journal of Spacecraft and Rockets.

6. I am an inventor on four (4) U.S. patents including U.S. Patent No. 7,401,475 ("Thermodynamic Systems Operating with Near-Isothermal Compression and Expansion Cycles"), U.S. Patent No. 7,654,104 ("Heat Pump System with Multi-Stage Compression"), U.S. Patent No. 7,810,353 ("Heat Pump System with Multi-Stage Compression"), and U.S. Patent No. 8,667,797 ("Organic Rankine Cycle with Flooded Expansion and Internal Regeneration").

7. I have received numerous awards for my research and teaching excellence including most notably the 2018 J&E Hall International Gold Medal in Refrigeration by the Institute of Refrigeration and the 2017 Peter Ritter von Rittinger International Heat Pump Award by the IEA Heat Pump Centre. In addition, I am an ASHRAE Distinguished Lecturer since 2011, a 2010-2011 ACE (American Council on Education) Fellow, a 2009-2010 CIC-ALP (Committee on Institutional Collaboration - Academic Leadership Program) Fellow, received the 2010 E.K. Campbell Award from ASHRAE, and was inducted into Purdue's Book of Great Teachers in 2008.

II. BASIS FOR OPINION AND MATERIALS REVIEWED

8. I have examined and rely principally upon the following documents:

Exhibit No.	Description
1001	U.S. Patent No 9,982,179 (the '179 Patent)
1002	U.S. Patent No. 8,197,706 ("the '706 Patent") Parent of the '179 Patent
1003	File History of the '179 Patent
1004	File History of the '706 Patent (parent of the '179 Patent)
1005	File History of U.S. Appln No. 10,937,736, Grandparent of the '179 Patent ("the '736 Application")
1006	U.S. Patent No. 6,207,071 ("Takigawa")
1007	U.S. Patent No. 6,606,868 ("Powell")
1008	U.S. Patent No. 6,863,840 ("Goble")
1009	U.S. Patent No. 5,688,432 ("Pearson")
1010	Board Decision in U.S. Appln No. 10,937,736 ("Decision")
1011	U.S. Pub. No. 2003/0062508 ("Singh")
1012	U.S. Patent No. 6,271,184 ("Seebauer")
1013	
1014	AHRI Standard 700
1015	Provisional Application 60/501,049
1016	U.S. Pub. No. 2005/008251
1017	U.S. Patent No. 10,703,949
1018	Federal Register, 71, 88, p. 56844, Sept. 28, 2006
1019	U.S. Patent No. 6,655,160 ("Roberts")
1020	Lemmon et al. Appendix B, Equations of States for Mixtures of R-32, R-125, R-134a, R-143a, and R-152a, Report No. DOE/OR22674/605-50010-01-Pt1_B ARTI-21CR/605-50010-01-Pt1_B; TRN: US200308%%85, Published 08-30-2002, available at https://www.osti.gov/biblio/808636 "Lemmon"

A. The Earliest Disclosure of the Ratios Claimed in the "179 Patent

9. I reviewed Exhibit 1001, U.S. Patent No 9,982,179 (the '179 Patent) and have been asked for my opinion on when certain disclosures were first made in the history of this patent. The cover page of this patent at fields (21) and (22) indicates that the application for the '179 Patent was United States Serial Number ("USSN") 13/493,491 filed June 11, 2012. The '179 Patent says in field (45) that it issued on May 29, 2018. According to field (63) on page 1 of Ex. 1001, this application is a continuation of Appln. No. 12/961,045, which matured into U.S. Patent 8,197,706 (the '706 patent, Ex.1002) which is a continuation of Appln. No. 10/937,736, filed on September 8, 2003, which was abandoned after an unsuccessful appeal. According to field (60), the '179 application ultimately claims priority of provisional application 60/501,048, filed September 8, 2003 (Exhibit 1016 herein). According to field (76), the named inventors are Kenneth M. Ponder and Steffan Thomas, Jr. I generally refer to them below as the "applicants" in discussing the file history of the '179 patent and its predecessors.

10. I reviewed the file history of the '179 patent and its predecessors to see when certain disclosures first appeared. It is my opinion that the two earliest patent filings in the related applications (the provisional application and the '736 application) do not support the claims of the '179 patent. The claims of the '179 patent contain specific ranges of components (59% to 57% of R125 and 41% to 43% R134a in claims 1, 8, 15, 21, 26 and 30; 58% R125 and 42% R134a in claims 5, 12, 18, 25, 30 and 35). However, those claimed ranges were not disclosed in the provisional application of 2003 nor in the application 10/937,736 filed Sept. 8, 2004, both of which I reviewed carefully. The provisional application and the '736 application were filed reciting proportions of R125 to R134a opposite to that of R421A. Concentrations corresponding to R421A did not appear in the string of applications until August 13, 2007. Ex. 1005 at 356.

11. At p. 6 the provisional specification teaches: "*about 40 to about 45 weight percent pentafluoroethane to about 55 to about 60 percent 1,1,1,2-tetrafluoroethane...about 42 weight percent pentafluoroethane to about 58 weight percent 1,1,1,2- tetrafluoroethane*." Ex 1016 at 9. This is repeated at p. 9 (Id. at 12), p. 10 (Id. at 13), p. 11 (Id. at 14) and in claim 1(Id. at 18), claims 6 and 9 (Id. at 19), claims 10, 11 and 13 (Id. at 19). Claim 14 claims 45% pentafluoroethane and 55 % tetrafluoroethane, and claim 15 claims 40% pentafluoroethane and 60 %

tetrafluoroethane. (Id. at 20). Claims 16, and 18-20 set forth similar percentages of pentafluoroethane and tetrafluoroethane (Id. at 21), as well as claims 21 and 23-25. (Id. at 22).

12. The provisional application fails to teach the 58/42 weight percentages of R125/R134a of R421A. The disclosure of the provisional application thus fails to teach or suggest R421A.

13. The reverse proportions were also present in the utility application 10/937,736 (Ex 1005 at 643, 644, 648, 649, 650, Claims 1, 3-6, 8-11, 13-16, 18-21 and 25 Id. 654-659) and in its publication US 2005/0082510, Ex 1017 (¶¶ 0024, 0050, 0052, 0056, 0062, Claims 1, 3-5, 8-10, 21, 23-25) published on April 21, 2005.

14. The "file history" of application 10/937,736 (Ex. 1005) shows that on August 13, 2007, the specification was amended to recite the R421A formulation in the discussion of the drawing figures. Ex. 1005 at 356. There was no indication in the specification or the drawing figures as originally filed, of the proportions of R421A. Moreover, the specification was not consistently amended to reflect the R421A formulation, and multiple references to the reverse formulation were retained.

15. For example, see the '706 Patent (Ex. 1002 at 4:26-27, 7:39, 8:13-15); the '179 Patent (Ex. 1001 4:31-33, 7:13-14, 7:46-47, 8:24-26); and the '949 Patent (Ex. 1017 4:46-48, 7:31-32, 7:65-66, 8:40-42).

16. The amended specification of the '736 application prompted a new matter rejection on August 20, 2007. Ex 1005 at 344-345. The Examiner stated, "*The specification as originally filed does not provide basis for switching the percentages of pentafluoroethane and tetraflurorethane*." Id. at 344, para. 2. See also, id. at 345, para. 4 ("*This is a new matter rejection…*"). The Amendment of October 30, 2007 traversed the new matter rejection and presented a Declaration by Andrew Gbur Ex. 1005 at 327-330. The Declaration (Id. 333-335) asserted that Fig. 1 obviously shows Pressure (liquid) vs. temperature profiles of 40/60, 45/55 and 42/58 of tetrafluoroethane and pentafluoroethane, respectively. I note that Fig. 1 as filed, see Ex.1001 at 661) shows pressure vs. temperature of various mixtures, and the key shown in Fig. 1 itself says "60-40," "55-45," and "58-42" (not 40-60, 45-55, or 42-58). The written text of the application describes Fig. 1 as opposite to the ratios stated October 30, 2007 Amendment. The specification says: "*Fig. 1 shows Pressure (liquid) vs. Temperature profiles for R-22 and blends of 60/40, 55/45, and 58/42 of tetrafluoroethane and pentafluoroethane, respectively*." Ex. 1005 at page 650, lines 12-13. Thus, the Amendment clearly misstated the ratios

that were disclosed in both the Figure 1 and its written description. In ¶ 7, the Declaration stated:

> "*With reference to Figure 1, for example, it is my opinion that one skilled in the art of refrigerant compositions would recognize that as the concentration of pentafluoroethane drops in a composition of pentafluoroethanne and tetrafluoroethane, the Pressure vs. Temperature profile curve would likewise drop because on skilled in the art would recognize that lowering the concentration of pentafluoroethane in such a composition would generally cause the vapor pressure of the composition at a given temperature to decrease as the amount of pentafluoroethane is decreased and not increase.*" Id. at 344.

17. However, pressure here is vapor pressure. One would realize that as the amount of higher molecular weight pentafluoroethane increases, the vapor pressure would decrease and not vice versa as stated in the Declaration.

18. First, it is my understanding, based on my own experience in filing patent applications, that when an inventor signs the Declaration when filing a patent application, the inventor attests to having reviewed and understood the disclosure. Ex. 1005 at 628-30.

19. I am informed that the lack of written description leads to a lack of priority until the missing subject matter was incorporated into the disclosure.

20. In the Amendment of October 30, 2007, the applicant referred to MPEP 2163.07(a) (Ex 1005 at 328), which states:

> *By disclosing in a patent application a device that inherently performs a function or has a property, operates according to a theory or has an advantage, a patent application necessarily discloses that* ***function, theory or advantage****, even though it says nothing explicit concerning it. The application may later be amended to recite the* ***function, theory or advantage*** *without introducing prohibited new matter. In re Reynolds..."Under the doctrine of inherent disclosure, when a specification describes an invention that has certain* ***undisclosed yet inherent properties****, that specification serves as adequate written description to support a subsequent patent application that explicitly recites the invention's inherent properties."...."To establish inherency, the* ***extrinsic evidence*** *must make clear that the missing descriptive matter is necessarily present in the thing described in the reference, and that it would be so recognized by persons of ordinary skill. Inherency, however, may not be established by probabilities or possibilities. The mere fact that a certain thing may result from a given set of circumstances is not sufficient." (citations omitted). (emphases added).*

21. However, in this case, it is clear that the new matter was not a function or property, but a concentration range. As a result, the inherency argument does not pertain. Moreover, the logic in the Gbur Declaration was faulty. Additionally, no extrinsic evidence was presented in the Gbur Declaration.

22. Accordingly, based on my examination of the documents and based on my technical expertise in this field, the two earliest patent applications do not support the specific ranges claimed in the '179 patent, and this subject matter was not disclosed before August 13, 2007.

III. SPECIFIC ART THAT CAN BE APPLIED AGAINST THE '179 PATENT

23. In my opinion, the following references are extremely pertinent to the validity of the claimed subject matter of the '179 Patent:

Ex. 1006 – U.S. Patent No. 6,207,071 ("Takigawa");

Ex. 1007 – U.S. Patent No. 6,606,868 ("Powell");

Ex. 1008 – U.S. Patent No. 6,863,840 ("Goble");

Ex. 1009 – U.S. Patent No. 5,688,432 ("Pearson");

Ex. 1010 – Board Decision in U.S. Appln. No. 10,937,736 ("Decision");

Ex. 1011 - U.S. Pub. No. 2003/0062508 ("Singh"); and

Ex. 1012 – U.S. Patent No. 6,271,184 ("Seebauer").

Ex. 1018 - Federal Register, 71, 88, p. 56844, Sept. 28, 2006

Ex. 1019 - U.S. Patent No. 6,655,160 ("Roberts")

Ex. 1020 - Lemmon et al. Appendix B, Equations of States for Mixtures of R-32, R-125, R-134a, R-143a, and R-152a, Report No. DOE/OR22674/605-

50010-01-Pt1_B; ARTI-21CR/605-50010-01-Pt1_B; TRN: US200308%%85,

Published 08-30-2002, available at https://www.osti.gov/biblio/808636

"Lemmon"

IV. SUMMARY OF OPINIONS

24. My opinions are in support of the *inter partes* review of the '179 Patent claims 1-37.

V. GROUNDS FOR INVALIDITY

25. The Grounds for invalidity of the '179 Patent include:

Ground	Claims	Basis (35 U.S.C. §)	Primary Reference	Further references
1	1-37	102(Claims 21-37) 103 (Claims 1-37)	Goble	Singh, Takigawa
2	1-37	103	Singh	Goble, Takigawa
3	1-37	103	Powell	Goble, Singh, Takigawa
4	1-37	103	Person	Goble, Singh, Takigawa
5	1-37	103	Federal Register	Goble, Singh, Takigawa
6	1-37	103	Roberts	Goble, Singh, Takigawa
7	1-37	103	Lemmon	Goble, Singh, Takigawa

26. The Factors leading to these grounds include:

a) The prior art references disclose ranges of R134a and R125 that encompasses the claimed range of R421A, and routine experimentation would lead to the R421A formulation.

b) The prior art references disclose ranges of R134a and R125 that encompasses the claimed range of R421A, and routine experimentation would lead to the R421A formulation, as was affirmed by the PTAB.

c) The claimed property is inherent to the R421A formulation.

d) The prior art references disclose an apparatus for use with a dichlorodifluoromethane refrigerant.

e) The prior art references disclose refrigeration equipment, air conditioning equipment or HVAC equipment.

f) The prior art reference discloses the claimed lubricating oil.

g) The prior art reference discloses the claimed additives.

h) Dependent claim limitations repeat a claim limitation recited in the corresponding independent claim, and add no additional weight.

It is my opinion that claims 1-37 of the ‘179 Patent are rendered anticipated for Goble or obvious under 35 U.S.C. § 103.

VI. BRIEF DESCRIPTION OF THE TECHNOLOGY AT ISSUE

27. The ’179 Patent (Ex. 1001) entitled “Refrigerant With Lubricating Oil For Replacement Of R22 Refrigerant”. The ’179 Patent has 37 claims. Claims 1, 8, 15, 26 and 31 are the only independent claims.

28. The technology of the ‘179 Patent pertains to formulations that encompass R421A refrigerant, which is replacement for R22 ($CHClF_2$). R421A is the following mixture:

a. 58 wt% (54.5 M%) R125, pentaflouroethane (CF_3CHF_2), and

b. 42% wt% (45.5 M%) R134a, tetrafluoroethane (CF_3CH_2F)

29. R421A is frequently mixed with a lubricant in order to inhibit pump breakdown. R421A is used as a replacement for environmentally harmful R22 (CF_2Cl : chlorodifluoromethane).

30. Independent claim 1 is an apparatus claim where R22 is replaced with an R421A formulation (57-59% R125 and 41-43% R134a) mixed with a lubricating oil selected from mineral oil and synthetic alkyl aromatic lubricants. Independent claim 8 is a method claim for filling an apparatus claim where R22 is replaced with R421A formulation mixed with a lubricating oil selected from mineral oil and synthetic alkyl aromatic lubricants. Independent claim 15 is a refrigerant composition that encompasses with R421A formulation mixed with a lubricating oil selected from mineral oil and synthetic alkyl aromatic lubricants.

Independent Claim 21 is an apparatus claim for use with R421A. Independent claim 26 is a method for filling an apparatus where R22 is replaced with R421A.

31. Independent claim 31 is the broadest claim and recites a refrigerant composition that encompasses R421A.

32. The claims of the ‘179 Patent are similar to the parent ‘760 Patent, except that the ‘760 Patent recite a napthenic lubricant either directly or by virtue of dependence.

33. The Background of the Invention section of the ’179 Patent identifies the problems the purported invention was designed to overcome, i.e., replacement of environmentally damaging R22 with refrigerant compositions that are less damaging to the ozone layer.

34. At column 3, the ‘179 Patent discusses prior art references that include USP 5,384,057 to Wilczek, USP 4,971,712 to Gorski, USP 5,145,594 to Anton, USP 4,983,312 to Tamura and USP 5,942,149 to Weber. Ex. 1001 at 3:20-62. These references were not filed in an IDS. The ‘179 Patent at column 3 specifically teaches the disadvantages of not using a lubricant. Ex. 1001 at 3:43-46. Nonetheless, the ‘179 Patent presents claims that contain no lubricant, for example, independent claims 26 and 31.

VII. Summary of the Prosecution History of the ‘179 Patent (Ex. 1003) and its parents the ’706 Patent (Ex. 1004), the ‘736 Application (Ex. 1005) and

Provisional Application 60/501,049

The '179 Patent

35. The prosecution of the '179 Patent included a non-final rejection mailed March 25, 2013, in which all the claims were rejected as being obvious under 35 U.S.C. § 103 over Takigawa (Ex. 1003 at 264-271). Importantly, the Takigawa reference was applied in both the parent and grandparent applications, and was contested on appeal in the grandparent application, where the PTAB upheld the Examiner's position that Takigawa rendered the invention obvious. See Decision Ex. 1010 at 8.

36. The Takigawa patent says that it is a continuation of application no. 08/503,619, filed on July 8, 1995, and that its issue date is March 27, 2001. The Examiner continued rejecting the pending claims over Takigawa on March 28, 2017 (Ex. 1003 at 147-153) and October 12, 2017 (Id. at 114-118). The Applicant's response included a Declaration by Kenneth Ponder (Id. at 96-104) that included graphs showing the performance of R421A, and purporting that these graphs show unexpected results over the prior art.

37. On February 23, 2018, the Examiner issued an Office Action containing a double patenting rejection but did not reject the claims over the art. Id. at 41-47.

38. On March 8, 2018, the Applicant filed an amendment that addressed

formal issues along with a terminal disclaimer. This amendment presented new, broader, claims which claimed R421 without a lubricant, corresponding to claims 26-37 of the issued patent. Id. at 17-32

39. On April 5, 2018 the Examiner entered a Notice of Allowance that did not set forth reasons for allowance or discuss the newly presented claims. Id. at 11-16.

The '706 Patent (The Parent Patent)

40. On December 6, 2010, the Applicants filed application no. 12/961,045 as a continuation application. It matured into the parent '706 Patent (Ex. 1002) on June 12, 2012. Its file history is Ex. 1004. The '706 Patent has 23 claims of which claims 1, 3 9, 11, 17 and 19 are independent. All the independent claims claim a mixture of pentafluoroethane (R125) and tetrafluoroethane defined by bubble point and dew point with additional lubricating components that can be napthenic distillate, napthenic distillate petroleum, or polyol. Id. at 9:55-12:40.

41. The Examiner rejected the claims of the '706 Patent application on June 6, 2011, as being obvious over Takigawa. Ex. 1004 at 72-78. Following an amendment and declaration, the Examiner allowed the claims on February 15, 2012, based on the lubricant, stating in the reasons for allowance (Id. at 26):

"*The closest prior art is Takigawa US 6,207,071.* ***The reference***

> ***discloses the utility of compositions pentafluoroethane and tetrafluoroeithan in amounts which make obvious those presently recited.*** *However, the reference further discloses that napthenic based lubricants and polyol esters were not satisfactory lubricants. As the present claims require those lubricants, they are not obvious over the prior art of record (emphasis added).*"

42. In the Notice of Allowability, the Examiner also entered an Examiner's Amendment which rewrote claims in Jepson format. Id. at 18-26.

The '736 Application

43. According to fields (21) and (63) of Ex. 1002 (the '706 patent), application 12/961,045 for the '706 Patent was filed as a continuation of Appln. No. 10/937,736 (Ex. 1005). That '736 application was abandoned (after losing an appeal from the Examiner's rejections. The '736 Application was filed on September 8, 2004 and was abandoned on August 8, 2011. Ex 1005 at 1-7. The Examiner entered Office Actions on February 24, 2006 (Id. at 575-580), June 5, 2006 (Id. at 556-561), August 20, 2007 (Id. at 342-347), December 17, 2007 (Id. at 319-324), and June 27, 2008 (Id. at 295-299). The '736 application entered appeal with the claims rejected as being obvious over Takigawa. Id. at 235.

44. On April 29, 2010, the Board of Patent Appeals and Interferences (the "BPAI") entered a Decision affirming the rejection over Takigawa. In the Decision, the BPAI made the following factual findings (Ex. 1010 at 3-4):

45. Takigawa discloses a refrigerant oil and a fluid composition for a refrigerator containing 1,1,1,2-tetrafluoroethane (HFC-134a) and/or pentafluoroethane (HFC-125) (col. 1, 11. 13-19).

46. Takigawa discloses that the HFC refrigerant contains HFC-134a and/or HFC-125 (col. 2, 11. 15-17; 23-24; 40-41).

47. Takigawa discloses that the HFC-134a and/or HFC-125 blend may include additional HFC refrigerants such as alkane fluorides having 1 to 3 carbon atoms (col. 8, 11. 20-28).

48. Takigawa claims that the HFC refrigerant used in the fluid composition contains "*at least one of HFC-134a and/or HFC-125*" (claim 1).

49. Takigawa discloses that HFC-134a is present in the refrigerant composition in an amount of 40 weight percent or greater and that HFC-125 is present in a most preferable amount of 40 weight percent or greater (col. 8, 11. 20-28).

50. For the purposes of this IPR Petition, I understand that Takigawa should be considered in light of the BPAI Decision in regard to formulations of R125 and R134a that render the R421A formulation obvious.

51. The rationale of the BPAI Decision also applies to the disclosures of new art, which encompass the R421A formulation. However, Takigawa has additional disclosure (such as additives) that is combinable with the other art

without taking the BPAI decision into account.

52. At pages 5 and 6 of the Decision Ex. 1010, the BPAI concluded:

> "*As the simplest binary mixture, the Examiner correctly determines... that HFC-134a would have been present in an amount of 40 to 60% by weight and HFC-125 correspondingly would be present in a range of 60 to 40% by weight (Ans. 3, 5). Therefore, Takigawa' s disclosure would have suggested that at least two of the end points of Appellants' claimed ranges (i.e., 40% HFC-134a and 60% HFC-125) and thus further narrowed Takigawa's range.* ***Accordingly, we agree with the Examiner that given the guidance provided by Takigawa, determining acceptable refrigerant gas concentration ranges would have been a matter of routine experimentation*** *(emphasis added)*."

53. Therefore, the USPTO has already determined that R421A by itself is obvious.

The Provisional Application

54. The '736 Application claims priority of provisional application no. 60/501,049, filed September 8, 2003. Based on my examination of the provisional application as filed, I find that it contains no teaching or suggestion of the claimed proportions of R125 and R134a claimed in the '179 Patent.

55. At p. 6 the provisional specification teaches: "*about 40 to about 45 weight percent pentafluoroethane to about 55 to about 60 percent 1,1,1,2-tetrafluoroethane...about 42 weight percent pentafluoroethane to about 58 weight*

percent 1,1,1,2- tetrafluoroethane." Ex 1015 at 9. This is repeated at p. 9 (Id. at 12), p. 10 (Id. at 13), p. 11 (Id. at 14) and in claim 1(Id. at 18), claims 6 and 9 (Id. at 19), claims 10, 11 and 13 (Id. at 19). Claim 14 claims 45% pentafluoroethane and 55 % tetrafluoroethane, and claim 15 claims 40% pentafluoroethane and 60 % tetrafluoroethane. (Id. at 20). Claims 16, and 18-20 set forth similar percentages of pentafluoroethane and tetrafluoroethane (Id. at 21), as well as claims 21 and 23-25. (Id. at 22).

56. The reverse proportions were also present in the utility application 10/937,736 (Ex 1005 at 643, 644, 648, 649, 650, Claims 1, 3-6, 8-11, 13-16, 18-21 and 25 Id. 654-659) and in its publication US 2005/0082510, Ex 1016 (¶¶ 0024, 0050, 0052, 0056, 0062, Claims 1, 3-5, 8-10, 21, 23-25) published on April 21, 2005.

57. On August 13, 2007, the specification was amended to reflect the R421A formulation in the discussion of the drawing figures. Ex. 1005 at 356. However, the specification was not consistently amended to reflect the R421A formulation, and multiple references to the reverse formulation were retained.

58. For Example, see the '706 Patent (Ex. 1002 4:26-27, 7:39, 8:13-15); the '179 Patent (Ex. 1001 4:31-33, 7:13-14, 7:46-47, 8:24-26); and the '949 Patent (Ex. 1017 4:46-48, 7:31-32, 7:65-66, 8:40-42). This raises written description issues that cannot be pursued in an IPR.

59. The amended specification of the '736 application prompted the Examiner to enter a rejection for introducing new matter on August 20, 2007. Ex 1005 at 344-345. The Amendment of October 30, 2007 traversed the new matter rejection and presented a Declaration by Andrew Gbur Ex. 1005 at 327-330. The Declaration (Id. 333-335) asserted that Fig. 1 obviously shows Pressure (liquid) vs. temperature profiles of 40/60, 45/55 and 42/58 of tetrafluoroethane and pentafluoroethane, respectively.

60. However, these arguments are not persuasive to a person having ordinary skill in the art (PHOSITA).

61. Accordingly, August 13, 2007 is the true priority date of the '179 Patent.

VIII. HISTORICAL BACKGROUND

62. In light of the state of the art and its historical development, the concept of environmentally friendly replacements for R22 were clearly well known.

63. For Example, Goble teaches:

> *"The U.S. Environmental Protection Agency and other world scientific bodies have determined that refrigerants comprised of chlorofluorocarbons (CFCs) cause harm to the Earth's stratospheric ozone layer after being released into the atmosphere. Hydrochlorofluorocarbons (HCFCs), which are chlorofluorocarbons*

containing one or more hydrogen atoms, also cause damage to the ozone layer, although much less so, and often twenty times less than CFCs. Various rules, regulations, protocols and treaties in the world have phased out CFCs, or are now doing so. HCFCs are being allowed as "transition" substances between CFCs and zero ozone depletion alternatives under development. HCFCs are also under phase outs, but on a much longer time scale than the CFCs, with the final HCFC phaseout being in the year 2030." Ex. 1008 at 2:61-3:7.

64. Goble solves this problem by starting at a formulation that approximates the formulation for R421: "*Applicant set the ratio of R125/R134a to establish a pressure temperature curve approximating R-22, which is roughly 56 weight percent R-125 and 44 weight percent R-134a.*" Ex 1008 at 7:6-9.

65. Goble's U.S. application filing date of June 25, 2003 is prior to the September 8, 2003 filing date of the provisional application of earliest ancestor of the '179 Patent. I am informed that Goble is prior art under at least 35 U.S.C. § 102(e) (pre-AIA).

66. Another example is Powell, who teaches:

"*R 22 is a chemical fluid and by far the largest HCFC refrigerant used globally in refrigeration and air conditioning equipment. R 22 has an Ozone Depletion Potential (ODP) of approximately 5% of CFC 11. After CFCs have been phased out, the chlorine content of R 22 will make it the largest ozone depleting substance in volumetric*

terms. R 22 is also the subject of a phase-out schedule under the Montreal Protocol. R 22 is prohibited from use in new equipment in some countries. Ex. 1007 at 1:26-34."

"*Any replacement for HCFC 22 must have no ability to deplete ozone. The compositions of the present invention do not include chlorine atoms and consequently they will have no deleterious effect on the ozone layer while providing a similar performance as a working fluid to R 22 in refrigeration apparatus*." Ex. 1007 at 1:35-40

67. Powell solves this problem by utilizing a mixture of R125 and R134a. Powell teaches 50-80% R125 and 50-20% R134a, ranges that encompass the 58/42 % range of R421A. Ex. 1007 at 2:50-53, Claim 1.

68. I am informed that Powell is prior art under 35 U.S.C. §102(a) (pre-AIA) because it issued on August 19, 2003 which antedates the September 8, 2003 filing date of the provisional application of the '179 Patent. I am informed that Powell's U.S. application filing date of October 2, 2000 also makes Powell prior art under 35 U.S.C. § 102(e) (pre-AIA).

69. Yet another example is Singh (Ex. 1011). Singh teaches providing hydrofluorocarbon compositions to replace chlorine-containing refrigerants. Ex. 1011 at ¶ 0003. Singh teaches concentration ranges that overlap the R421A formulation, the most preferred being about 48 to about 80 parts by weight of

R125 and about 18 to about 60 parts by weight of R134a. Id. ¶ 0020. Singh also teaches lubricants and additives. Id. ¶¶ 0021-0029.

70. I am informed that Singh is prior art under at least 35 U.S.C. 102(a) (pre-AIA) because it was published on April 3, 2003, which was prior to even the September 8, 2003 filing date of the provisional application of the '179 Patent. I am informed that it is also prior art under § 102(e) (pre-AIA) because it was filed in the U.S. on September 21, 2001.

71. Pearson teaches replacing R22 with a mixture of R125 and R134a with the addition of a hydrocarbon. Ex. 1010 at Abstract. Pearson teaches 0.5% to 60% R125 and 30 to 90% R134a. Ex. 1009 at 2:19-29. Pearson issued on November 18, 1997 and is therefore, I am informed, prior art under 35 U.S.C. § 102(b).

72. Another Example is Federal Register (Ex. 1018), published on September 28, 2006, less than one year before August 13, 2007. I am informed that the Federal Register is prior art under 35 U.S.C. § 102(e). Federal register at P. 2, first column teaches: "*R-421A is a blend of 48% by weight hydrofluorocarbon (HFC)-125 (pentafluoroethane VASID #354-33-6), and 425 by weight HFC-134a (1,1,1,2-tetrafluoroethane, CAS ID # 811-97-2)*." Federal register thus encompasses all the R421 formulations claimed in the '179 patent. See also Roberts (Ex. 1019) and Lemmon (Ex. 1020).

73. Roberts has a PCT publication date of June 7, 2001, which I am informed makes it prior art to the '179 Patent under pre-AIA 35 U.S.C. § 102(b). Roberts pertains to refrigerant compositions. Roberts Ex. 1019 2:48-52 discloses a refrigerant composition containing 35-60 wt% R134A and 35-60 wt% R125, which encompasses the 58/42 wt% proportions of R125/R134A of R421A. Roberts in Table 1 has a formulation that is 58.9% R125 and 40.1% R134A. Id. 4:11. This latter formulation is very close to the 58/42% proportion of R421A. Interestingly, Fig. 1 of Roberts shows performance of R134A (balance R125) with a solvent that shows a steep drop in performance as the concentration of R134A goes above 42%. Moreover, Fig 2 of Roberts shows performance of R134A (balance R125) with a solvent that has an inflection point hovering over 42%.

74. Lemmon, entitled "Equations of State for Mixtures of R-32, R-125, R-134a, R-143a, and R-152a," was published on August 30, 2002, more than a year before the filing of the provisional application of the '179 Patent. I am informed that Lemmon is thus prior art under 35 U.S.C. § 102(b). In Table 4, Ex 1020 at P. 27, Lemmon summarizes studies published on mixtures of R125 and R 134a, where ranges of R125 (balance R134a) were studied including mole fractions of R125 of 0.349-0.719, 0.0865-0.923, 0.250-0.751, 0.179-0.776, 0.259-0.649, 0.0001-0.813, 0.254-0.749, 0.0865-0.923, 0.222-0.718, and 0.348-

0.693.

75. Therefore, the solution to the problem, which the '179 Patent is purported to solve, was known in the art before the earliest filing associated with the '179 Patent.

IX. CLAIM CONSTRUCTION AND VALIDITY OF THE '179 PATENT

A. Person Having Ordinary Skill In The Art

76. In connection with the interpretation of the '179 Patent, I understand that I am to adopt the viewpoint of a hypothetical person having ordinary skill in the art ("PHOSITA"). Counsel has instructed me on the factors related to profiling such a person, including the educational level of the inventor, the type of problems encountered in the art, prior art solutions to these problems, rapidity with which the inventions are made, sophistication of the technology, and the educational level of active workers in the field.

77. It is my opinion that in the alternative refrigerant field of endeavor exemplified by the '179 Patent, a PHOSITA would have had a bachelor's degree in chemistry, chemical engineering or a related field or, as a substitute, at least three years of work or research experience in refrigerant formulation. Preferably, a PHOSITA would have a Ph.D. in chemistry or chemical engineering. This is based upon my experience in the field of refrigerants

B. Claim Construction

78. It is my understanding that in an IPR, claim terms in an unexpired patent are given their ordinary and customary meaning in light of the specification of the patent in which they appear. I am informed that any prior claim construction determination concerning a term of the claim in a civil action, or a proceeding before the International Trade Commission, that is timely made of record in the *inter partes* review proceeding will be considered.

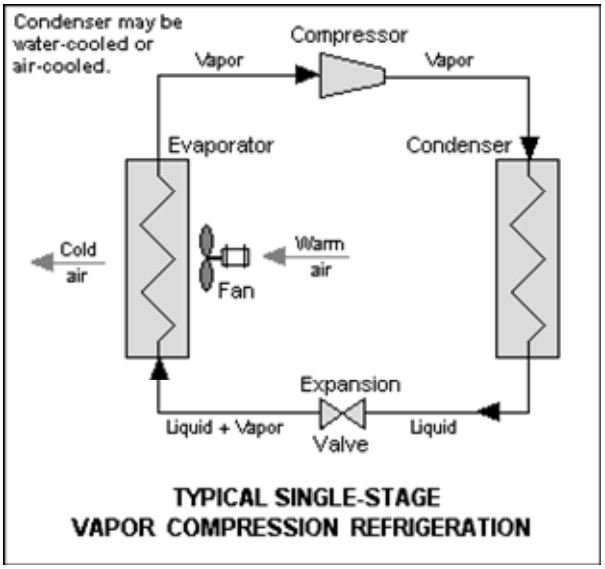
a. "phase change"

79. A phase change is used to describe transitions between states of matter, i.e., between solid, liquids and gases. In the '179 Patent there is no definition for the term "phase change." However, one of skill in the art would recognize that this means the transition of the refrigerant from the liquid to the gaseous state (and *vice versa*) of the refrigerant.

80. The requirement for a phase change of the refrigerant is well known in the art, and is part of the necessary vapor-compression cycle. The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. The drawing figure below provides a schematic diagram of the components of a typical vapor-compression refrigeration system.

81. The requirement for a phase change of the refrigerant is well known in

the art and is part of the necessary vapor-compression cycle. For Example, Lemmon Ex. 1020 at 13 details the equation of state for vapor-liquid equilibrium. Moreover, Goble Ex. 1008 6:63-67 describes boiling point ranges; at 10:56 describes an evaporator, at 10:59 a condenser. All these teach a phase change.



82. In this cycle, a circulating working fluid commonly called refrigerant such as a halocarbon enters the compressor as a vapor. The vapor is compressed at constant entropy and exits the compressor superheated. The superheated vapor travels through the condenser which first cools and removes the superheat and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. The liquid refrigerant goes through the expansion valve (also called a throttle valve) where its pressure abruptly decreases, causing flash

evaporation and auto-refrigeration of, typically, less than half of the liquid.

83. Accordingly, a "phase change", as is set forth in claims 1, 8 and 26 of the '179 Patent is an inherent property of fluorocarbon mixture which, I understand, has no patentable weight. I understand that to establish inherency, the extrinsic evidence 'must make clear that the missing descriptive matter is necessarily present in the mixture described in the reference, and that it would be so recognized by persons of ordinary skill.

b. "dew point"

84. The dew point is the point at which the first drop of a gaseous mixture begins to condense. If the pressure is held constant, the dew point is expressed as temperature.

c. "bubble point"

85. The bubble point is the point at which the first drop of a liquid mixture begins to vaporize. If the pressure is held constant, the dew point is expressed as temperature. The '079 Patent recites the bubble point and dew point at 1 standard atmosphere of pressure.

d. Relationship between dew point and bubble point

86. As is well known in the art, the relationship between the dew point and the bubble point of a mixture is governed by Raoult's Law, which states that the partial pressure of each component of an ideal mixture of liquids is equal to the

vapor pressure of the pure component multiplied by its mole fraction in the mixture. This is mathematically expressed as:

$$y_i\rho_i = x_i\ \rho_i^*(T), \text{ for each component at temperature T}$$

where ρ_i is the partial pressure of the component i in the gaseous mixture (above the solution), ρ_i^* is the equilibrium vapor pressure of the pure component i, y_i is the vapor mole fraction of the component, and x_i is the mole fraction of the component i in the mixture (in the solution).

87. Thus for the two component mixture of R421A:

$$y_{R125}\rho_{R125} = x_{R125}\ \rho_{R125}^*(T)$$

$$y_{R134a}\rho_{R134a} = x_{R134a}\ \rho_{R134a}^*(T)$$

and the two equations can be added to yield:

$$\rho = x_{R125}\ \rho_{R125}^*(T) + (1- x_{R125})\ \rho_{R134a}^*(T).$$

88. Thus, the -32°F dew point and the -41.5°F bubble point recited in the claims of the '179 patent are inherent properties of the R421A formulation. Moreover, noting that ranges (57-59% R125, 41-43% R134A) are claimed, the resulting properties will vary accordingly. This variation in properties arises from the mixture being a zoetrope whose properties vary with concentration and are not constant. The recited dew point and bubble point accordingly do not add any patentable weight to the claims.

89. I am informed that each claim limitation must be expressly, implicitly, or inherently supported in the originally filed disclosure, according to the *Manual of Patent Examination Procedure* ¶ 2163(II)(3)(b). I understand that when an explicit limitation in a claim is not present in the written description whose benefit is sought it must be shown that a person of ordinary skill would have understood, at the time the patent application was filed, that the description requires that limitation.

90. The independent claims of the '179 Patent recite the proportions of R125 and R134a using the restrictive "consisting" language. See claims 1, 8, 15, 21, 26 and 31. I understand that this language excludes the addition of additional refrigerants to the formulation. It is well known in the chemical arts that a specific formulation will have specific properties. As a result, the claimed bubble point, dew point and glide are inherent properties of the claimed refrigerant formulations and do not further restrict the claim.

e. e. "glide"

91. The term "glide" is not defined in the specification of the '179 Patent. The term "glide" is mentioned at column 8, line 22 of the '179 Patent, and the phrase "9.5 ^{o}F glide" is recited in dependent claims 6, 13, 19, 24 and 29.

92. As is known in the art, glide is the difference between the bubble point and the dew point of a zeotropic refrigerant mixture. Also, a zoetrope is a

refrigerant mixture or blend that boils across a range of temperatures at any given pressure.

93. Accordingly, since a dew point of -32 ^{o}F and a bubble point of -41.5 ^{o}F is recited in the independent claims, reciting the difference of 9.5 ^{o}F in dependent claims does not add any patentable weight.

94. I understand that p*roducts of identical chemical composition cannot have mutually exclusive properties*. That is a chemical compound and its properties are inseparable. Therefore, I understand that if the prior art teaches the identical chemical structure, the properties applicant discloses and/or claims are necessarily present. For the '179 Patent, the proportions of R134a and R125 are set forth using "consisting" language, which I understand prohibits the addition of additional refrigerants to the formulation. Thus properties such as bubble point, dew point and glide are fixed to this specific formulation. These properties do not add additional patentable weight to the claims. That is, once the ratios of components are named, specifying the bubble point, dew point, and glide are properties that are determined by the ratios and do not add any further specificity. Instead, they merely add what is implicit. Ie understand that adding what is implicit from something already stated in the claim is simply adding words or data but not adding any additional distinctions to the claim.

C. Overview of the Unpatentability of the '179 Patent

a. The R421A Formulation

95. The technology of the '179 Patent revolves around a formulation of pentafluoroethane (R125) and 1,1,1,2 tetrafluoroethane (R134a) that encompasses the 58% R125 and 42% R134a formulation of R124A. Each independent claim of the '179 Patent recites a formulation that can be compared to the prior art, as is set forth in the table below.

Limitation	Prior Art Comparison
"a blend of tetrafluoroethane and pentafluoroethane"	Takigawa (Ex. 1006) at 2:15-17. Powell (Ex. 1007) at 2:42-4. Goble (Ex. 1008) at Abstract. Pearson (Ex. 1009) at 2:20-29. Decision (Ex.1010) at p.3-4. Singh (Ex. 1011) at ¶ 0010. Federal Register Ex. 1018 at 2. Roberts (Ex 1019) 2:48-52. Lemmon Ex. 1020 at 27.
"said pentafluoroethane is present in an amount of 59% to 57% by weight"	Takigawa (Ex. 1006) at 8:28 (40% by weight or more). Powell (Ex. 1007) at 2:50-53 (50-80%). Goble (Ex. 1008) at 7:6-9 (56%),16: 28-30 (30-70%). Pearson (Ex. 1009) at 2:20 (0.5-60%). Decision (Ex. 1010) at p.4. Singh (Ex.1011) at ¶ 0020. Federal Register (Ex. 1018) at 2. Roberts (Ex 1019) 2:48-52. Lemmon Ex. 1020 at 27.
"and said tetrafluoroethane is present in an amount of 41% to 43% by weight"	Takigawa (Ex. 1006) at 8:23-24 (40% by weight or more) Powell (Ex. 1007) at 2:50-53 (50-20%)

Limitation	Prior Art Comparison
	Goble (Ex. 1008) at 7:6-9 (44%) 16: 28-30 (15-60%) Pearson (Ex. 1009) at 2:28-29 (30-90%) Decision (Ex. 1010) at p. 4 Singh (Ex.1011) at ¶ 0020 Federal Register (Ex. 1018) at 2. Roberts (Ex 1019) 2:48-52. Lemmon Ex. 1020 at 27.
"and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane"	Takigawa (Ex. 1006) at 8:24 Powell (Ex. 1007) at Abstract, 2:43 Pearson (Ex. 1009) at Abstract Decision (Ex. 1010) at p. 4 Singh (Ex.1011) at ¶ 0010 Federal Register (Ex. 1018) at 2 Roberts (Ex 1019) 2:48-52. Lemmon (Ex. 1020)1 at 27

96. As this table shows, formulations encompassing the R421A formulation were well known in the art at the time the invention was made.

97. Indeed, the Goble Patent Ex. 1008 at 7:6-9 teaches a formulation that closely approximates the R421 formulation and provides motivation to optimize: "*Applicant set the ratio of R125/R134a to establish a pressure temperature curve approximating R-22, which is roughly 56 weight percent R-125 and 44 weight percent R-134a.*" Id. 7:6-9. That is, Goble discloses the 57-59% R125 and 41-43% R134a claimed in the independent claims of the '179 Patent. This clearly reads on the ratio set forth in the independent claims of the '179 Patent.

98. I understand that a *prima facie* case of obviousness exists where the claimed ranges and prior art ranges do not overlap but are close enough that one skilled in the art would have expected them to have the same properties. I understand that a court held as proper a rejection of a claim directed to an alloy of "having 0.8% nickel, 0.3% molybdenum, up to 0.1% iron, balance titanium" as obvious over a reference disclosing alloys of 0.75% nickel, 0.25% molybdenum, balance titanium and 0.94% nickel, 0.31% molybdenum, balance titanium.).

99. Moreover, Goble provides a motivation to combine R125/R134a to establish a pressure temperature curve approximating R22. In so doing, Goble determines that the ratio of R125/R134a is *"roughly 56 weight percent R-125 and 44 weight percent R-134a.*"

100. Further, I understand that the use of the word "roughly" in the Goble disclosure makes a clear overlap with the R421A formulation. For example, if the prior art taught carbon monoxide concentrations of "about 1-5%" while the claim was limited to "more than 5%," then "about 1-5%" allowed for concentrations slightly above 5% thus the ranges overlapped.)

101. Thus, I understand that Goble fulfills the requirement for anticipating the '179 Patent's R421 formulation under 35 U.S.C. § 102 and clearly renders R421 obvious under 35 § U.S.C. 103.

102. Additionally, starting from the 56% R125 and 44% R134a taught by Goble, it is clearly within the ambit of routine experimentation to obtain the proportions set forth in the independent claims of the '179 Patent. This clearly reads on the ratio set forth in the independent claims of the '179 Patent. I understand that where the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation.

103. Referring back to the Table above, I understand that the overlapping ranges taught by the prior art render these limitations of the claims of the '179 Patent obvious. It is my understanding that, in the case where the claimed ranges "overlap or lie inside ranges disclosed by the prior art" a *prima facie* case of obviousness exists. In one example, the prior art taught carbon monoxide concentrations of "*about 1-5%*" while the claim was limited to "more than 5%," then that "*about 1-5%*" allowed for concentrations slightly above 5% thus the ranges overlapped. For example, a claim reciting thickness of a protective layer as falling within a range of "*50 to 100 Angstroms*" is considered *prima facie* obvious in view of prior art reference teaching that "for suitable protection, the thickness of the protective layer should be not less than about 10 nm [i.e., 100 Angstroms]." I understand that it has been held that "*by stating that 'suitable protection' is provided if the protective layer is 'about' 100 Angstroms thick,*

[the prior art reference] directly teaches the use of a thickness within [applicant's] claimed range."). Moreover, I understand that a prior art reference that discloses a range encompassing a somewhat narrower claimed range is sufficient to establish a *prima facie* case of obviousness. In the case of the '179 Patent, a comparative close range is the 50-80% R125 and 50-24% R134a taught in the Powell Patent. From these teachings alone, or combined with the teachings of the other art, the formulation of R421A can be achieved through routine experimentation. Generally, I understand that differences in concentration or temperature will not support the patentability of subject matter encompassed by the prior art unless there is evidence indicating such concentration or temperature is critical. That is, where the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation.

104. Also, I understand that the conclusions reached by the BPAI in finding Takigawa rendering the R421 formulation obvious is equally applicable to Powell (as well as to Goble and to Pearson). Accordingly, anticipation and a *prima facie* case of obviousness exists for the proportions of R125 and R134a claimed in the '179 Patent.

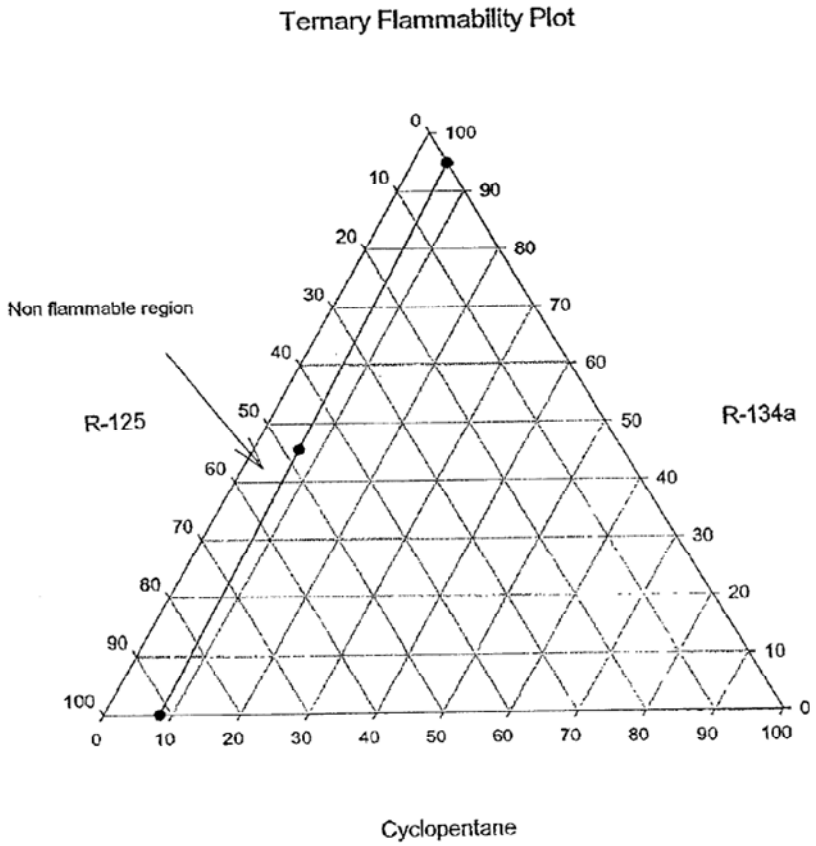
105. The Pearson Patent (Ex. 1009), entitled "Replacement Refrigerant Composition," teaches a replacement for R22 and R12 with a mixture of R125

and R134a. Pearson at 2:19-21 teaches 0.5 to 60 wt% of R125 and at 2:26-28 teaches 30 to 90 wt% of R134. Accordingly, the overlapping ranges make the R421A. formulation obvious at least due to the overlapping formulations.

106. I understand that Pearson has a PCT date of December 20, 1994 and a § 102(e) date of April 19, 1996, which was before the September 8, 2003 provisional application of the '179 Patent.

107. Another reference that teaches ranges overlapping R421A is the Singh U.S. Patent Publication US 2003/0062508 A1 (Ex. 1011). I understand that Singh is prior art under at least 35 U.S.C. 102(a) (pre-AIA) because it was published on April 3, 2003, which was prior to the September 8, 2003 filing date of the provisional application of the '179 Patent. It is also prior art under § 102(e) (pre-AIA) because it was filed in the U.S. on September 21, 2001.

108. Singh teaches concentration ranges that overlap the R421 formulation, the most preferred being about 48 to about 80 parts by weight of R125 and about 18 to about 60 parts by weight of R134A. Ex. 1011 ¶0020. Motivation to readily achieve R421can be found in Figure 1 of Singh:



109. A horizontal isocline drawn through the tip of the arrow will yield the 58/42% R125/R134a percentage of R421A. This arrow and the midrange data point (closest to the arrow) would motivate a PHOSITA seeking to optimize and R125/R134a formulation, to start experimenting at where the arrow is pointing or the midrange data point. That is, the PHOSITA seeking to optimize by taking incremental measurements from a starting point, and an optimal place to start would be mid-range. Either way, the arrow points to the 58/42% R421A formulation and a midrange point very close to this formulation.

110. Moreover, this midrange data point is very close to the 58/42% formulation. Starting from this data point, it would be routine experimentation to

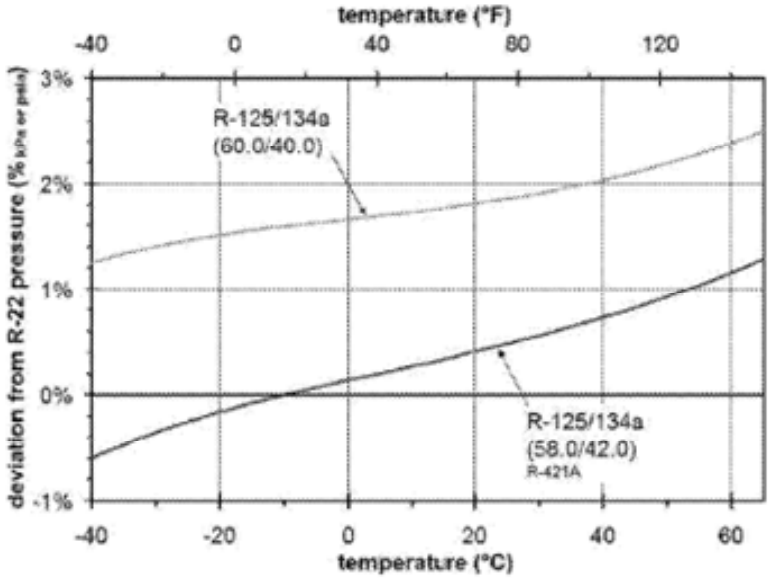
arrive at the R421A formulation. That is, a PHOSITA seeking to optimize the formulation, would take incremental data points starting from this midrange data point.

111. Another relevant prior art reference is Pearson. Pearson teaches replacing R22 with a mixture of R125 and R134a with the addition of a hydrocarbon. Ex. 1009 at Abstract. Pearson teaches 0.5% to 60% R125 and 30 to 90% R134a. Id. 2:19-29. Pearson issued on November 18, 1997 and, I am informed, that makes it prior art under 35 U.S.C. § 102(b).

X. NO UNEXPECTED RESULTS

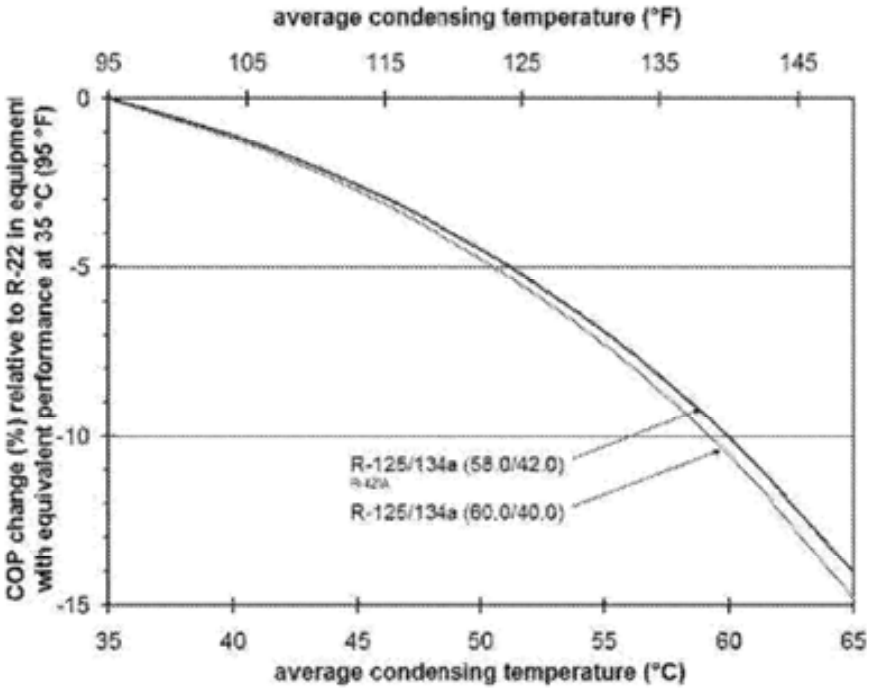
112. During the prosecution of the '179 Patent, the applicant presented a Declaration under 37 C.F.R. § 1.132 by Kenneth Ponder alleging purported unexpected results in order to rebut the Examiner's finding of unpatentability over the Takigawa Patent. Ex. 1003 at 96-104.

113. The declaration of Kenneth Ponder presented two graphs. One graph showed theoretical calculations of deviations from R22 comparing the 60/40 and 58/42 mixtures:



114. The declaration asserted that the 58/42 mixture better approximates the pressure-temperature characteristics of R22. At page 3, the declaration asserted that the 58/42 mixture unexpected better approximates the pressure-temperature characteristics of R22. However, there was no data showing that this fit had a significant effect on actual performance.

115. At ¶ 8 the Ponder declaration presented a coefficient of performance (COP) for 60/40 and 58/42 mixtures:



116. There is barely any difference over much of the temperature range. Even at 65ºC, the difference is likely less than 1%. Accordingly, the results presented in the declaration fail to demonstrate unexpected results.

117. During the prosecution of the parent '736 application, the applicant presented a report by James M. Calm as evidence, which compared R410A, R421A, R422B and R422D to R22. Ex. 1005 at 55-68. This report presented Figures that showed no appreciable difference between the performance of R421A against similar R-22-substitute refrigerants. An example is shown in Figure 2 below (Ex. 1005 at 66):

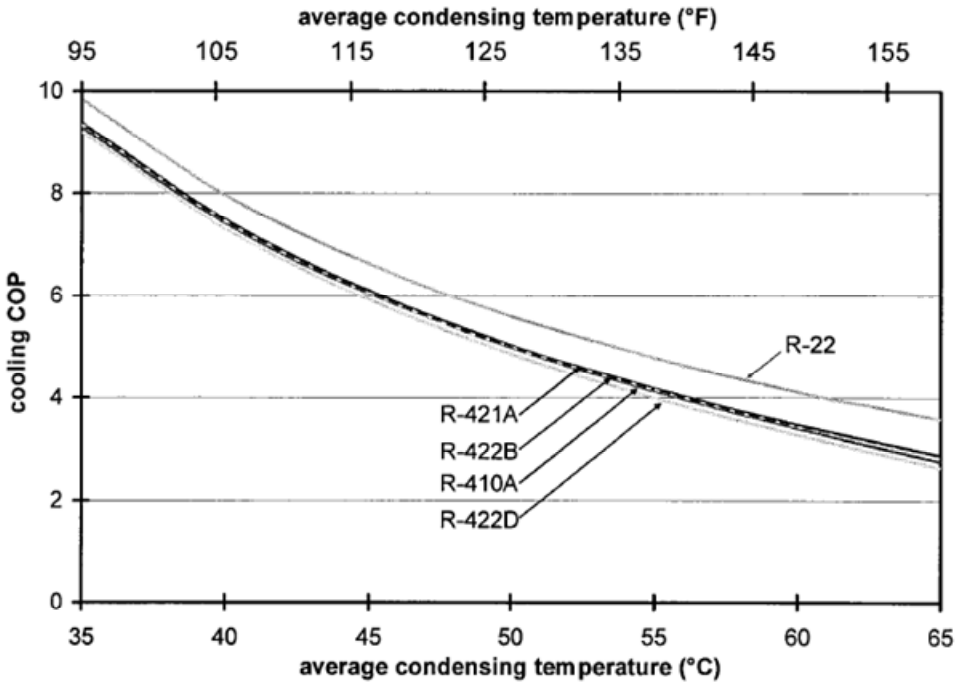


Figure 2: Cooling Coefficient of Performance (COP) Comparison

118. As can be seen, the performance of R421A is virtually identical to substitute refrigerant formulations R422B and R410A, and very close to R422D. There is no indication that theR421A COP is unexpectedly closer to the R22 COP.

119. I understand that the question is: are these theoretical results greater than expected? I understand that the courts have held that a greater than expected result is an evidentiary factor pertinent to the legal conclusion of obviousness ... of the claims at issue." I understand that applicants must further show that the results were greater than those which would have been expected from the prior art to an unobvious extent, and that the results are of a **significant, practical advantage**.

120. In this case, the Applicant of the '179 Patent argued that differences are indicated between 58/42 and 60/40 formulations. However, the Applicant of the '179 Patent made no observations as to whether these differences would have a significant effect on the performance of the refrigerant.

121. Moreover, the closest formulation in the prior art is the 56% R125 and 44% R134 at set forth by Goble 7:6-9 (Ex. 1008 at 7:6-9). There were no experimental results presented by the Applicant of the'179 Patent for this formulation.

122. Further, a Declaration by Kenneth Ponder (one of the named patent applicants) was submitted in the grandparent application (10/937,176) Ex 1005 at 289 (Discussing the development of R421A and discussing the Takigawa reference), along with a Declaration by Gbur. Ex 1005 at 315-317 (presenting no data but merely discussing the teachings of Takigawa). However, the BPAI found:

> *"Appellants' evidence of unexpected results is not persuasive because* ***it fails to compare the claimed invention to the closest prior art (i.e., Takigawa)*** *as noted by the Examiner (Ans. 7). Instead, the Ponder and Gbur Declarations compare the claimed invention to the refrigerant R421B (85% pentafluoroethane and 15% tetrafluoroethane), a refrigerant composition not disclosed by Takigawa. Though the declarations may establish that*

> *different combinations of refrigerant gases produce refrigerant compositions with different properties, the comparison of R421A to R421B fails to account for Takigawa' s disclosure of a binary refrigerant composition having 40% or greater tetrafluoroethane content (i.e., HFC-134a) and preferably 40% or greater pentafluoroethane content (i.e., HFC-125).*" Ex. 1011 at p. 7 (emphasis added).

123. Accordingly, it is my understanding that the applicant of the '179 Patent failed to rebut a finding of *prima facie* obviousness.

XI. APPARATUS IN THE CLAIMS

124. Claims 1, 21 and 26 of the '179 Patent recite methods using an "apparatus" associated with the refrigerant. Dependent claims 2 and 10 further define the apparatus as being selected from refrigeration equipment, air-conditioning equipment and HVAC equipment. Independent claim 8 recites a method for refilling apparatus. Independent claim 15 is drawn to a refrigerant composition.

125. The use of refrigerants with this type of equipment is well known in the art. See Takigawa (Ex. 1006) at 2:22 (refrigerator), 11:21 (air-conditioner); Powell (Ex. 1007) at 1:6-7 ("a refrigerant particularly but not exclusively for air conditioning systems."), 10:42-47 (rooftop heat pump, which is an HVAC

system); Goble (Ex. 1008) at 8:59 (air-conditioner), 10:48-49 (2.5 ton R-22 home central air conditioning split system, which is an HVAC system.); Singh (Ex. 1011) at ¶¶ 0036-0037 (refrigeration system).

126. The "apparatus" limitation is thus notoriously well known in the art.

XII. EXPLANATION OF GROUNDS FOR UNPATENTABILITY

127. It is my understanding that the criteria for unpatentability are the so-called Graham Factors, which include: A) determine the scope and contents of the prior art; (B) ascertain the differences between the prior art and the claims in issue; (C) determine the level of ordinary skill in the pertinent art; and (D) evaluate any evidence of secondary considerations.

A. GROUND I – GOBLE AS PRIMARY REFERENCE

128. Goble's U.S. application filing date of June 25, 2003 is prior to the September 8, 2003 filing date of the provisional application of earliest ancestor of the '179 Patent. As such, Goble is prior art under at least 35 U.S.C. § 102(e) (pre-AIA).

129. Goble U.S. Patent 6,863,840 (Ex. 1008), entitled "Nonflammable, Nonozone Depleting, Refrigerant Mixtures Suitable For Use In Mineral Oil," teaches a replacement for R22 (Abstract) that can be 30-70% R125 and 15-60% R134a at 16:28-30, which encompasses the claimed range of the '179 Patent. Goble 2:61-3:7 teaches that chlorine containing refrigerants harm the ozone layer

and are being phased out. Goble solves this problem by starting with a formulation that approximates the formulation for R421: "*Applicant set the ratio of R125/R134a to establish a pressure temperature curve approximating R-22, which is* ***roughly 56 weight percent R-125 and 44 weight percent R-134a.*** " (emphasis added) Id. 7:6-9.

130. Goble thus teaches a formulation that discloses the 57-59% R125 and 41-43% R134a claimed in the independent claims of the '179 Patent. This clearly reads on the ratio set forth in the independent claims of the '179 Patent.

131. I understand that a *prima facie* case of obviousness exists where the claimed ranges and prior art ranges do not overlap but are close enough that one skilled in the art would have expected them to have the same properties, where it has been held as proper a rejection of a claim directed to an alloy of "*having 0.8% nickel, 0.3% molybdenum, up to 0.1% iron, balance titanium*" as obvious over a reference disclosing alloys of 0.75% nickel, 0.25% molybdenum, balance titanium and 0.94% nickel, 0.31% molybdenum, balance titanium.).

132. Moreover, Goble provides a motivation to combine R125/R134a to establish a pressure temperature curve approximating R22. In so doing, Goble (Ex. 1008) at 7:6-9 determines that the ratio of R125/R134a is *"**roughly** 56 weight percent R-125 and 44 weight percent R-134A.*"

133. Further, the use of the word "roughly" in the Goble disclosure makes

a clear overlap with the R421A formulation. I am told that a relevant court decision is *In re Woodruff*, 919 F.2d 1575, 16 USPQ2d 1934 (Fed. Cir. 1990) (The prior art taught carbon monoxide concentrations of "about 1-5%" while the claim was limited to "more than 5%." I am informed that the court held that "about 1-5%" allowed for concentrations slightly above 5% thus the ranges overlapped.)

134. Thus, Goble discloses the '179 Patent's R421A formulation or, on the other hand, strongly suggest the R421A formulation.

135. Additionally, starting from the 56% R125 and 44% R134a taught by Goble, it is clearly within the ambit of routine experimentation to obtain the proportions set forth in the independent claims of the '179 Patent. Id. ¶108. *"[W]here the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation*." *In re Aller*, 220 F.2d 454, 456, 105 USPQ 233, 235 (CCPA 1955).

136. The independent claims of the '179 Patent recite a dew point at about -32° F or a bubble point at about -41.5 ° F. Related to this, the independent claims of the '179 patent recite the formulation of pentafluoroethane and tetrafluoroethane using the closed "consisting" language, which excludes other refrigerants being added to the formulations. As is well known in the chemical arts, a specific formulation will have specific properties. Accordingly, the recited dew point and bubble point are inherent to the closed refrigerant composition claimed in the '179

Patent. *"[T]he discovery of a previously unappreciated property of a prior art composition, or of a scientific explanation for the prior art's functioning, does not render the old composition patentably new to the discoverer*." *Atlas Powder Co. v. IRECO Inc.*, 190 F.3d 1342, 1347, 51 USPQ2d 1943, 1947 (Fed. Cir. 1999).

137. The independent claims of the '179 Patent recite a "phase change," which is well known in the art as being a necessary property of a refrigerant.

138. Moreover, Goble 6:63-67 describes boiling point ranges; at 10:56 describes and evaporator, at 10:59 a condenser. All these teach a phase change.

139. At Ex. 1008 2:15-22 Goble teaches lubricating oils that includes mineral oils polyolefin ester (POE) oils, and at 2:35 teaches alkyl benzene oils.

140. Goble at, e.g., 7:45-48 teaches storing refrigerant in a cylinder. Goble at 8:59-64 teaches a Frigidaire air conditioner fitted with Shraeder valves, which corresponds to a manifold. Goble thus teaches the equipment of independent claims 8 and 26 of the '179 Patent. Moreover, cylinders and manifolds are notoriously well known in the art.

141. The following chart shows how Goble applies to independent claim 1:

No.	Limitation	Relevant Art - Goble Ex. 1008
1.1	1. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Goble at 10:48-51 explains use in an air conditioning system operating with R22 (a chlorodifluoromethane refrigerant).

No.	Limitation	Relevant Art - Goble Ex. 1008
1.2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Goble 6:63-67 describes boiling point ranges; at 10:56 describes an evaporator, at 10:59 a condenser. All these teach a phase change of a substitute refrigerant.
1.3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Goble at 7:6-9. The "consisting" language excludes the addition of additional refrigerants, i.e., HFCs. The substitute refrigerant gases consist of a blend of tetrafluoroethane and pentafluoroethane.
1.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ^{o} F. at about one standard atmosphere of pressure,	Inherent; Since the "consisting" language excludes additional HFCs, the bubble point and dew point are specific to the claimed proportion of R125 and R134a. These numerical limitations would be inherent in the blend that Goble suggests.
1.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Goble discloses these ranges: • 6:24-25 (1-85% R125, 1-80% R134a), • 7:6-9 (~56% R125, ~44 % R134a); • 16:28-30 (30-70% R125, 15-60% R134a);
1.6	and wherein the refrigerant	Goble 2:15-36 teaches that the

No.	Limitation	Relevant Art - Goble Ex. 1008
	composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil,	substitute refrigerant composition also includes non-refrigerant gas components, (mineral oil, alkylbenzene). Alkylbenzene is a synthetic aromatic lubricant.
1.7	wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethanes	Goble does not teach the 20% limitation explicitly, but this range is well known in the prior art; Takigawa Ex. 1006 Claim 1(for 20%); Singh Ex.1011 at ¶ 0018 for solubility
1.8	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Goble 2:15-37 (mineral oil, alkylbenzene);
1.9	and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Goble at 1:40 teaches this specific tetrafluoroethane.

142. The claim charts below refer back the limitations enumerated for claim 1 above.

143. The following claim chart applies to independent claim 8.

No.	Limitation	Relevant Art - Goble Ex. 1008
8.1	8. A method for refilling an apparatus designed for use with a chlorodifluoromethane refrigerant, the method comprising:	Goble 10:48-52 (charging an air conditioner operating with R22);
8.2	(1) selecting a substitute refrigerant composition designed to achieve a phase change and comprising a combination of refrigerant gases,	See 1.2
8.3	the refrigerant gases consisting of a	See 1.3

No.	Limitation	Relevant Art - Goble Ex. 1008
	blend of tetrafluoroethane and pentafluoroethane,	
8.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F at about one standard atmosphere of pressure,	Inherent; See 1.4
8.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
8.6	(2) supplying the substitute refrigerant composition under pressure, in a cylinder can fitted with an outlet compatible with a chlorodifluoromethane recharging manifold of the apparatus; and	Goble 7:45-53,10:48-59;
8.7	(3) adding to said apparatus via the manifold the substitute refrigerant composition for chlorodifluoromethane, wherein the refrigerant composition further comprises non-refrigerant gas components,	Goble 10:48-51
8.8	said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane,	See 1.6/1.7

No.	Limitation	Relevant Art - Goble Ex. 1008
	tetrafluoroethane and pentafluoroethane,	
8.9	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	See 1.8
8.10	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

144. The following chart applies to independent claim 15:

No.	Limitation	Relevant Art - Goble Ex. 1008
15.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
15.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	See 1.4
15.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
15.4	wherein the refrigerant composition	See 1.6/1/7

No.	Limitation	Relevant Art - Goble Ex. 1008
	further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	
15.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

145. The following chart applies to independent claim 21:

No.	Limitation	Relevant Art - Goble Ex. 1008
21.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
21.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
21.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the	See 1.5

No.	Limitation	Relevant Art - Goble Ex. 1008
	pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	
21.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.7
21.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

146. The following chart applies to independent claim 26:

No.	Limitation	Relevant Art- Goble Ex. 1008
26.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
26.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4

No.	Limitation	Relevant Art- Goble Ex. 1008
26.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
26.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.6/1.7
26.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

147. The following chart applies to independent claim 31:

No.	Limitation	Relevant Art- Goble Ex. 1008
31. 1	31. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane	See 1.3

No.	Limitation	Relevant Art- Goble Ex. 1008
31.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
31.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
31.4	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

The dependent Claims

148. Many of the dependent claims fail to further limit the independent claim on which it depends. Claims 2, 9, 16, 23, 28 and 33 contain the limitation "*the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure*." However, this limitation is already present in each independent claim as an inherent property of the formulation. These claims thus fail to further limit the claim from which they depend and add no patentable weight. I understand that according to patent

practice, *one or more claims may be presented in dependent form, referring back to* ***and further limiting*** *another claim or claims in the same application*

149. Similarly, dependent claims 7, 14, 20, 22 and 32 recite "*a dew point of -32 ^{o} F*" while their respective independent claims recite "*a dew point of* ***about*** *-32 ^{o} F* (emphasis added)." Removal of the term "about" does little to further limit the independent claim where the claimed proportions are encompassed by the prior art.

150. In determining the range encompassed by the term "*about*," I understand that one must consider the context of the term as it is used in the specification and claims of the application, and for example a limitation defining the stretch rate of a plastic as "*exceeding about 10% per second*" is definite because infringement could clearly be assessed through the use of a stopwatch. However, in another case, the court held that claims reciting "at least about" were invalid for indefiniteness where there was close prior art and there was nothing in the specification, prosecution history, or the prior art to provide any indication as to what range of specific activity is covered by the term "*about*."

151. In the specification and the prosecution history of the '179 Patent, no definition of the word "*about*" could be found. That is, although the word is used, no ± range is given. Thus, it is questionable that removal of "about" further limits the independent claim. In any case, the ranges taught by Goble still encompass the ranges of the '179 Patent, and due to the "consisting" language of the independent

claims, the resulting properties are fixed.

152. Another issue arises from claiming a glide of 9.5 ^{o}F in dependent claims 6, 13, 19, 24, 29 and 34. However, the glide is the difference in temperature between the dew point and bubble point, which are recited in the respective base claims. As a result, the glide is already implicitly claimed in the corresponding independent claim.

153. Dependent claims 4, 11and 17 set forth additives, reciting: "wherein the lubricating oil includes an additive selected from the group consisting of an acrylic polymer, a corrosion inhibitor, a surfactant, a foaming agent, and mixtures thereof." Adding additives to lubricating oil was already well known to a PHOSITA in the art. For example, Takigawa Ex. 1006 at 8:1-14: teaches:

> "It is also possible, if required, to use singly or jointly suitable conventional additives in the refrigerating machine oil for the purpose of improving the oil in properties. The suitable conventional additives include anti-oxidants...wear resistant additives...extreme pressure ... ...anti-foaming agents ... metal inactivators ...pour point depressants; and detergent-dispersants. These additives may be used singly or in combination."

154. Takigawa Ex. 1006 at 5:31-45 teaches phosphorous compounds for wear resistance. Optionally, Seebauer Ex.1012 at 1:33-37, 56-59 teaches acrylic polymer added to lubricant to modulate viscosity. Singh Ex. 1011 ¶0025 teaches polymethcrylates, at ¶0022 corrosion inhibitors and at ¶0021 surfactants and anti-

foaming agents. Seebauer issued on August 7, 2001 and is a divisional of USSN 09/218, 905, filed on December 12, 1998. I understand Seebauer is thus prior art under 35 U.S.C. § 102(b).

155. Singh includes an exhaustive review of additives at Ex. 1011 ¶¶ 0021-0029. These include corrosion inhibitors, surfactants (lubricity additives" and antifoaming agents at ¶0021, and acrylic polymer antifoaming agents in ¶ 0028.

156. Roberts Ex. 1019 3:9-26 discusses oils and additives, including polyols, mineral oil, napthenic oil, antiwear additives, oxidation and thermal stability improves, corrosion inhibitors, anti-foaming agents and viscosity adjusters. A PHOSITA would thus add the additive teachings of Takigawa, Singh, and Seebauer to the rejection of the independent claims to reject dependent claims 4, 11and 17.

157. Claims 3, 10, 36 and 37 of the '179 Patent recite "*wherein the apparatus is selected from the group consisting of refrigeration equipment, air-conditioning equipment, and HVAC equipment.*" These were already well known in the art. For example:

158. Goble Ex. 1008 8:59-60 teaches window A/C units at 3:18, a Frigidaire window air conditioning unit, at 10:48-49, a 2.5 ton HVAC unit, and at 1:8 to "refrigerants generally," which covers refrigeration equipment.

159. Takigawa Ex. 1006 at 2:22 (refrigerator),11:21 (air conditioner);

160. Powell Ex.1007 at 1:6-7 (air conditioning systems),10:42-47 (5 ton rooftop heat pump);

161. Singh Ex.1011 at ¶¶ 0037,0038 (refrigerant heating systems);

162. Federal Register Ex. 1018 at 2 (chillers, industrial air conditioning, retail refrigeration, cold storage warehouses, refrigerated transport, household refrigerators, etc.

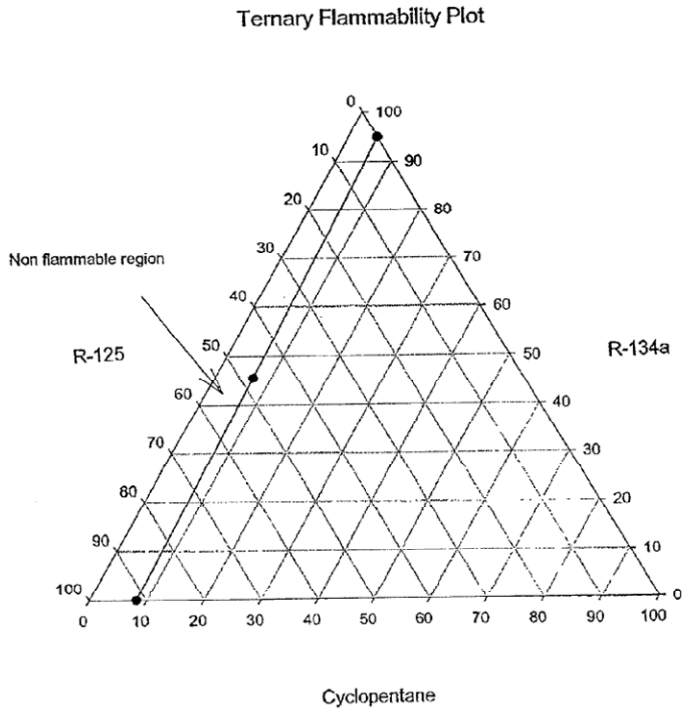
163. Accordingly, all the dependent claims either fail to further limit the independent claim or would have been *prima facie* unpatentable to a PHOSITA at least further in view of Goble, Takigawa and Singh. In conclusion, in light of the discussion of the relationship between a chemical formulation and its properties set forth in Section IV(C)(d) above, the R421A formulations claimed in claims 26-37, along with the refrigeration equipment, cylinder and manifold are all taught or inferred by the single reference of Goble. Claims 26-37 are thus either anticipated by or obvious over Goble and are thus invalid. The addition of the teaching of Takigawa and Singh, would render all claims 1-37 invalid.

B. GROUND 2 – SINGH AS PRIMARY REFERENCE

164. I understand that Singh is prior art under at least 35 U.S.C. 102(a) (pre-AIA) because it was published on April 3, 2003, which was prior to even the September 8, 2003 filing date of the provisional application of the ‘179 Patent. It is

also prior art under 35 U.S.C. § 102(e) (pre-AIA) because it was filed in the U.S. on September 21, 2001.

165. Singh teaches concentration ranges that overlap the R421A formulation, the most preferred being about 48 to about 80 parts by weight of R125 and about 18 to about 60 parts by weight of R134A. Ex. 1011 at ¶0020. Motivation to readily achieve R421is found in Figure 1 of Singh:



166. A horizontal isocline drawn through the tip of the arrow will yield the 58/42% R125/R134a percentage of R421A. This arrow and the midrange data point (closest to the arrow) will motivate a PHOSITA seeking to optimize and R125/R134a formulation, to start experimenting at where the arrow is pointing or, alternately, the midrange data point. That, is a PHOSITA seeking to optimize by

taking incremental measurements, would be motivated to start at the midpoint as a logical beginning.

167. That is, the arrow points to the 58/42% formulation and the midrange data point lies very close to this formulation. Starting from the midrange data point, it would be routine experimentation to arrive at the R421A formulation.

168. I *understand that the use of patents as references is not limited to what the patentees describe as their own inventions or to the problems with which they are concerned. They are part of the literature of the art, relevant for all they contain*. A reference may be relied upon for all that it would have reasonably suggested to one having ordinary skill the art, including nonpreferred embodiments.

169. In this case, Singh has an arrow pointing at the R421A formulation and a midrange data point very close to this formulation

170. Moreover, I understand that in the case where the claimed ranges "overlap or lie inside ranges disclosed by the prior art" a case of obviousness exists.

171. As noted above, Singh teaches the additives claimed in the '179 Patent at Ex. 1011 ¶¶0021-0029 and claim 4. Singh Id. ¶0012 discloses mineral oil and alkyl benzene oil.

172. How Singh applies to independent claim 1 is shown in the following

chart:

No.	Limitation	Relevant Art -Singh Ex. 1011
1.1	1. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Singh ¶13 teaches replacing CFCs (chlorofluorocarbons) in a refrigerant system
1.2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Singh ¶3 teaches replacing CFCs and evaporation.
1.3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Singh ¶10 teaches R125 and R134a.
1.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32º F or a bubble point at about -41.5 º F. at about one standard atmosphere of pressure,	Inherent. Since the "consisting" language excludes additional HFCs, the bubble point and dew point are specific to the claimed proportion of R125 and R134a. These numerical limitations would be inherent in the blend that Singh suggests.
1.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said	Singh ¶20 teaches 47-80% R125, 15-60%R134a. 0.1% cyclopentane would be an impurity.

No.	Limitation	Relevant Art -Singh Ex. 1011
	pentafluoroethane and said tetrafluoroethane totaling 100%,	
1.6	and wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil,	Singh ¶36 teaches lubricant, i.e., mineral oil.
1.7	wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethanes	Takigawa Ex. 1006 Claim 1(for 20%); Singh ¶18 for solubility.
1.8	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Singh ¶32 mineral oil, and alkylbenzene oil, which is a synthetic alkyl aromatic lubricant.
1.9	and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Singh ¶10.

173. How Singh applies to independent claim 8 is shown in the following chart:

No.	Limitation	Relevant Art - Singh Ex. 1011
8.1	8. A method for refilling an apparatus designed for use with a chlorodifluoromethane refrigerant, the method comprising:	Singh ¶34 teaches a method for recharging a system containing chlorine-containing refrigerants.
8.2	(1) selecting a substitute refrigerant composition designed to achieve a phase change and comprising a combination of refrigerant gases,	See 1.2
8.3	the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3

No.	Limitation	Relevant Art - Singh Ex. 1011
8.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F at about one standard atmosphere of pressure,	Inherent; See 1.4
8.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
8.6	(2) supplying the substitute refrigerant composition under pressure, in a cylinder can fitted with an outlet compatible with a chlorodifluoromethane recharging manifold of the apparatus; and	Goble 7:45-53,10:48-59;
8.7	(3) adding to said apparatus via the manifold the substitute refrigerant composition for chlorodifluoromethane, wherein the refrigerant composition further comprises non-refrigerant gas components,	Goble 10:48-51
8.8	said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane,	See 1.6/1.7

No.	Limitation	Relevant Art - Singh Ex. 1011
8.9	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	See 1.8
8.10	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

174. How Singh applies to independent claim 15 is shown in the following chart:

No.	Limitation	Relevant Art - Singh Ex. 1011
15.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
15.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	See 1.4
15.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
15.4	wherein the refrigerant composition	See 1.6/1/7

No.	Limitation	Relevant Art - Singh Ex. 1011
	further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	
15.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

175. How Singh applies to independent claim 21 is shown in the following chart.

No.	Limitation	Relevant Art Singh Ex. 1011
21.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
21.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
21.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present	See 1.5

No.	Limitation	Relevant Art Singh Ex. 1011
	in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	
21.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.7
21.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

176. How Singh applies to independent claim 26 is shown in the following chart:

No.	Limitation	Relevant Art- Singh Ex. 1011
26.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
26.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected	Inherent; See 1.4

No.	Limitation	Relevant Art- Singh Ex. 1011
	such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	
26.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
26.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.6/1.7
26.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

177. How Singh applies to independent claim 31 is shown in the following chart:

178.

No.	Limitation	Relevant Art- Singh Ex. 1011
31. 1	31. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane	See 1.3
31.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
31.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
31.4	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

179. A PHOSITA would thus achieve claims 21-37 of the '179 Patent from a knowledge of the single reference of Singh. Claims 1-37 would be rendered invalid from a knowledge of Singh, Goble and Takigawa.

180. Regarding the dependent claims, as discussed above in ¶¶149-163, the dependent claims are either repetitive, a trivial removal of the term "about" or

recitations of additives (exhaustively detailed in Singh) or equipment that are well known in the art.

181. The dependent claims thus do not address the failures of the independent claims to be valid. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Singh, Goble and Takigawa.

C. GROUND 3 – POWELL AS PRIMARY REFERENCE

182. I understand that Powell is prior art under 35 U.S.C. §102(a) (pre-AIA) because it issued on August 19, 2003 which antedates the September 8, 2003 filing date of the provisional application of the '179 Patent. Powell's U.S. application filing date of October 2, 2000 also makes Powell prior art under 35 U.S.C. § 102(e) (pre-AIA).

183. Powell Ex. 1007 1:26-34 discusses that R22 and other chlorine-containing refrigerants are to be phased out due to ozone depletion. Powell Id. 1:35-40 notes that the replacement refrigerant must have no chlorine.

184. Powell teaches 50-80% R125 and 50-20% R134a, ranges that encompass the 58/42 % range of R421A. Id. 2:50-53. Claim 1 Id. 15:49-59 sets forth this range:

1. A refrigerant composition comprising 1,1,1,2-tetrafluoroethane (R 134a), pentafluoroethane (R 125) and an additive selected from a saturated hydrocarbon or mixture thereof boiling in the range −5 to +70° C., wherein the weights of R 125 to R 134a are in the ranges:

R 125	50–80%
R 134a	50–20%.

185. Powell at 10: 42-50 discloses a commercial 5 ton heat pump and throughout the examples uses "standard refrigeration cycle analysis techniques," at e.g., Id. 4:53-54.

186. A PHOSITA would thus produce the formulation of the '179 Patent from a knowledge of Powell through routine experimentation.

187. Powell fails to explicitly disclose a cylinder and manifold (although using cylinders and manifolds for refrigerants is well known in the art). This lack is addressed by Goble Ex. 1008 7:45-48. See also Roberts Ex. 1019 3:44.

188. Powell fails to disclose lubricants and additives. As noted above, Singh teaches the additives claimed in the '179 Patent at Ex. 1011 ¶¶0021-0029. Singh Id. ¶0012 discloses mineral oil and alkyl benzene oil. Moreover, Singh Id. ¶0027 teaches a broadly defined "refrigeration system," Singh Id. ¶0021-0029. Singh Id. ¶0038 teaches refrigeration and heat pump applications as well as condensing and evaporating (phase change), Singh Id. ¶0044 teaches a 2 ton air conditioner system.

189. Powell and Singh fail to disclose that the lubricant is present up to about 20% by weight. This lack is addressed by Takigawa at Ex. 1006 8:59-63.

190. How Powell applies to independent claim 1 is shown in the following chart:

No.	Limitation	Relevant Art - Powell Ex. 1007
1.1	1. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Powell Title, 1:8.
1.2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Powell 1:35-36, 45-62.
1.3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Powell 2:42-4.
1.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F. at about one standard atmosphere of pressure,	Inherent; Groll at ___. Since the "consisting" language excludes additional HFCs, the bubble point and dew point are specific to the claimed proportion of R125 and R134a. These numerical limitations would be inherent in the blend that Singh suggests.
1.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present	Powell 2:50-53.

No.	Limitation	Relevant Art - Powell Ex. 1007
	in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	
1.6	and wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil,	Powell 2:44-46
1.7	wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethanes	Takigawa Ex. 1006 Claim 1(for 20%); Singh ¶18 for solubility.
1.8	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Singh ¶32 mineral oil, and alkylbenzene oil, which is a synthetic alkyl aromatic lubricant.
1.9	and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Powell 2:43-44

191. How Powell applies to independent claim 8 is shown in the following chart:

No.	Limitation	Relevant Art - Powell Ex. 1007
8.1	8. A method for refilling an apparatus designed for use with a chlorodifluoromethane refrigerant, the method comprising:	See 1.1
8.2	(1) selecting a substitute refrigerant composition designed to achieve a	See 1.2

No.	Limitation	Relevant Art - Powell Ex. 1007
	phase change and comprising a combination of refrigerant gases,	
8.3	the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
8.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F at about one standard atmosphere of pressure,	Inherent; See 1.4
8.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
8.6	(2) supplying the substitute refrigerant composition under pressure, in a cylinder can fitted with an outlet compatible with a chlorodifluoromethane recharging manifold of the apparatus; and	Goble 7:45-53,10:48-59;
8.7	(3) adding to said apparatus via the manifold the substitute refrigerant composition for chlorodifluoromethane, wherein the refrigerant composition further comprises non-refrigerant gas components,	Goble 10:48-51
8.8	said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to	See 1.6/1.7

No.	Limitation	Relevant Art - Powell Ex. 1007
	about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane,	
8.9	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	See 1.8
8.10	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

192. How Powell applies to independent claim 15 is shown in the following chart:

No.	Limitation	Relevant Art Powell Ex. 1007
15.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
15.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	See 1.4
15.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and	See 1.5

No.	Limitation	Relevant Art Powell Ex. 1007
	tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	
15.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.6/1/7
15.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

193. How Powell applies to independent claim 21 can be found in the following chart.

No.	Limitation	Relevant Art - Powell Ex. 1007
21.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
21.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard	Inherent; See 1.4

No.	Limitation	Relevant Art - Powell Ex. 1007
	atmosphere of pressure,	
21.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
21.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.7
21.5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

194. How Powell applies to independent claim26 can be found in the following chart:

No.	Limitation	Relevant Art - Powell Ex. 1007

No.	Limitation	Relevant Art - Powell Ex. 1007
26.1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	See 1.3
26.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
26.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
26.4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	See 1.6/1.7
26.5	and wherein the tetrafluoroethane is	See 1.9

No.	Limitation	Relevant Art - Powell Ex. 1007
	1,1,1,2-tetrafluoroethane.	

195. How Powell applies to independent claim 31 is shown in the following chart:

No.	Limitation	Relevant Art- Powell Ex. 1007
31. 1	31. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane	See 1.3
31.2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent; See 1.4
31.3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	See 1.5
31.4	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	See 1.9

196. As discussed above in ¶¶149-163, the dependent claims are either

repetitive, a trivial removal of the term "about" or recitations of additives (exhaustively detailed in Singh) or equipment that are well known in the art.

197. The dependent claims thus do not address the failures of the independent claims to be valid.

198. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Powell, Goble, Singh and Takigawa.

D. GROUND 4 – PEARSON AS PRIMARY REFERENCE

199. Pearson issued on November 18, 1997 and is prior art under pre-AIA 35 U.S.C. § 102(b).

200. Pearson teaches replacing R22 with a mixture of R125 and R134a with the addition of a hydrocarbon. Ex. 1009 at Abstract. Pearson teaches 0.5% to 60% R125 and 30 to 90% R134a. Id. 2:19-29.

201. Pearson at 1:13-14 discloses domestic refrigerators and car air conditioning systems. Pearson at 1:36-39 teaches vapor compression refrigerators and refrigeration equipment. Pearson Id. 3:66 discloses a water chilling system.

202. A PHOSITA would thus produce the subject matter of claims 21-37 of the '179 Patent through routine experimentation starting from Pearson.

203. Pearson fails to explicitly disclose a cylinder and manifold (although using cylinders and manifolds for refrigerants is well known in the art). Pearson fails to explicitly disclose a cylinder and manifold (although using cylinders and

manifolds for refrigerants is well known in the art). This lack is addressed by Goble Ex. 1008 7:45-48. See also Roberts Ex. 1019 3:44.

204. Pearson and Singh fail to disclose that the lubricant is present up to about 20% by weight. This lack is addressed by Takigawa Ex. 1006 8:59-63.

205. How Pearson applies to independent claim 1 is shown in the following chart:

No.	Limitation	Relevant Art Pearson Ex. 1009
1.1	1. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Peason Abstract.
1.2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Pearson Abstract.
1.3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Pearson Abstract.
1.4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F. at about one standard atmosphere of pressure,	Inherent. Since the "consisting" language excludes additional HFCs, the bubble point and dew point are specific to the claimed proportion of R125 and R134a. These numerical limitations would be inherent in the blend that Singh suggests.

No.	Limitation	Relevant Art Pearson Ex. 1009
1.5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Pearson 2:19-20,27-28.
1.6	and wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil,	Singh Ex.1011 at ¶ 0036
1.7	wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethanes	Takigawa Ex. 1006 Claim 1(for 20%); Singh ¶18 for solubility.
1.8	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Singh ¶32 mineral oil, and alkylbenzene oil, which is a synthetic alkyl aromatic lubricant.
1.9	and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Pearson Abstract

206. The claim charts for independent claims 8, 15, 21, 26 and 31 are the same as those set forth for Powell in the previous section. For brevity, they are not reproduced here.

207. As discussed above in ¶¶149-163, the dependent claims are either

repetitive, a trivial removal of the term "about" or recitations of additives (exhaustively detailed in Singh) or equipment that are well known in the art.

208. The dependent claims thus do not address the failures of the independent claims to be valid.

209. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Pearson, Goble, Singh and Takigawa via routine experimentation.

E. GROUND 5 – FEDERAL REGISTER AS PRIMARY REFERENCE

210. As is discussed in the section detailing prosecution history, the true priority date is August 13, 2007, the date when the 58/42 R125/R134a proportions were added to the application by amendment.

211. Federal Register Ex. 1018 was published on September 28, 2006, less than a year before the true August 13, 2007 priority date of the '179 Patent. Federal Register is thus prior art under 35 U.S.C. § 102(e).

212. Federal Register at P. 2, first column teaches: "*R-421A is a blend of 48% by weight hydrofluorocarbon (HFC)-125 (pentafluoroethane VASID #354-33-6), and 425 by weight HFC-134a (1,1,1,2-tetrafluoroethane, CAS ID # 811-97-2)*."

213. Federal Register thus encompasses all the R421 formulations claimed

in the '179 Patent.

214. Federal Register at column 1 also discloses R421A being used in refrigerators, air conditioners, etc.

215. Federal Register fails to disclose lubricants and additives. Federal Register additionally fails to disclose a cylinder and manifold (although using cylinders and manifolds for refrigerants is well known in the art). Federal Register also fails to disclose 20% lubricating oil.

216. As noted above Goble, Singh, Roberts and Takigawa address these deficiencies.

217. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Federal Register, Goble, Singh and Takigawa via routine experimentation.

F. GROUND 6 – ROBERTS AS PRIMARY REFERENCE

218. Roberts has a PCT publication date of June 7, 2001, which makes it prior art to the '949 Patent under pre-AIA 35 U.S.C. § 102(b).

219. Roberts pertains to refrigerant compositions. Roberts Ex. 1019 2:48-52 discloses a refrigerant composition containing 35-60 wt% R134A and 35-60 wt% R125, which encompasses the 58/42 wt% proportions of R125/R134A of R421A. Roberts in Table 1 has a formulation that is 58.9% R125 and 40.1% R134A. Id. 4:11. This latter formulation is very close to the 58/42% proportion of

R421A.

220. Interestingly, Fig. 1 of Roberts shows performance of R134A (balance R125) with a solvent that shows a steep drop in performance as the concentration of R134A goes above 42%:

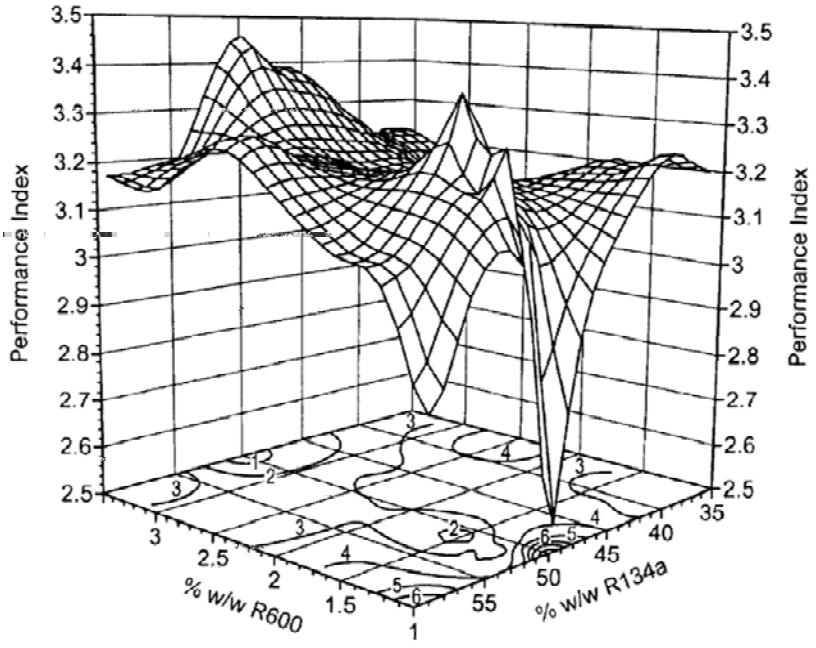


FIG. 1

221. Moreover, Fig 2 of Roberts shows performance of R134A (balance R125) with a solvent that has an inflection point hovering over 42%:

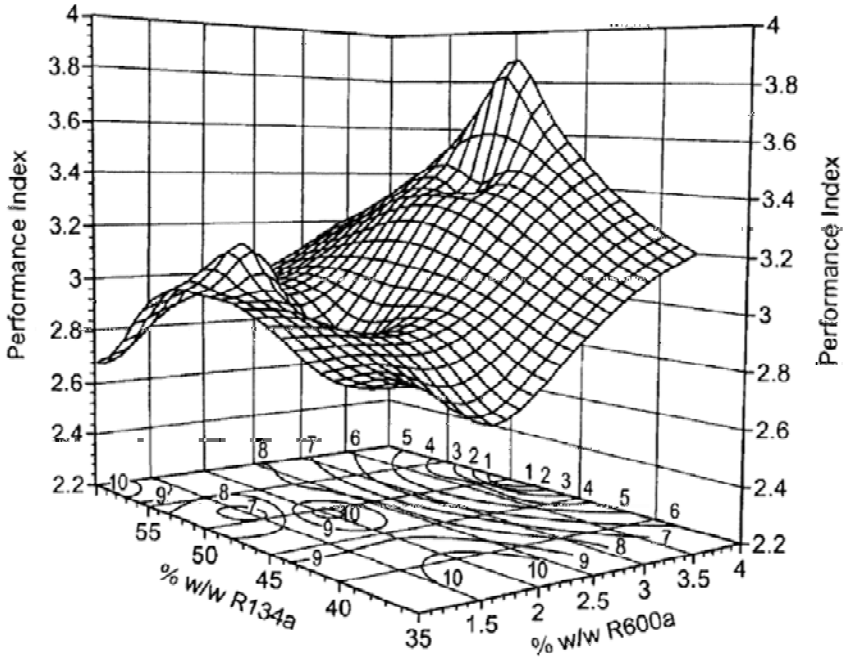


FIG. 2

222. The information in these graphs would point a PHOSITA in the direction of the 58/42 R125/R134A proportion of R421A.

223. Roberts Id. 1:2-6 discusses replacements in refrigeration equipment For R12 and R22. Roberts Id. 3:9-20 teaches lubrication oils. Roberts Id. 3:21-27 teaches additives. Roberts Id. 3:44-45 teaches charging from a cylinder.

224. Any failures of Roberts are addressed by the secondary references of Goble, Singh and Takigawa, as discussed above.

225. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Roberts, Goble, Singh and Takigawa via routine experimentation.

G. GROUND 7 – LEMMON AS PRIMARY REFERENCE

226. Lemmon, entitled "Equations of State for Mixtures of R-32, R-125, R-134a, R-143a, and R-152a," was published on August 30, 2002, more than a year before the filing of the provisional application of the '179 Patent. Lemmon is thus prior art under 35 U.S.C. § 102(b).

227. In Table 4, Ex 1020 at P. 27, Lemmon summarizes studies published on mixtures of R125 and R 134a, where ranges of R125 (balance R134a) were studied including mole fractions of R125 of 0.349-0.719, 0.0865-0.923, 0.250-0.751, 0.179-0.776, 0.259-0.649, 0.0001-0.813, 0.254-0.749, 0.0865-0.923, 0.222-0.718, and 0.348-0.693.

228. All the above mole fractions of R125 (balance R134a) encompass the 0.545 R125 and 0.455 R134a mole fractions of R421A.

229. Lemmon teaches bubble point and dew point can be calculated. Id. at 2. Moreover, these properties are inherent to R421A.

230. Lemmon fails to disclose lubricants and additives. Lemmon additionally fails to disclose a cylinder and manifold (although using cylinders and manifolds for refrigerants is well known in the art). Lemmon also fails to disclose 20% lubricating oil.

231. As noted above Goble, Singh, and Takigawa address these deficiencies.

232. A PHOSITA would thus achieve all the claims of the '179 Patent from a knowledge of Lemmon, Goble, Singh and Takigawa via routine experimentation.

XIII. CLAIM CHARTS – THE INDEPENDENT CLAIMS

233. The grounds for unpatentability were discussed above. As detailed below, the claim charts show how each and every element of claims 1-37 of the '179 Patent are unpatentable as being obvious under 35 U.S.C. § 103.

a. Independent Claim 1

234. The limitations of independent claim 1 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	1. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Takigawa Ex. 1006 1:20-25; Powell Ex.1007 Title 1:8; Goble Ex.1008 10:48-49; Pearson Ex.1009 at Abstract; Singh Ex.1011 at ¶ 37; Roberts Ex. 1019 2:48-52 Federal Register Ex. 1019 at 2; Lemmon Ex. 1021 at 8.
2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Powell 1:35-36,45-62; Goble 6:63-67; Pearson at Abstract Singh ¶ 0003; Federal Register at 2

No.	Limitation	Relevant Art
3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Takigawa 2:15-17; Powell 2:42-4; Goble 7:6-9; Pearson Abstract; Decision Ex.1010 p.3-4; Singh ¶ 0010 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F. at about one standard atmosphere of pressure,	Inherent;
5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Takigawa 8:20-28; Powell 2:50-53; Goble 6:24-25, 7:6-9; 16:28-30; Pearson 2:19-20,27-28; Decision p.4; Singh ¶ 0020 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
6	and wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil,	Takigawa 2:49,4:51; Powell 2:44-46, 4:23; Goble 2:15-22; Singh ¶ 0036; Roberts 3:9-20
7	wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethanes	Takigawa Claim 1(for 20%); Singh ¶ 0018 for solubilty
8	wherein the lubricating oil is	Takigawa 2:25-29;

No.	Limitation	Relevant Art
	selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Singh ¶ 0032; Goble 2:15-35; Roberts 3:9-20
9	and the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Pearson at Abstract; Decision p.4; Singh ¶ 0010 Federal Register at 2 Roberts 2:48-52; Lemmon1021 at 27

235. All of the prior art references in the above table are in the same field of endeavor, i.e., refrigerant formulations to replace chlorine-containing refrigerants. I understand that any need or problem known in the field of endeavor at the time of invention and addressed by the patent can provide a reason for combining the elements in the manner claimed.

236. As a result, there are combinations of the prior art that render claim 1 of the '179 Patent obvious.

237. The limitations of independent claim 8 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	8. A method for refilling an apparatus designed for use with a	Takigawa Ex. 1006 1:20-25; Powell Ex.1007 Title 1:8;

No.	Limitation	Relevant Art
	chlorodifluoromethane refrigerant, the method comprising:	Goble Ex.1008 10:48-49; Pearson Ex.1009 at Abstract; Singh Ex.1011 at ¶ 37 Federal Register Ex. 1018 at 2 Lemmon Ex. 1020 at 8
2	(1) selecting a substitute refrigerant composition designed to achieve a phase change and comprising a combination of refrigerant gases,	Powell 1:35-36,45-62; Goble 6:63-67; Pearson at Abstract; Singh ¶ 0003; Federal Register at 2 Lemmon at 8
3	the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Takigawa 2:15-17; Powell 2:42-4; Goble 7:6-9; Pearson at Abstract; Decision p.3-4 Singh ¶ 0003 Federal Register at 2 Roberts 2:48-52 Lemmon at 27
4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5 ° F at about one standard atmosphere of pressure,	Inherent;
5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Takigawa 8:20-28; Powell 2:50-53; Goble 6:24-25, 7:6-9; 16:28-30; Pearson 2:19-20,27-28; Decision p.4; Singh ¶ 0020; Federal Register at 2; Roberts 2:48-52; Lemmon at 27
6	(2) supplying the substitute	Goble 7:45-53,10:48-59;

No.	Limitation	Relevant Art
	refrigerant composition under pressure, in a cylinder can fitted with an outlet compatible with a chlorodifluoromethane recharging manifold of the apparatus; and	Roberts 3:44-45
7	(3) adding to said apparatus via the manifold the substitute refrigerant composition for chlorodifluoromethane, wherein the refrigerant composition further comprises non-refrigerant gas components,	Goble 10:48-51
8	said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane,	Takigawa 2:49,4:52, Claim 1(for 20%); Powell 2:44-46, 4:23; Goble 2:15-22; Singh ¶ 0018 Federal Register at 2
9	wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof,	Takigawa 2:25-29; Singh ¶ 0032; Goble 2:15-22 for mineral oil
10	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Pearson at Abstract; Decision p.4; Singh ¶ 0010; Federal Register at 2; Roberts 2:48-52; Lemmon at 27

238. As was noted above, all the prior art references are in the same field of

endeavor, and the bubble point and the dew point claimed are inseparable properties of the claimed mixture of R125 and R134a.

239. As a result, independent claim 8 is rendered obvious over the prior art.

b. Independent Claim 15

240. The limitations of independent claim 15 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	15. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Takigawa Ex. 1006 2:15-17; Powell Ex.1007 2:42-4; Pearson Ex.1009 at Abstract; Goble Ex.1008 at 7:6-9; Decision Ex.1010 p.3-4; Singh Ex.1011 at ¶ 0010; Federal Register Ex. 1018 at 2; Roberts Ex. 1019 2:48-50; Lemmon Ex. 1020 at 27
2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent;
3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined	Takigawa 8:20-28; Powell 2:50-53; Goble 6:24-25,7-6-9; 16:28-30; Pearson 2:19-20,27-28; Decision p.4; Singh ¶ 0020; Federal Register at 2; Roberts 2:48-50;

No.	Limitation	Relevant Art
	weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Lemmon at 27
4	wherein the refrigerant composition further comprises non-refrigerant gas components, said non-refrigerant gas components including a lubricating oil, wherein the lubricating oil is present up to about 20% by weight of the refrigerant gases and is soluble in chlorodifluoromethane, tetrafluoroethane and pentafluoroethane, wherein the lubricating oil is selected from the group consisting of mineral oil, synthetic alkyl aromatic lubricants, and mixtures thereof	Takigawa 2:25-29, 49-4:51, Claim 1(for 20%); Powell 2:44-46, 4:23; Singh ¶¶ 0018,0036; 2:15-22 for mineral oil; Roberts 3:9-20
5	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Pearson at Abstract; Singh ¶ 0010; Decision p.4; Federal Register at 2; Roberts 2:48-52; Lemmon at 27

241. As was noted above, all the prior art references are in the same field of

endeavor, and the bubble point and the dew point claimed are inseparable and inherent properties of the claimed mixture of R125 and R134a. Claim 15 is thus clearly obvious in light of the prior art.

c. Independent Claim 21

242. The limitations of independent claim 21 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	21. In an apparatus designed for use with chlorodifluoromethane refrigerant,	Takigawa Ex. 1006 1:20-25; Powell Ex.1007 Title 1:8; Goble Ex.1008 10:48-49; Pearson Ex.1009 at Abstract; Singh Ex.1011 ¶ 37 Federal Register Ex. 1018 at 2; Roberts Ex. 1019 2:48-52; Lemmon Ex. 1021 at 8
2	the improvement comprising substituting the chlorodifluoromethane with a refrigerant composition designed to achieve a phase change,	Powell 1:35-36,45-62; Goble 6:63-67; Pearson at Abstract; Singh ¶ 0003; Federal Register at 2; Roberts 2:48-52; Lemmon Ex. 1021 at 8
3	the refrigerant composition comprising a combination of refrigerant gases, said refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Takigawa 2:15-17 Powell 2:42-4; Goble 7:6-9; Pearson at Abstract; Singh ¶ 0010; Decision p.3-4 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
4	the ratio of the tetrafluoroethane to the	Inherent;

No.	Limitation	Relevant Art
	pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F or a bubble point at about -41.5° F at about one standard atmosphere of pressure,	
5	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Takigawa 8:20-28; Powell 2:50-53; Goble 6:24-25,7-6-9; 16:28-30; Pearson 2:19-20,27-28; Singh ¶ 0020; Decision p.4 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
6	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Pearson at Abstract; Singh ¶ 0010; Decision p.4 Federal Register at 2 Roberts 2:48-52; Lemmon at 27

243. As was noted above, all the prior art references are in the same field of endeavor, and the bubble point and the dew point claimed are inseparable properties of the claimed mixture of R125 and R134a. Claim 21 is thus clearly

obvious over the prior art.

d. Independent Claim 26

244. The limitations of independent claim 26 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	26. A method for refilling an apparatus designed for use with a chlorodifluoromethane refrigerant, the method comprising:	Takigawa Ex. 1006 1:20-25; Powell Ex.1007 Title 1:8; Goble Ex.1008 10:48-49; Singh Ex.1011 at ¶ 37; Pearson Ex.1009 at Abstract Federal Register Ex. 1018 at 2 Roberts Ex. 1019 2:48-52; Lemmon Ex. 1020 at 8
2	(1) selecting a substitute refrigerant composition designed to achieve a phase change	Powell 1:35-36,45-62; Goble 6:63-67; Singh ¶ 0003 Pearson at Abstract; Federal Register at 2 Roberts 2:48-52; Lemmon at 8
3	and comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane,	Takigawa 2:15-17 Powell 1:35-36,45-62; Goble 6:63-67,7:6-9; Pearson at Abstract; Singh ¶ 0010 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
4	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32º F or a bubble point at about -41.5 º F at about one standard atmosphere of pressure,	Inherent;
5	wherein in the substitute refrigerant	Takigawa 8:20-28;

No.	Limitation	Relevant Art
	said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Powell 2:50-53; Goble 6:24-25,7:6-9,16:28-30; Pearson 2:19-20,27-28; Singh ¶ 0020; Decision p.4 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
6	(2) supplying the substitute refrigerant composition under pressure, in a cylinder can fitted with an outlet compatible with a chlorodifluoromethane recharging manifold of the apparatus; and	Goble 7:45-53,10:48-59
7	(3) adding to said apparatus via the manifold the substitute refrigerant composition for chlorodifluoromethane,	Goble 10:48-51
8	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Decision p.4; Pearson at Abstract; Singh ¶ 0010 Federal Register at 2 Roberts 2:48-52; Lemmon at 27

245. As was noted above, all the prior art references are in the same field of endeavor, and the bubble point and the dew point claimed are inseparable properties of the claimed mixture of R125 and R134a. Claim 26 is thus clearly obvious over combinations of the prior art.

e. Independent Claim 31

246. The limitations of independent claim 31 and their relationship to the prior art are set forth in the table below.

No.	Limitation	Relevant Art
1	31. A refrigerant composition comprising a combination of refrigerant gases, the refrigerant gases consisting of a blend of tetrafluoroethane and pentafluoroethane	Takigawa Ex. 1006 2:15-17 Powell Ex.1007 2:42-4; Goble Ex.1008 at 7:6-9; Singh Ex.1011 at ¶ 0010 Decision Ex.1010 p.3-4 Federal Register Ex. 1018 at 2 Roberts Ex. 1019 2:48-52 Lemmon Ex. 1021 at 27
2	the ratio of the tetrafluoroethane to the pentafluoroethane being selected such that the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5° F. at about one standard atmosphere of pressure,	Inherent;
3	wherein in the substitute refrigerant said pentafluoroethane is present in an amount of 59% to 57% by weight and said tetrafluoroethane is present in an amount of 41% to 43% by weight of the combined weight of the pentafluoroethane and tetrafluoroethane on the basis of the combined weights of said pentafluoroethane and said tetrafluoroethane totaling 100%,	Takigawa 8:20-28; Powell 2:50-53; Goble 6:24-25, 7:6-9; 16:28-30; Pearson 2:19-20,27-28; Singh ¶ 0020 Decision p.4 Federal Register at 2 Roberts 2:48-52; Lemmon at 27
4	and wherein the tetrafluoroethane is 1,1,1,2-tetrafluoroethane.	Takigawa 1:18-19; Powell 2:43-44; Goble 1:40; Singh ¶ 0020;

No.	Limitation	Relevant Art
		Decision p.4; Pearson at Abstract Federal Register at 2 Roberts 2:48-52; Lemmon at 8

247. As was noted above, all the prior art references are in the same field of endeavor, and the bubble point and the dew point claimed are inseparable properties of the claimed mixture of R125 and R134a.

248. Independent claim 31 is the broadest independent claim in the '179 Patent. Claim 31 corresponds to the formulation of R421A. The invalidity of patenting this formulation was verified the BPAI's decision over Takigawa. The invalidity of patenting the R421A formulation was also analyzed in Section IX supra, where in light of the Decision of the BPAI, this formulation can be achieved by routine experimentation over any of the cited references that teach ranges the bracket the 58/42% R124/R134a proportion of R421A.

XIV. THE DEPENDENT CLAIMS

249. Many of the dependent claims fail to further limit the independent claim on which it depends. Claims 2, 9, 16, 23, 28 and 33 contain the limitation "*the blend exhibits a dew point at about -32° F. or a bubble point at about -41.5^{o} F. at about one standard atmosphere of pressure*." However, this limitation is

already present in each independent claim as an inherent property of the formulation. These claims thus fail to further limit the claim in which it depends and is therefore improper and adds no patentable weight. See Manual of Patent Examination Procedure § 706.03(k) and 37 C.F.R. § 1.75 ("*One or more claims may be presented in dependent form, referring back to* ***and further limiting*** *another claim or claims in the same application*.") (emphasis added).

250. Similarly, dependent claims 7, 14, 20, 22 and 32 recite "*a dew point of -32 ^{o} F*" while their respective independent claims recite "*a dew point of* ***about*** *-32 ^{o} F* (emphasis added)." Removal of the term "about" does little to further limit the independent claim.

251. I understand that in determining the range encompassed by the term "*about*," one must consider the context of the term as it is used in the specification and claims of the application, and that a limitation defining the stretch rate of a plastic as "*exceeding about 10% per second*" is definite because infringement could clearly be assessed through the use of a stopwatch. However, I understand that in another case, the court held that claims reciting "at least about" were invalid for indefiniteness where there was close prior art and there was nothing in the specification, prosecution history, or the prior art to provide any indication as to what range of specific activity is covered by the term "*about*."

252. In the specification and the prosecution history of the '179 Patent, no definition of the word "*about*" could be found. That is, although the word is used, no ± range is given. Thus, it is problematic that removal of this limitation further limits the independent claim.

253. Another issue arises from claiming a glide of 9.5 °F in dependent claims 6, 13, 19, 24, 29 and 34. However, the glide is the difference in temperature between the dew point and bubble point, which are recited in the respective base claims. As a result, the glide is already implicitly claimed in the corresponding independent claim.

254. Dependent claims 4, 11and 17 set forth additives, reciting: "wherein the lubricating oil includes an additive selected from the group consisting of an acrylic polymer, a corrosion inhibitor, a surfactant, a foaming agent, and mixtures thereof." Adding additives to lubricating oil is well known in the art. For example, Takigawa Ex. 1006 at 8:1-14: teaches:

> "*It is also possible, if required, to use singly or jointly suitable conventional additives in the refrigerating machine oil for the purpose of improving the oil in properties. The suitable conventional additives include anti-oxidants...wear resistant additives...extreme pressure ... ...anti-foaming agents ... metal inactivators ...pour point depressants; and detergent-dispersants. These additives may be used singly or in combination*."

255. Takigawa Ex. 1006 at 5:31-45 teaches phosphorous compounds for wear resistance. Optionally, Seebauer Ex.1013 at 1:33-37, 56-59 teaches acrylic polymer added to lubricant to modulate viscosity. Singh Ex. 1011 ¶ 0025 teaches polymethcrylates, at ¶ 0022 corrosion inhibitors and at ¶ 0021 surfactants and anti-foaming agents. Seebauer issued on August 7, 2001 and is a divisional of USSN 09/218, 905, filed on December 12, 1998. I understand that Seebauer is thus prior art under 35 U.S.C. § 102(b).

266. Singh includes an exhaustive review of additives at Ex. 1011 ¶¶ 0021-0029. These include corrosion inhibitors, surfactants (lubricity additives" and antifoaming agents at ¶ 0021, and acrylic polymer antifoaming agents in ¶ 0028.

267. Being in the same field of endeavor, and seeking to optimize the formulation, a PHOSITA would thus add the additive teachings of Takigawa, Singh, and Seebauer to the rejection of the independent claims to reject dependent claims 4, 11and 17.

268. Claims 3, 10 and 37 recite "*wherein the apparatus is selected from the group consisting of refrigeration equipment, air-conditioning equipment, and HVAC equipment*." These are well known in the art for example at Takigawa Ex. 1006 at 2:22,11:21; Powell Ex.1007at 1:6-7,10:42-47; Goble Ex.1008 at 8:59,10:48-49; Singh Ex.1011 at ¶¶ 0037,0038, 17; Federal Register Ex. 1018 at

2.

267. Accordingly, all the dependent claims either fail to further limit the independent claim or would be prima facie unpatentable to a PHOSITA.

CONCLUSION

268. In my opinion, the problem that the named inventors sought to solve is completely routine. The solution was a completely routine exercise in applying the prior art, in my opinion. It was well known to the entire industry that R-22 and the other chlorine-containing refrigerants had to be replaced due to legislation and/or regulations. At that time, there was a huge installed base of cooling systems that relied on the refrigerants that were being phased out. The replacement refrigerants needed to have the same characteristics as the refrigerant being replaced. That meant that the PHOSITA was motivated to obtain a refrigerant or refrigerant combination that would have the same, or substantially the same bubble point, dew point and glide. The PHOSITA would have been informed to use the combination of R125 and R134a by numerous items of prior art, such as I have explained above.

269. Additionally, it was well known that lubrication was necessary to prevent damage to the compressor of the refrigeration equipment, and a PHOSITA needed to include a miscible lubricant. These lubricants were well known in the art before the earliest filing date of the '179 Patent, and include

mineral oil, alkyl aromatic oil, alkyl benzene oils, naphthenic oils, polyalkyl glycol oils, polyol ester (POE) oils and mixtures thereof. The ROYCO® 2302 lubricant utilized by the applicants was a commercially available off-the-shelf lubricant that would routinely be added to the refrigerant mixture.

270. As such, combining R125 and R134a, as refrigerant, with a known lubricant was an utterly routine task and solution for a PHOSITA before 2003. The specific ranges and values were dictated by the characteristics that needed to be matched, and the choice of lubricant was a routine matter. Only minor experimentation would have been required, and the formulation would have been arrived at easily and expectedly. Also, any evidence presented by the applicants utterly failed to display unexpected results.

271. Overall, the differences between the subject matter claimed in the claims at issue and the prior art were not significant, in my opinion, and the overall combinations were certainly well within the grasp of a PHOSITA. Before 2003, a PHOSITA would have arrived at the claimed combinations by the routine exercise of technical skills. Also, there was no technical reason not to combine the items set forth in the claims, and the PHOSITA would have had a strong expectation of success in combining these elements to result in a substitute refrigerant for use in several systems that required them such as air conditioners, coolers, HVAC systems, etc.

272. I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States code and that such willful false statements may jeopardize the validity of the petition and IPR.

Date 09/21/2020 Eckhard A. Groll

Eckhard Groll

APPENDIX A

C.V. OF ECKHARD GROLL

Dr.-Ing. Eckhard A. Groll
Reilly Professor of Mechanical Engineering
William E. and Florence E. Perry Head of Mechanical Engineering

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RESUME – August 2020

EDUCATION:

02/94 "Doktor-Ingenieur" (Doctor of Engineering) in Mechanical Engineering
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11/89 "Diplom-Ingenieur" (Diploma of Engineering) in Mechanical Engineering
Ruhr-University of Bochum, Bochum, Germany
10/86 "Diplom-Vorprüfung" (Pre-Diploma of Engineering) in Mechanical Engineering
Ruhr-University of Bochum, Bochum, Germany

ACADEMIC FACULTY AND RESEARCH APPOINTMENTS:

05/13 – present	**Reilly Professor of Mechanical Engineering**, Purdue University, Ray W. Herrick Laboratories, West Lafayette, Indiana, USA
04/07 – 07/07	**Guest Professor**, University of Karlsruhe, Institute of Turbomachinery, Karlsruhe, Germany
08/05 – 05/13	**Professor of Mechanical Engineering**, Purdue University, Ray W. Herrick Laboratories, West Lafayette, Indiana, USA
01/03 – 07/03	**Guest Professor**, University of Karlsruhe, Institute of Technical Thermodynamics, Karlsruhe, Germany
08/00 – 07/05	**Associate Professor of Mechanical Engineering**, Purdue University, Ray W. Herrick Laboratories, West Lafayette, Indiana, USA
07/94 – 07/00	**Assistant Professor of Mechanical Engineering**, Purdue University, Ray W. Herrick Laboratories, West Lafayette, Indiana, USA
12/91 – 06/94	**Faculty Research Assistant**, University of Maryland, Center for Environmental Energy Engineering, Dept. of Mechanical Engineering, College Park, MD
01/90 – 11/91	**Research Assistant**, University of Hannover, Institute of Refrigeration, Hannover, Germany
03/89 – 10/89	**Research Assistant**, Hoechst AG, Technical Examination, Frankfurt, Germany
01/88 – 12/88	**Research Assistant**, Texas A&M University, Dept. of Mechanical Engineering, College Station, Texas, USA
04/87 – 12/87	**Research Assistant**, Ruhr-University of Bochum, Institute of Energy Plant Technology, Bochum, Germany

ACADEMIC ADMINISTRATIVE APPOINTMENTS:

07/19 – present **William E. and Florence E. Perry Head of Mechanical Engineering,** Purdue University, College of Engineering, West Lafayette, Indiana, USA
- Responsible for all undergraduate and graduate educational programs in the School of Mechanical Engineering (approximately 1,400 undergraduate and 600 graduate students)
- Manages annual operating budget of $46 million+
- Oversight of 84 Faculty Members
- Oversight of approximately 50 Staff Members
- Oversight of instructional and research facilities in main ME Building, Ray W. Herrick Laboratories, and Maurice J. Zucrow Laboratories

01/18 – 06/19 **Associate Dean for Undergraduate and Graduate Education,** Purdue University, College of Engineering, West Lafayette, Indiana, USA
- Responsible for all undergraduate and graduate education programs within the College of Engineering (total of approximately 13,000 students)
- Manages annual operating budget of $5 million+
- Oversight of 12 Direct Reports
- Oversight of 8 Program Offices with 38 Staff Members

01/12 – 07/12 **Interim Assistant Dean of Engineering for Research**, Purdue University, College of Engineering, West Lafayette, Indiana, USA
- Oversight of Summer Undergraduate Research Fellowship (SURF) program
- Conduct ranking of limited submission research proposals
- Evaluate cost share requests and approval of research proposals
- Represent College of Engineering to other organizations

09/10 – 05/11 **ACE Fellow**, Georgia Institute of Technology, Office of the Vice Provost on International Initiatives, Atlanta, Georgia
- Shadow Georgia Tech President on numerous occasions
- Evaluate operation of global satellite campuses
- Make recommendations to increase student participation in global programs

08/08 – 12/17 **Director of the Office of Professional Practice,** Purdue University, College of Engineering, West Lafayette, Indiana, USA
- Oversight of 7 FTE Staff Members
- Managed annual operating budget of $500k+
- Responsible for cooperative education programs in 46 academic disciplines located within 8 colleges
- Responsible for the GEARE program and global research experiences
- Responsible for interactions with more than 300 employers participating in various programs
- Increased overall student participation in Professional Practice Programs from approximately 650 students during academic year 2007-08 to more than 1500 students during academic year 2016-17.
- Founded new G-PAL program (Global Partners in Apprenticeship Learning), Master-level Co-Op program, and Parallel Co-Op program
- Introduced corporate partnership program raising approximately $50k per year
- Raised $200k for lobby renovation project in Potter Engineering Center

- Raised $100k endowment to offer engineering courses to on-campus co-op students during summer sessions
- Raised $200k gift money to support better delivery of on-line course for Professional Practice students while away from campus
- Raised $200k gift money to support travel assistantships for students participating in the undergraduate GEARE program

09/07 – 07/08 **Interim Director of the Office of Professional Practice,** Purdue University, College of Engineering, West Lafayette, Indiana, USA
- Responsibilities were the same as outlined above under Director of the Office of Professional Practice

07/05 – 07/08 **Director of Global Initiatives, Cooperative Education and Professional Experiences**, Purdue University, School of Mechanical Engineering, West Lafayette, Indiana, USA
- Co-Op Coordinator for approximately 150 undergraduate ME students
- Major contributor to the development of the unique and award-winning undergraduate GEARE program
- Primary responsibility for developing the global design team projects that are part of the undergraduate GEARE program
- Advisor of ME students' participation in the undergraduate GEARE program

PERSONAL:

German Citizen; U.S. Permanent Resident; Bilingual (German, English).

PROFESSIONAL MEMBERSHIPS:

- American Society of Engineering Education (ASEE)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- American Society of Mechanical Engineers (ASME)
- Deutscher Kälte- und Klimatechnischer Verein (German Society of Refrig. and Climate Tech.)
- International Institute of Refrigeration (IIF/IIR)

PROFESSIONAL AWARDS:

- 2020 Best Student Paper Award (with PhD student Junyoung Kim), 2020 Rankine Conf., Virtual Event, Glasgow, Scotland, July 27 - 31, 2020.
- 2019 Best Student Paper Award (with PhD student Xinye Zhang), 11th Int'l Conf. on Compressors and their Systems, City University London, UK, September 9-11, 2019.
- 2018 Silver Anniversary Needle for 25-Year Membership in the German Society of Refrigeration and Climate Technology (DKV)
- 2018 Inductee Cooperative Education Hall of Fame at Purdue University
- 2018 J&E Hall International Gold Medal of Refrigeration, Institute of Refrigeration, UK
- 2017 Shortlisted for Best Technical Paper, 10th International Conf. on Compressors and their Systems, City University of London, UK, Sept. 11-13.
- 2017 Peter Ritter von Rittinger International Heat Pump Award, IEA Heat Pump Centre.

- 2016 Honorary Faculty Member, Barbara Cook Chapter of Mortar Board at Purdue (National College Senior Honor Society)
- 2015 Top 10 HVAC Heating Professors, as named by HVACClasses.org, owned and operated by Sechel Ventures
- 2014-2017 Distinguished Overseas Professor, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China
- 2014 Inductee into Purdue Innovator Hall of Fame
- 2014 DAAD Alumni Award (German Academic Exchange Service)
- 2014 ASHRAE Exceptional Service Award
- 2013 Discovery in Mechanical Engineering Award, School of Mech. Eng., Purdue University
- 2013 Global Impact Award, College of Engineering, Purdue University
- 2011 Purdue University Research Acorn Award
- 2011 ASHRAE Distinguished Lecturer
- 2010-2011 ACE Fellow (American Council on Education)
- 2010 E. K. Campbell Award from ASHRAE in recognition of outstanding service and achievement in teaching and research in subjects relating to the industry and professions represented by ASHRAE.
- 2009-10 CIC-ALP Fellow (Committee on Institutional Collaboration – Academic Leadership Program)
- 2009 Faculty Advising Excellence Award, College of Engineering, Purdue University
- 2008 Inductee into Book of Great Teachers, Purdue University
- 2007 Ruth and Joel Spira Award for outstanding contributions to the School of Mechanical Engineering for inspiring students and fostering excellence in commercial or defense product realization.
- 2007 Purdue University Faculty Scholar Award
- 2006 ASHRAE Fellow
- 2005 Fellow of Purdue's Teaching Academy
- 2005 Wilbur T. Pentzer Achievement and Leadership Award for outstanding contributions to the growth and well-being of the International Institute of Refrigeration (IIR) and the U.S. National Committee of the IIR.
- 2005 Charles B. Murphy Award for outstanding undergraduate teaching for meritorious and effective performance in the instruction of undergraduate students at Purdue University.
- 2004 Team Excellence Award in the Schools of Engineering at Purdue University for outstanding innovation and interdisciplinary teamwork in creating and developing the Global Engineering Alliance for Research and Education (GEARE)
- 2003-2005 B.F.S. Schaefer Outstanding Young Faculty Scholar Award, School of Mechanical Engineering, Purdue University
- 2003 ASHRAE Distinguished Service Award
- 2003 DAAD (German Academic Exchange Service) Guest Professorship at the University of Karlsruhe, Germany, from January 1 to July 31
- 2002-2003 Senior Resource Faculty for Teacher for Tomorrow Award Program at Purdue University
- 2002 Solberg Award for Best Teacher in Mechanical Engineering at Purdue University
- 1997 ASHRAE New Investigator Award
- 1998 DAAD (German Academic Exchange Service) Six-Month International Scholarship for studies at Texas A&M University

BOARD ACTIVITIES:

- DAAD Alumni Association: Board Member 2014, Vice President (2015 – 2018)
- ASHRAE Board of Directors: Director-At-Large (2010 – 2013)
- Karlsruhe House of Young Scientists, KHYS: Advisory Board Member (2009 – 2011)
- Friends of Purdue Convocations: Advisory Board Member (2007 – 2012), Advisory Board Vice President (2012 – 2013)
- Purdue University Press: Editorial Board Member (1999 – 2003)

PROFESSIONAL SOCIETY ACTIVITIES:

- ASHRAE Standards Committee: Consultant (17 – 18)
- ASHRAE Tech Council: Member-At-Large (13 – 16)
- ASHRAE Data Center Working Group: Chair (12 – 13)
- ASHRAE Conferences and Exposition Committee (CEC): Member (08 – 10)
- ASHRAE Professional Development Committee (PDC): Member (07 – 10)
- ASHRAE Technical Activities Committee (TAC): Member (01 – 06), Head Section 4 (01-03), Head Section 8 (03-04), TTS Subcomm. Chair (02-04), Vice Chair (04-05), Chair (05-06)
- ASHRAE Course Development Committee: Member (99 – 01)
- ASHRAE TC 1.3: Corresponding Member (98 – present)
- ASHRAE TC 3.1: Corresponding Member (08 – present)
- ASHRAE TC 7.6: Research Subcommittee Chairman (96 – 00)
- ASHRAE TC 7.6: Project Monitoring Subcommittee Member of 1121-RP (99 – 01)
- ASHRAE TC 7.6: Member (98 – 02), Corresponding Member (95 – 98 and 02 – 03)
- ASHRAE TC 8.1: Corresponding Member (08 – present)
- ASHRAE TC 8.3: Handbook Subcommittee Chairman (96 – 98)
- ASHRAE TC 8.3: Member (98 – 02), Corresponding Member (95 – 98 and 02 – present)
- ASHRAE TC 8.4: Corresponding Member (01 – present)
- ASHRAE TC 8.11: Member (03 – 05 and 06 – 10), Corspd. Member (05 – 06 and 10 – present)
- ASHRAE TC 10.7: Program Subcom. Chair (96 – 98), Secretary (96 – 98), Chair (99 – 01)
- ASHRAE TC 10.7: Member (96 – 01), Corresponding Member (95 – 96 and 01 – present)
- USNC/IIR (U.S. National Committee of the Int'l Institute of Refrig.): Member (95 – present)
- USNC/IIR: Secretary (99 – 03), 2nd Vice-Chair (03 – 07), Chair (08 – 11)
- USNC/IIR: Board of Directors (99 – present)
- IIR: Chair of Task Group “Increasing the Involvement of Young People in the IIR” (04-05)
- IIR: Member of the IIR Strategic Planning Committee (2004)
- IIR: Commission E1 "Air Conditioning": Member (95 – 07)
- IIR: Commission B2 "Refrigeration Equipment": Member (07 – 11), VP (11 – 15), President (15 – 19)
- IIR: Section B "Refrigeration and Thermodynamics": President (19 – present)

CONFERENCE AND SHORTCOURSE ACTIVITIES:

- General Conference Chair: 25th Int’l Compressor Engineering Conference at Purdue, 18th Int’l Refrigeration and Air Conditioning Conference at Purdue, and 6th Int’l High Performance Buildings Conference at Purdue, May 2021.

- Session Chair: Session "Screw Compressor 1," 11th Int'l Conf. on Compressors and their Systems, City University London, UK, September 9-11, 2019.
- Scientific Committee Member: 11th Int'l Conf. on Compressors and their Systems, City University London, UK, September 9-11, 2019.
- Scientific Committee Member: 25th IIR Int'l Congress of Refrigeration, Montreal, Quebec, Canada, August 24-30, 2019.
- Chairman of Academic Committee: 9th Int'l Conference on Compressor and Refrigeration (ICCR 2019), Xi'an Jiaotong University, China, July 10-12, 2019.
- ASHRAE Advisory and Scientific Committee Member: 12th REHVA World Congress, CLIMA 2019, Bucharest, Romania, May 26-29, 2019.
- Scientific Committee Member: 10thInt'l Conference on Screw Machines, Dortmund, Germany, Sept. 18-19, 2018.
- Session Chair: Session "Screw Compressor Systems," 10thInt'l Conference on Screw Machines, Dortmund, Germany, Sept. 18-19, 2018.
- Scientific Committee Member: 1st IIR Int'l Conf. on the Application of HFO Refrigerants, Birmingham, UK, Sept. 2-5, 2018.
- General Conference Chair: 24th Int'l Compressor Engineering Conference at Purdue, 17th Int'l Refrigeration and Air Conditioning Conference at Purdue, and 5th Int'l High Performance Buildings Conference at Purdue, July 9-12, 2018.
- Co-Organizer: Short Course on "Compressor 103 – Generalized Simulation Framework for Positive Displacement Compressors and Expanders," at Purdue University, July 8, 2018.
- Scientific Committee Member: 13th IIR Gustav Lorentzen Natural Working Fluids Conference, Valencia, Spain, June 21-24, 2018.
- Session Chair: Session "CO2 System Applications," 13th IIR Gustav Lorentzen Natural Working Fluids Conference, Valencia, Spain, June 21-24, 2018.
- Scientific Committee Member: Cold Climate HVAC 2018, the 9th Int'l Cold Climate Conf. on Sustainable New and Renovated Bldgs in Cold Climates, Kiruna, Sweden, March 12-15, 2018.
- Steering Committee Member: 20th Annual Colloquium on International Engineering Education: "Proven Methods and New Frontiers," Northern Arizona Univ., Flagstaff, AZ, Nov. 2-3, 2017.
- Scientific Committee Member: Int'l Conf. on Compressors and their Systems, City University London, UK, September, 2017.
- Steering Committee Member: 19th Annual Colloquium on International Engineering Education: "Preparing the Global Workforce," Newport, Rhode Island, November 3-4, 2016.
- Scientific Committee Member: 12th IIR Gustav Lorentzen Natural Working Fluids Conference, Heriot- Watt University, Edinburgh, UK, August, 21-24, 2016.
- General Conference Chair: 23rd Int'l Compressor Engineering Conference at Purdue, 16th Int'l Refrigeration and Air Conditioning Conference at Purdue, and 4th Int'l High Performance Buildings Conference at Purdue, July 11-14, 2016.
- Co-Organizer: Short Course on "Oil Management in Compressors and Their Systems," at Purdue University, July 10, 2016.
- ASHRAE Advisory and Scientific Committee Member: 12th REHVA World Congress, CLIMA 2016, Aalborg, Denmark, May 22-25, 2016.
- Steering Committee Member: 18th Annual Colloquium on International Engineering Education: "Building Strategic International Partnerships," hosted by IIE and the German Academic Exchange Service (DAAD) in New York City, New York, November 5-6, 2015.

- Scientific Committee Member: ASME ORC 2015 3rd International Seminar on ORC Power Systems, Brussels, Belgium, October 12-14, 2015.
- Session Chair: Session "Rotary Compressors," Int'l Conf. on Compressors and their Systems, City University London, UK, September 1-4, 2015.
- Co-Organizer, IEA HPP Annex 41 Workshop "Cold Climate Heat Pumps: Improving Low Ambient Temp. Performance of Air-Source Heat Pumps," Yokohama, Japan, August19, 2015.
- Co-Organizer 3rd Working Meeting, IEA HPP Annex 41 "Cold Climate Heat Pumps: Improving Low Ambient Temperature Performance of Air-Source Heat Pumps," Austria Institute of Technology (AIT), Vienna, Austria, May 7-8, 2015.
- Steering Committee Member: 17th Annual Colloquium on International Engineering Education, Providence, RI, November 7-10, 2014.
- General Conference Chair: 22nd Int'l Compressor Engineering Conference at Purdue, 15th Int'l Refrigeration and Air Conditioning Conference at Purdue, and 3rd Int'l High Performance Buildings Conference at Purdue, July 14-17, 2014.
- Co-Organizer, Short Course on "Experimental Techniques to Measure Compressor Performance and Reliability," at Purdue University, July 13, 2014.
- Co-Organizer 2nd Working Meeting, IEA HPP Annex 41 "Cold Climate Heat Pumps: Improving Low Ambient Temperature Performance of Air-Source Heat Pumps," Montréal, Quebéc, Canada, May 12, 2014.
- Scientific Committee Member: 1st International Conference on Energy and Indoor Environment for Hot Climates, Doha, Qatar, February 24-26, 2014.
- Steering Committee Member: 16th Annual Colloquium on International Engineering Education, Lexington, KY, November 6-9, 2013.
- Session Chair: Session 16 "Novel Compressors," Int'l Conf. on Compressors and their Systems, City University London, UK, September 9-10, 2013.
- Session Co-Chair: "Rotary, scroll and screw compressors I," 8th Int'l Conf. on Compressors and Coolants, Smolenice, Slowakia, September 2-4, 2013.
- International Scientific Committee Member: 8th Int'l Conf. on Compressors and Coolants, Smolenice, Slowakia, September 2-4, 2013.
- Co-Organizer 1st Working Meeting, IEA HPP Annex 41 "Cold Climate Heat Pumps: Improving Low Ambient Temperature Performance of Air-Source Heat Pumps," Ray W. Herrick Laboratories, Purdue University, July 1, 2013.
- Session Co-Chair: HVAC Systems Operation and Design, 11th CLIMA 2013 Congress, Prague Czech Republic, June 17, 2013.
- ASHRAE Advisory and Scientific Committee Member: 11th REHVA World Congress, CLIMA 2013, Prague, Czech Republic, June 16-19, 2013.
- Session Co-Chair: Oral Session F – Refrigeration Engineering 2, 5th Int'l Conf. on Cryogenics and Refrigeration (ICCR2013), Zhejiang University, Hangzhou, China, April 8, 2013.
- International Program Committee Member: 5th International Conference on Cryogenics and Refrigeration (ICCR2013), Zhejiang University, Hangzhou, China, April 6-9, 2013.
- Steering Committee Member: 15th Annual Colloquium on International Engineering Education, Newport, Rhode Island, November 1-3, 2012.
- Panel Moderator: "Why is there a difference in the dominant focus regarding refrigerants within Europe, North America and Asia?" ASHRAE/NIST Refrigerants Conference, NIST, Gaithersburg, MD, October 29-30, 2012.

- Steering Committee Member: ASHRAE/NIST Refrigerants Conference, NIST, Gaithersburg, MD, October 29-30, 2012.
- General Conference Chair: 21st Int'l Compressor Engineering Conference at Purdue, 14th Int'l Refrigeration and Air Conditioning Conference at Purdue, and 2nd Int'l High Performance Buildings Conference at Purdue, July 15-18, 2012.
- Co-Organizer, Short Course on "Advanced Compressor Modeling (Compressors 102)" at Purdue University, July 13-14, 2012.
- Steering Committee Member: 14th Annual Colloquium on International Engineering Education, "Educating Global Leaders," Provo, Utah, November 3-5, 2011.
- Steering Committee Member: 13th Annual Colloquium on International Engineering Education, Newport, Rhode Island, November 4-6, 2010.
- Member Scientific Committee: Joint UNEP-ASHRAE Conference on "Road to Climate Friendly Chillers: Moving Beyond CFCs and HCFCs," Cairo, Egypt, Sept. 30-Oct. 1, 2010.
- General Conference Chair: 20th Int'l Compressor Engineering Conference at Purdue, 13th Int'l Refrigeration and Air Conditioning Conference at Purdue and 1st Int'l High Performance Buildings Conference at Purdue, July 10-15, 2010.
- Co-Organizer, Short Course on "Introduction to Compressors (Compressors 101)" at Purdue University, July 10-11, 2010.
- Steering Committee Member: Joint ASHRAE/CIBSE Conference, Dubai, UAE, April 2010.
- Member International Advisory Committee: Engineering Congress on Alternative Energy Applications: Option or Necessity? Kuwait, November 3-5, 2009.
- Steering Committee Member: 12th Annual Colloquium on International Engineering Education, Iowa State University, Ames, IA, October 22-25, 2009.
- Roundtable Panelist: "In Times of Global Financial Crisis: Impacts on Cooperative Education & Industrial Partners," WACE (World Association of Cooperative Education) Conference, Vancouver, BC, June 23-27, 2009.
- Session Chair: "Defining Curriculum in Co-operative Education," WACE (World Association of Cooperative Education) Conference, Vancouver, BC, June 23-27, 2009.
- Session Chair: "Moments of Truth: An Expert Panel Faces the Toughest Issues for Co-op/Internship Professionals," WACE (World Association of Cooperative Education) Conference, Vancouver, BC, June 23-27, 2009.
- Steering Committee Member: 11th Annual Colloquium on International Engineering Education, Newport, Rhode Island, November 2-5, 2008.
- Session Chair: "General Knowledge 4," 8th IIR – Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark, September 10, 2008.
- Session Chair: "Heat Pumps 3," 8th IIR – Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark, September 9, 2008.
- Member Scientific Committee: 8th IIR – Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark, September 8-10, 2008.
- General Conference Chair: 19th Int'l Compressor Engineering Conference at Purdue and 12th Int'l Refrigeration and Air Conditioning Conference at Purdue, July 14-17, 2008.
- Chair of Organizing Committee, 10th Annual Colloquium on International Engineering Education, Purdue University, November 1-4, 2007.
- Session Chair, Panel Session 6: "Globalization Efforts of Engineering Programs at Int'l Institutions," 10th Annual Colloquium on International Engineering Education, Purdue University, November 3, 2007

- Session Co-Chair, Session B2-7 "Compressor I," 22st International Congress of Refrigeration, IIF/IIR, Beijing, China, August 25, 2007.
- Chair, 18th International Compressor Engineering Conference at Purdue, July 2006.
- Organizer, Short Course on "Analysis of Miniature-Scale Vapor Compression Refrigeration Systems for Electronics Cooling," 22nd Semi-Therm Symposium and Exposition, Dallas, TX, March 13, 2006.
- Session Chair, Session CR/TP-1 "Carbon Dioxide 1," IIR International Conferences on Commercial Refrigeration and Thermophysical Properties and Transfer Processes of Refrigerants, Vicenza, Italy, August 31, 2005
- Poster Session Co-Chair and Member of Organizing Committee, 8th IEA Heat Pump Conference, Las Vegas, NV, June 2005
- Chair, 10th Int'l Refrigeration and Air Conditioning Conference at Purdue, July 12-15, 2004
- Moderator of Panel Discussion on "Current Status and Future Trends of the Transcritical Carbon Dioxide Technology," 10th International Refrigeration and Air Conditioning Conference at Purdue, July 14, 2004
- Liaison to Organizing Committee for "Short Course on Simulation Tools for Vapor Compression System and Component Analysis," Purdue University, July 10-11, 2004
- Program Co-Chair, 21st International Congress of Refrigeration, IIF/IIR, Washington, DC, August 18-22, 2003
- Session Chair, Session B1-8 "A New Old Refrigerant: Carbon Dioxide – Heat Transfer," 21st International Congress of Refrigeration, IIF/IIR, Washington, DC, August 18-22, 2003
- Co-Organizer, Short Course on "Modeling and Design of Vapor Compression Systems" at Ingersoll-Rand, Davidson, NC, August 12-14, 2003
- Vice-Chair Scientific Committee, 5th IIR – Gustav Lorentzen Conference on Natural Working Fluids, Guangzhou, China, September 17-20, 2002
- Session Chair, Session 2 "Natural Working Fluids – CO_2 Experiments," 5th IIR – Gustav Lorentzen Conference on Natural Working Fluids, 2002
- Member of Technical/Scientific Committee, International Conference on New Technologies in Commercial Refrigeration, University of Illinois at Urbana-Champaign, July 22-23, 2002
- Chair, 9th Int'l Refrigeration and Air Conditioning Conference at Purdue, July 16-19, 2002
- Co-Organizer, Short Course on "Analysis and Design of Microchannel Heat Exchangers" at Purdue University, July 14-15, 2002
- Chair, Organizing Committee of the 4th IIR – Gustav Lorentzen Conference on Natural Working Fluids, Purdue University, July 25-28, 2000
- Co-Organizer, Short Course on "Fundamentals of the Transcritical Carbon Dioxide Cycle Technology" at Purdue University, July 24, 2000
- Session Chair, Session N-9 "Compressors II, Lubrication, and Expansion Devices," 4th IIR – Gustav Lorentzen Conference on Natural Working Fluids, 2000
- Panelist of Panel # 7 – "CO_2", IIAR 2000 Ammonia Refrigeration Conf. and Trade Show
- Co-Organizer, Short Course on "Modeling and Design of Vapor Compression Systems" at Purdue University, June 1-4, 1999
- Symposium Chair, Symposium CH-99-04 "Effects of Controlling Humidity on Energy Consumption of Supermarkets," 1999 ASHRAE Winter Meeting in Chicago
- Chair, 7th International Refrigeration Conference at Purdue, July 1998
- Session Chair, Session R-4 "Transcritical CO_2 Technology," 7th International Refrigeration Conference at Purdue, July 1998

- Session Chair, Session TS 5 "Gas Cycles," IIR – Gustav Lorentzen Conference on Natural Working Fluids '98
- Session Chair, Session 3 "Secondary Refrigerants," IIR Conference on Heat Transfer Issues in Natural Refrigerants at University of Maryland, 1997
- Co-Organizer, Short Course on "Modeling and Design of Vapor Compression Systems with an Emphasis on Refrigerant Mixtures" at Purdue University, July 21-23, 1997
- Forum Moderator, Forum 19 "Parasitic Losses in Supermarket Refrigeration Systems," 1997 ASHRAE Annual Meeting in Boston
- Program Chair, 6th International Refrigeration Conference at Purdue, July 1996
- Session Chair, Session R-11 "Refrigeration Systems for Supermarket Applications," 6th International Refrigeration Conference at Purdue, July 1996
- Session Chair, Session R-13 "R-502 and R-114 Replacements," 5th International Refrigeration Conference at Purdue, July 1994

EDITOR AND REVIEW ACTIVITIES:

- Regional Editor for the Americas, *International Journal of Refrigeration* (2008 – present)
- Co-Editor, Special Issue on Compressor Technology, *Int'l J. Refrig.*, Vol. 36, No. 7, 2013.
- Guest Editor, "Making the Odd Couple Work: Combining Engineering and Language Education," Festschrift in honor of John Grandin, *Online Journal for Global Engineering Education* (2011 – 2012)
- Editor, Special Issue on Ejector Technology, *Int'l J. Refrig.*, Vol. 34, No. 8, 2011.
- Guest Editor, Topical Issue, *HVAC&R Research*, Carbon Dioxide Update, Vol. 13, No. 3, 2007.
- Advisory Board Member of International Journal of Refrigeration (2000 – 2007)
- Journal Reviewer for: AIAA J. Thermophysics & Heat Transfer, ASHRAE Trans., ASME J. Energy Resources & Technology, ASME J. Fluids Engineering, Int'l J. HVAC&R Research, Int'l J. Refrigeration, Int'l J. Thermal Sciences, Applied Thermal Engineering, J. Process Mechanical Engineering, IEEE Transactions on Components and Packaging Technologies, Heat Transfer Engineering
- Proposal Reviewer for: ASHRAE, DOE, Idaho Board of Education, Southern Technology Council, U.S. Civilian Research & Development Foundation, USDA

PROFESSIONAL CONTRIBUTIONS AT PURDUE UNIVERSITY:

- International Programs: International Liaison Officer (2018 – present)
- Global Competency Task Force, College of Engineering: Co-Chair (2014 – 2016)
- Corporate Partnerships Service Model - Working Group: Member (2014)
- School of ME Impact and Reputation Committee: Member (2014)
- Faculty Search Committee Member: Thermal/Fluid Sciences (2013 – 2014)
- Coop and Internship Fee Review Committee: Member (2012 – 2013)
- Purdue University Global Council: Member (2011 – 2013)
- Faculty Search Committee Member: Thermodynamics (2011)
- Faculty Search Committee Member: Herrick Professor of Engineering (2010)
- Campus Information Technology Planning Committee: Member (2010)
- College of Engineering Strategic Plan Roadmap: Co-Captain of Team VIII A&B on Global Undergraduate Student Experiences (2009)

- Vice Provost of Global Affairs Search Committee: Member (2009)
- Office of Professional Practice Search Committee: Chair for three Staff Positions (2008, 2012)
- Professional Practice Ambassadors: Faculty Advisor (2008 – 2017)
- GEARE Ambassadors: Faculty Advisor (2006 – 2017)
- GEARE (Global Engineering Alliance for Research and Education) – Graduate Program: Founding member (2005)
- ME Honors Committee: Member (2006 – 2008)
- Co-operative Engineering Education Committee: ME Co-op Coordinator (2005 – 2008)
- ME Leadership Team: Member (2005 – 2008)
- ME Cabinet: Member (2005 – 2008)
- Global Engineering Programs Team: Member (2005 – 2017)
- College of Engineering Curriculum Reform Task Force: Member (2004 – 2007)
- ME Program Review Committee: Member (Spring 2004)
- GEARE (Global Engineering Alliance for Research and Education) – Undergraduate Program: Founding member (2002 – 2003)
- Teaching for Tomorrow Group Activities (academic year 2002 – 2003)
- Committee for Faculty Relations (CFR): Member (1998 – 2003)
- Purdue Student Branch of ASHRAE: Faculty Advisor (1995 – present)
- ME Curriculum Committee: Member (1995 – 2008)
- Thermodynamics Ph.D. Area Exam Chair or Co-Chair: Spring 1997, Fall 1997, Spring 1998, Fall 2002, Spring 2006, Fall 2008, Fall 2011, Spring 2012, Fall 2015, Spring 2016.
- Faculty Search Committee Member: Thermal Systems/Heat Transfer (Oct. 1999 to May 2001)
- Faculty Search Committee Member: Herrick Professor of Engineering (Dec. 1998 to May 2001)
- Faculty Search Committee Member: Fluid Mechanics (Nov. 1997 to May 1998)
- Faculty Search Committee Member: Thermal/Fluid Sciences (Sept. 1996 to April 1997)
- Herrick Labs Staff Search Committee: member of search committees for one mechanical and two electrical staff, one electronic shop coordinator, two conference secretaries, and one administrative assistant
- Fulbright Scholar Evaluation Committee: Member (1997 – 2017)
- Study Abroad Student Evaluation Committee: Member (1995 – 2010)

TEACHING EXPERIENCE:

- Overall Teaching Evaluation (all courses and all students, 1810 students): 4.52/5.0
- ME 200 – Thermodynamics I, 645 Students (6 semesters), Teaching Evaluation: 4.4/5.0
- ME 263L – Sophomore Design Lab, 16 Students (1 sem.), Teaching Evaluation: 4.9/5.0
- ME 297G – Cultural Engineering Orientation, 25 Students (2 sem.), Teach. Eval.: 4.4/5.0
- ME 300 – Thermodynamics II, 310 Students (9 semesters), Teaching Evaluation: 4.5/5.0
- ME 315 – Heat and Mass Transfer, 50 Students (1 semester), Teaching Evaluation: 4.5/5.0
- ME 418 – Analysis and Design of HVAC&R Systems and Equipment, 44 Students (3 sem.), Teaching Evaluation: 4.6/5.0
- ME 463 – Senior Design, 133 Students (9 semesters), Teaching Evaluation: 4.5/5.0
- ME 497E – Energy in a Global Context, 20 Students (1 sem.), Teaching Eval.: 5.0/5.0
- ME 500 – Advanced Thermodynamics, 362 Students (10 sem.), Teaching Eval.: 4.6/5.0
- ME 518 – Analysis of Thermal Systems, 201 Students (7 sem.), Teaching Eval.: 4.8/5.0
- ME 597 – Int'l Refrig. and Compressor Course, 28 Students (4 sem.), Teaching Eval.: 5.0/5.0

- EPICS – SGSC Team, 40 Students (4 semesters), Teaching Evaluation: 4.4/5.0
- Developed new junior level course: ME 297G – Cultural Engineering Orientation
- Developed new senior level course together with Srinivas Garimella from Georgia Tech: ME 497E – Energy in a Global Context
- Developed new graduate level course with J.E. Braun: ME 518 – Analysis of Thermal Systems
- Developed new graduate level course with Prof. U. Hesse from TU Dresden, Germany: ME 597 – Int'l Refrigeration and Compressor Course
- Short Course Lecturer on "Modeling and Design of Vapor Compression Systems with an Emphasis on Refrigerant Mixtures" (1 of 3 lecturers – taught 4 of 12 lectures), Evaluation for all lecturers by 20 participants: 4.7/5.0, July 1997.
- Short Course Lecturer on "Modeling and Design of Vapor Compression Systems" (1 of 3 lecturers – taught 3 of 18 lectures), Eval. for all lecturers by 42 participants: 4.7/5.0, June 1999.
- Short Course Lecturer on "Fundamentals of the Transcritical Carbon Dioxide Cycle Technology" (1 of 6 lecturers – taught 1 of 6 lectures), 72 participants, no evaluation, July 2000
- Short Course Lecturer on "Analysis and Design of Microchannel Heat Exchangers" (1 of 8 lecturers – taught 2 of 12 lectures), 50 participants, no evaluation, July 2002.
- Short Course Lecturer on "Analysis of Miniature-Scale Vapor Compression Refrigeration Systems for Electronics Cooling" (taught all lectures – 8 lectures), Evaluation by 18 Participants: 4.25/5.0, March 2006.
- Short Course Lecturer on "Latest Developments with Respect to the Transcritical CO_2 Cycle Tech." (1 of 5 Lecturers – taught 3 of 12 lectures), 52 participants, no evaluation, July 2006.
- Short Course Lecturer on "Introduction to Compressors (Compressors 101)" (1 of 9 Lecturers – taught 2 of 11 lectures), 52 participants, no evaluation, July 2010.
- Short Course Lecturer on "Advanced Compressor Modeling (Compressors 102)" (1 of 11 Lecturers – taught 2 of 14 lectures), 56 participants, no evaluation, July 2012.
- Short Course Lecturer on "Experimental Techniques to Measure Compressor Performance and Reliability," (1 of 8 Lecturers – taught 1 of 8 lectures), 53 participants, no evaluation, July 2014.
- Short Course Lecturer on "Oil Management in Compressors and Their Systems," (1 of 8 Lecturers – taught 1 of 8 lectures), 48 participants, no evaluation, July 10, 2016.
- Workshop Lecturer on "Energy Utilization and Refrigeration Technologies," (Only Lecturer – taught 5 lectures), 16 participants, no evaluation, Cuenca, Ecuador, June 22-23, 2017.

RESEARCH AND EDUCATION GRANTS
Total amount of grants received at Purdue University (including Co-PIs): $13,842,844

a.) Completed Research Grants ($10,107,762 total):

1. "Light Hydrocarbons as Replacements for Refrigerant R-22", sponsored by Copeland Corp. and Whirlpool Corp., 1/1/94 – 8/31/95, $100,000, Co-PIs: J.E. Braun, D.R. Tree.
2. International Travel Grant to attend 19th Intl. Congress of Refrig., The Hague, The Netherlands, sponsored by the Purdue Research Foundation, $1,116, 8/96.
3. "Development of a Supplemental Diesel-Fired Automobile Passenger Compartment Heater", sponsored by Ford Motor Co., 9/31/95 – 12/31/95, $7,950, Co-PI: S. Ramadhyani.
4. "A Feasibility Study of Air-Cycle Technology for Air Conditioning Application", sponsored by Whirlpool Corp., 12/1/95 – 1/31/96, $9,900, Co-PIs: J.E. Braun, P.B. Lawless, S. Ramadhyani, W. Soedel.

5. "Capacity and Power Demand of Unitary Air Conditioners and Heat Pumps Under Extreme Temperature and Humidity Conditions", sponsored by ASHRAE (859-RP), 9/1/95 – 11/30/96, $58,885, Co-PI: J.E. Braun.
6. "Study of Oil Circulation in Vapor Compression Systems", sponsored by United Technologies Carrier Corp., 6/1/95 – 8/31/97, $51,000, Co-PI: V.W. Goldschmidt.
7. "Modeling of Transcritical Thermodynamic Cycle Technology", sponsored by the Purdue Research Foundation, 9/1/95 – 8/31/97, $20,400.
8. "Mathematical Modeling of Scroll Compressors", sponsored by Matsushita Electric Corp. of America, 9/1/95 – 9/30/97, $131,999, Co-PIs: J.E. Braun, D.R. Tree.
9. "Testing of Secondary Loop Refrigeration Systems for Supermarket Applications", sponsored by Tyler Refrig. Corp. and 3M Specialty Chemicals Division, 12/1/96 – 11/30/97, $46,308.
10. "Performance Comparison of Transcritical CO_2-Technology with CFC-, HCFC-, and HFC-Technology", sponsored by the U.S. Army Communications-Electronics Command, 9/1/97 – 11/30/98, $25,000.
11. "Evaluation of Secondary Refrigerants for Supermarket Applications", sponsored by ASHRAE as part of the 1997 ASHRAE New Investigator Award, 5/1/97 – 4/30/99, $45,000.
12. "Testing of Carbon Dioxide Fin-Tube Gas Coolers and Evaporators", sponsored by Modine Manufacturing Company, 8/1/98 – 5/31/99, $20,126.
13. "Effects of Application on Reliability and Performance of Unitary Split Systems", sponsored by United Technologies Carrier Corp., 9/1/97 – 9/30/99, $116,767, Co-PI: V.W. Goldschmidt.
14. "Heat Transfer and Pressure Drop Characteristics during In-Tube Gas Cooling of Supercritical Carbon Dioxide", sponsored by ASHRAE (913-RP), 5/1/97 – 01/31/00, $81,292, Co-PI: S. Ramadhyani.
15. "Transcritical Carbon Dioxide Cycle Efficiency", sponsored by The Trane Company, 9/1/99 – 12/31/99, $13,200.
16. "Feasibility Study of Air Cycle Technology for Domestic Tumbler Dryer Applications", sponsored by Whirlpool Corporation, 10/1/99 – 1/31/00, $18,000, Co-PI: J.E. Braun.
17. "Phase II of Mathematical Modeling of Scroll Compressors", sponsored by Matsushita Compressor Corp. of America, 12/1/97 – 07/31/00, $136,000, Co-PI: J.E. Braun.
18. "Modeling of Direct Expansion and Secondary Loop Refrigeration Systems for Supermarket Applications", sponsored by the Purdue Research Foundation, 9/1/98 – 8/31/00, $24,351.
19. "Experimental Investigation of Carbon Dioxide-Based Environmental Control Units to Replace HCFC-22 Units", sponsored by the U.S. Army Communications-Electronics Command, 10/1/99 – 12/31/00, $75,000.
20. "Supermarket Refrigeration System Consortium", sponsored by Sporlan Valve Company and Tyler Refrigeration Corporation, 3/1/99 – 2/28/01, $75,000.
21. "Accurate Modeling of Refrigerant Inventory in Unitary Air Conditioners and Heat Pumps", sponsored by the Trane Company, 8/1/99 – 4/30/01, $82,744, Co-PI: J.E. Braun.
22. "Analysis of Refrigerant Flow Devices", sponsored by Aeroquip Corporation, 7/1/99-8/31/01, $144,977, Co-PIs: J.E. Braun, S.H. Frankel.
23. "Performance of Plate Fin and Spine Fin Heat Exchanger after Contamination and Cleaning", sponsored by the Trane Company, 9/1/00 – 12/31/01, $33,440, Co-PI: J.E. Braun.
24. "Theoretical Investigation of the Feasibility of the Transcritical Carbon Dioxide Cycle for various AC&R Applications", sponsored by Tecumseh Products Inc., 10/2/00 – 12/31/01, $30,500.

25. "Development of a Carbon Dioxide-Based Field Deployable Environmental Control Unit to Replace HCFC-22 or HFC-134a Units", sponsored by the U.S. Air Force Research Laboratory, 3/1/00 – 3/31/02, $158,371, Co-PI: P.B. Lawless.
26. "Evaluation of the Performance Potential of CO_2 as a Refrigerant in Air-To-Air Air Conditioners and Heat Pumps: System Modeling and Analysis", sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 610-10030), 5/1/00 – 5/31/02, $84,384.
27. "Model the Performance Characteristics of Environmental Control Units (ECUs) based on the Transcritical CO_2 Cycle to demonstrate its Feasibility over a wide Range of Air Conditioning and Heat Pumping Operating Conditions", sponsored by WhiteMoss, Inc. through a Phase I U.S. Army SBIR Grant, 2/1/02 – 7/31/02, $34,843.
28. "Phase Separator Optimization", sponsored by the Trane Company, 9/1/00 – 12/31/02, $79,000, Co-PI: J.E. Braun.
29. "Microchannel Heat Exchanger Defrost Performance and Reliability", sponsored by ASHRAE (1195-RP), 2/1/01 – 1/31/03, $90,123.
30. "Measurement of Performance of Carbon Dioxide Compressors", sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 611-10070), 06/01/01 – 12/31/02, $99,075.
31. "Testing of a Carbon Dioxide Compressor for Automotive Heat Pump Applications," sponsored by Ford Motor Company, 05/18/01 – 05/31/03, $29,400.
32. "The Role of Filtration in Maintaining Clean Heat Exchange Coils", sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 610-40050), 10/1/01 – 4/30/04, $159,908, Co-PI: J.E. Braun.
33. "Critical Literature Review of Lubricant Influence on Refrigerant Heat Transfer and Pressure Drop," sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 611-20080), 5/1/02 – 5/31/03, $61,839.
34. "Capacity Control of Compressors", sponsored by Tecumseh Products Inc., 8/1/02 – 12/31/05, $33,000.
35. "Modeling and Testing of an Automotive Scroll Compressor", sponsored by Nanjing Aotecar Refrigerating Company, Ltd., 10/01/02 – 9/30/03, $79,193, Co-PI: J.E. Braun.
36. "Performance Evaluation of Duct Insulation Materials," sponsored by Reflectix, Inc., 01/01/03 - 10/31/03, $38,270, Co-PI: J.E. Braun.
37. "Miniature-Scale Vapor Compression Systems for Electronics Cooling," sponsored by Cooling Technologies Research Center (CTRC), 01/01/03 - 12/31/05, $134,628, Co-PI: S. Garimella.
38. "Analysis of Diaphragm Compressors for Electronic Cooling Applications," sponsored through the B.F.S. Schaefer Young Faculty Scholar Award, 11/01/03 – 04/30/05, $60,000.
39. "Electro-Pump for Residential Heating and Cooling Applications, Phase I: Refrigerant Selection and Initial Design," sponsored by Electro Industries, Inc., 01/01/04 - 07/31/04, $21,179.
40. "Electro-Pump for Residential Heating and Cooling Applications, Phase II: Construction and Simulation of Bread Board Heat Pump System," sponsored by Electro Industries, Inc., 08/01/04 – 12/31/05, $89,863.
41. "Testing of a Prototype Hermetic Carbon Dioxide Compressor", sponsored by Tecumseh Products Inc., 10/1/04 – 12/31/04, $5,000.
42. "Testing of a Prototype Carbon Dioxide Compressor", sponsored by Danfoss A/S, 3/1/04 – 4/30/04, $4,200.

43. “Modeling and Testing of a Hermetic Rotary Compressor, Phase I: Model Setup and External Compressor Measurements,” sponsored by LG Electronics Co., 01/03/03 - 02/29/04, $75,000, Co-PI: J.E. Braun.
44. “Modeling and Testing of a Hermetic Rotary Compressor, Phase II: Internal Compressor Measurements, Model Validation and Parametric Studies,” 03/01/04 - 09/30/04, $25,000, Co-PI: J.E. Braun.
45. “Development of a Miniature-Scale Refrigeration System for Electronics Cooling Phase I: Proof-Of-Concept,” sponsored by Intel Corporation, 09/20/04 – 06/31/05, $139,684, Co-PI: S. Garimella.
46. “Testing of a Prototype Hermetic Carbon Dioxide Compressor”, sponsored by Tecumseh Products Inc., 03/01/05 – 04/30/05, $6,000.
47. “Reliability Testing of Prototype Carbon Dioxide Compressors”, sponsored by Tecumseh Products Inc., 04/01/05 – 11/30/05, $39,533.
48. “Improvement and Validation of Unitary Air Conditioner and Heat Pump Simulation Models for R-22 and HFC Alternatives at Off-Design Conditions”, sponsored by ASHRAE (1173-RP), 9/1/02 – 1/31/06, $137,156, Co-PI: J.E. Braun.
49. “Experimental Investigation of a Carbon Dioxide-Based Reversible Heat Pump System,” sponsored by WhiteMoss, Inc. through a Phase II U.S. Army SBIR Grant, 1/21/04 – 1/20/06, $160,000.
50. “Analysis of Miniature-Scale Diaphragm Compressors for Electronic Cooling Applications,” sponsored by Purdue Research Foundation: XR Grant, 05/01/04 – 04/30/06, $29,694.
51. “R-410A Enthalpy Measurements in the Liquid Sub-Cooled Region,” sponsored by Copeland Corp., 11/01/05 – 07/31/06, $41,433, Co-PI: J.E. Braun.
52. “Effects of Dissolved Refrigerant on Oil Viscosity, Phase 1: Experimental Measurements of Dilution and Viscosity Inside the Compressor Crankcase,” sponsored by Copeland Corp., 05/01/05 – 07/31/06, $19,000.
53. “Modeling and Testing of a Twin Rotary Compressor,” sponsored by LG Electronics Co., 09/01/05 – 12/31/06, $84,906, Co-PI: J.E. Braun.
54. “Alternative Cooling Technologies”, sponsored by Tecumseh Products Inc., 8/1/02 – 12/31/06, $226,411.
55. “Miniature-Scale Diaphragm Compressors,” sponsored by Cooling Technologies Research Center (CTRC), 08/01/04 - 12/31/07, $140,000, Co-PI: S. Garimella.
56. “Refrigerant Flow Boiling Heat Transfer Correlations in Mini-Channel Cold Plate Evaporators for Electronics Cooling,” sponsored by Cooling Technologies Research Center (CTRC), 01/01/06 - 12/31/07, $80,000, Co-PI: S. Garimella.
57. “Recovery of Throttling Losses by a Two-Phase Ejector in a Vapor Compression Cycle,” sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 616-10110), 10/01/06 – 03/31/08, $61,158.
58. “Optimizing Refrigerant Distribution in Evaporators,” sponsored by the Air Conditioning and Refrigeration Technology Institute (ARTI Project 616-06040), 05/01/07 – 02/29/08, $40,797, Co-PI: J.E. Braun.
59. “Testing of an Automotive A/C System,” sponsored by Visteon – Autopal, 05/01/07 - 04/30/08, $26,400.
60. “Increasing the Energy Efficiency of Vapor Compression Systems by using “Smart” and Cost-effective Compressor,” sponsored by California Energy Commission - Energy Innovations Small Grant (EISG) Program, 01/01/07 – 6/30/07, $94,999, Co-PI: S. Pekarek.

61. "Off-Design Performance of Residential Heat Pumps," sponsored by Ecotope, Inc., 09/01/06 – 08/31/08, $80,230, Co-PI: J.E. Braun.
62. "Technical Review and Thermal Modeling of a Hermetic CO_2 Scroll Compressor," sponsored by Hitachi Electrical Appliances Co. Ltd., 10/01/06 - 08/31/08, $64,894.
63. "Acoustical Enhancement of Heat Transfer," sponsored by Cooling Technologies Research Center (CTRC), 01/01/08 - 5/31/09, $40,000, Co-PI: S. Bolton.
64. "Analysis of a 0.5 HP Scroll Compressor for Oxygen Compression," sponsored by Sci-Tech Research and Service Co., 03/01/08-05/31/09, $40,000.
65. "Miniature-Scale Linear Compressor for Electronics Cooling," sponsored by Cooling Technologies Research Center (CTRC), 01/01/08 - 12/31/09, $90,000, Co-PI: S. Garimella.
66. "Performance of Microchannel and Plate Fin Heat Exchangers after Air-Side Fouling and Cleaning," sponsored by Guentner AG Co. KG, 03/01/08 - 12/31/09, $34,657.
67. "Alternative Cooling Technologies", sponsored by Herrick Foundation, 11/01/07 – 12/31/09, $144,000.
68. "Conduction Cooled Electronic/Electrical Modules in Liquid Cooled Cabinets," sponsored by The Boeing Company, 01/01/09-12/31/09, $70,571.
69. "Energy and Performance of Secondary Coolant Low-Temperature Refrigeration Systems," sponsored by ASHRAE, Inc. (1484-RP), 04/01/08-01/31/10, $71,259.
70. "Development of a System Design Methodology for Robust Thermal Control Systems to Support Operationally Responsive Space," sponsored by Space Vehicles Directorate of the U.S. Air Force Research Laboratory, 05/01/06 – 09/30/10, $205,961, Co-PI: J.E. Braun.
71. "Testing of a Prototype Hermetic Carbon Dioxide Compressor", sponsored by EcoThermics, 05/1/09 – 12/31/10, $19,000, Co-PI: W.T. Horton.
72. "Analysis of Heat Rejection Technologies and Waste Heat Recovery Options," sponsored by Hoosier Energy, 01/01/10-12/31/10, $169,336, Co-PI: S. Garimella.
73. "Conduction Cooled Electronic/Electrical Modules in Liquid Cooled Cabinets, Phase II: Experimental Analysis," sponsored by The Boeing Company, 02/23/10-02/28/11, $91,394.
74. "Performance Evaluation of Non-metallic Scroll Compressors," sponsored by Air Squared Inc., 09/01/10 - 12/31/10, $9,252.
75. "2007 Purdue University Faculty Scholar Award," sponsored by Purdue University, 09/01/06 – 08/31/11, $50,000.
76. "Compressor Research," sponsored by Torad Engineering LLC, 03/01/11 - 6/30/11, $5,000.
77. "Compressor Research," sponsored by Torad Engineering LLC, 08/15/11 - 12/31/11, $13,886.
78. "Optimizing Refrigerant Distribution in Evaporators," sponsored by the California Energy Commission, Building Energy Research Grant (BERG), 10/22/09-04/15/12, $249,729, Co-PI: J.E. Braun.
79. "Organic Rankine Cycle with Solution Circuit for Electronic Waste Heat Recovery," sponsored by Cooling Technologies Research Center (CTRC), 06/01/10 - 05/31/12, $80,000, Co-PI: S. Garimella.
80. "Annual Performance Comparison between Single Speed, Variable Speed, and Mini-Split Air Conditioners," sponsored by Trane Residential Systems, 01/01/11-12/31/12, $140,000, Co-PIs: J.E. Braun, W.T. Horton.
81. "Performance Comparison of Liquid-Loop Coolants for Electronics Cooling," sponsored by Cooling Technologies Research Center (CTRC), 01/01/12-12/31/12, $40,000, Co-PI: S. Garimella.

82. “Organic Rankine Cycle with Solution Circuit for Waste Heat Recovery,” sponsored by The Herrick Foundation, 01/01/10-12/31/12, $149,600, Co-PIs: W.T. Horton, J.E. Braun.
83. “Air Source Cold Climate Heat Pump,” sponsored by the U.S. Department of Defense ESTCP, 02/18/2011-08/31/2013, $462,499, Co-PI: W. Hutzel.
84. “Development of a High Performance Cold Climate Heat Pump,” sponsored by U.S. Department of Energy, 07/01/10 - 09/30/13, $1,331,435, Co-PIs: W.T. Horton, J.E. Braun.
85. “Thermal Integration of Household Appliances and Solar Hot Water, Ph. 1,” sponsored by Whirlpool Corp., 08/01/13 - 12/31/13, $9,500.
86. “Cold Climate Heat Pump Commercialization - Phase I,” sponsored by Unico, Inc., 06/01/13-02/28/14, $25,000, Co-PI: W. Hutzel.
87. “Testing of Innovative CO_2 Compressors,” sponsored by Holekamp Foundation, 02/01/13-12/31/13, $33,000.
88. “Modeling of a Novel Rotating Spool Expander,” sponsored by Torad Engineering, LLC, 08/15/13-05/15/14, $26,000.
89. “Transcritical CO2 Refrigeration System using Oil-less, Integrated Expander/Compressor Unit,” sponsored by S-RAM Dynamics via U.S. Army SBIR Phase I Grant, 07/01/14 - 11/30/14, $20,000.
90. “Performance of Finned Heat Exchangers and Heat Sinks after Air-Side Fouling and Cleaning,” sponsored by Cooling Technologies Research Center (CTRC), 01/01/13-12/31/14, $80,000, Co-PI: S.V. Garimella.
91. “High COP Heat Pumps for Commercial Energy Applications,” sponsored by Cooling Technologies Research Center (CTRC), 01/01/14-12/31/14, $40,000, Co-PI: K. Yazawa.
92. “Innovative Cooling Equipment for Military Environmental Control Units (ECU),” sponsored by Adams Communication & Engr Tech, 01/01/14 – 12/31/15, $200,000.
93. “Thermal Integration of Household Appliances and Solar Hot Water, Ph. 2,” sponsored by Whirlpool Corp., 01/01/14 – 12/31/15, $100,000.
94. “New ORC Test Stand for Scroll Expander Performance Testing,” sponsored by Cummins Business Services, 09/01/13 – 05/31/15, $15,000.
95. “Regenerative Air Cycle Heat Pump for Commercial and Industrial Applications,” sponsored by S-RAM Dynamics, 01/01/14 – 05/31/15, $99,021.
96. “Modeling of a Novel Rotating Spool Expander,” sponsored by Torad Engineering, LLC, 08/15/14 – 07/31/15, $9,000.
97. “Oil Return Measurement of 2 Ton Refrigeration Unit Using Different Refrigerant/Oil Mixtures,” sponsored by BMP USA Inc., 01/01/15 – 04/30/15, $16,190. Co-PI: O. Kurtulus.
98. “ReNEWW House Modifications towards Net-Zero Water,” sponsored by Whirlpool Corp., 01/01/15 – 12/31/15, $75,000.
99. “Heat Exchanger Performance of Heat Pump Clothes Dryer,” sponsored by Whirlpool Corp., 01/01/15 – 12/31/15, $5,000.
100. “Characterization and Performance Testing of Natural Gas Compressors for Residential and Commercial Applications,” sponsored by BlackPak Inc. via ARPA-E SBIR Phase II Grant, 06/01/15 – 11/30/16, $199,725.
101. “Performance Testing of a "Level 1" Unitary Split-System Heat Pump,” sponsored by Electric Power Research Institute (EPRI), 12/04/15 – 12/31/16, $51,152.
102. “Updraft Tower Dry Cooling and Waste Heat Utilization for Power Plants,” sponsored by Duke Energy Indiana, Inc., 12/04/15 - 11/30/16, $60,000, Co-PI: J. Weibel.

103. "Development of a simulation model predicting efficiency gains for residential appliances utilizing thermal integration," sponsored by Center for High Performance Buildings at Purdue, 01/01/16 - 12/31/16, $50,000.
104. "Optimizing Seasonal Cooling and Heating Performance of Unitary Heat Pumps using Variable Speed Compressors and Fans," sponsored by Center for High Performance Buildings at Purdue, 01/01/16 - 12/31/16, $60,000.
105. "Modeling of Roots Expanders and Organic Rankine Cycles in support of Eaton's "Affordable Rankine Cycle" Project," sponsored by Eaton Corp. via DOE Grant, 02/15/16 - 03/31/17, $130,000, Co-PI: J.E. Braun.
106. "Testing of an Automotive AC Compressor using a Tescor Compressor Calorimeter," sponsored by Den Black, 08/01/16 - 04/01/17, $9,000.
107. "Technical Review Assistance to the MOXIE Experiment on the Mars 2020 Mission," sponsored by Jet Propulsion Laboratory, 08/10/15 – 09/24/17, $45,008.
108. "Modeling and Analysis of the Meso-Scale Ericsson Power Generation System (MEPS)," sponsored by Inventherm via NASA SBIR Phase I Grant, 07/01/17 - 12/31/17, $25,000, Co-PI: J.E. Braun.
109. "Vapor Compression Refrigeration System for Cold Storage on Spacecrafts," sponsored by Air Squared Inc. via NASA SBIR Phase I Grant, 06/09/17 - 12/31/17, $20,000.
110. "Measurements of Discharge Gas Pulsations in Scroll Compressors," sponsored by Hi-Bar Blowers, Inc., 10/01/17-04/30/18, $10,000.
111. "Multi-Temperature Refrigerated Container System (MTRCS) Analysis, Part 1: Test Stand Design and System Simulations," sponsored by S-RAM Dynamics Inc. via U.S. Army SBIR Phase II Grant, 04/01/16 - 08/31/18, $160,000.
112. "Advanced Manufacturing of a Linear Compressor for Isothermal Compression with an Integrated Heat Pipe," sponsored by Oak Ridge National Laboratory, 05/15/17 - 09/30/18, $82,206, Co-PI: J.A. Weibel.
113. "Next Generation Unitary AC & HP Equipment," sponsored by United Technologies Carrier Corp., 01/01/16 - 12/31/18, $180,000, Co-PIs: J.E. Braun & W.T. Horton.
114. "Development of general purpose simulation tools for positive displacement compressors (PDsim)," sponsored by Center for High Performance Buildings (CHPB) at Purdue, 01/01/16 - 12/31/18, $160,000.
115. "Development of a Comprehensive Simulation Model to Predict the Performance of Bristol's Hermetic Reciprocating Compressors," sponsored by Bristol Compressors, Inc., 05/01/16 - 12/31/18, $43,000, Co-PIs: J.E. Braun & W.T. Horton.
116. "Modeling and Testing of an Automotive Scroll Compressor using Carbon Dioxide as the Refrigerant," sponsored by Nanjing Aotecar Refrigerating Co. LTD, 10/01/16 - 12/31/18, $106,000, Co-PI: J.E. Braun.
117. "Development of general purpose simulation tools for unitary equipment (ACHPsim)," sponsored by Center for High Performance Buildings (CHPB) at Purdue, 01/01/17 - 12/31/18, $110,000.
118. "Development of Residential Thermally Integrated Appliances (TIRA)," sponsored by Whirlpool Corp., 01/01/17 - 12/31/18, $100,000.
119. "Feasibility of Employing Polymers in Reciprocating Compressors," Sponsored by Solvay Specialty Polymers USA, LLC, 03/01/18 - 10/31/18, $62,855.

b.) Current Research Grants ($1,356,003 total):

120. "Performance Testing for Unitary Split-System Heat Pump with Viper Expander," sponsored by Regal Beloit, 06/01/14 - 12/31/19, $125,000.
121. "Organic Rankine Cycle as a Bottoming Cycle for Waste Heat Recovery from Internal Combustion Engines," sponsored by Air Squared Inc. via ARPA-E SBIR Phase I, II, IIs Grants, 05/01/16 - 06/30/19, $213,750.
122. "Evaluating Adhesive Bonding of Aluminum and Copper in HVAC&R Applications," sponsored by Oak Ridge National Lab, 01/25/17 - 03/05/20, $150,000, Co-PI: J.A. Weibel.
123. "Oil Return and Retention in Unitary Split System Gas Lines with HFC and HFO Refrigerants," sponsored by ASHRAE (1721-RP), 04/01/17 - 03/31/19, $120,714, Co-PI: J.E. Braun.
124. "Development of a mechanistic model for twin-screw compressors with detailed sub-models for estimating the bearing loads," sponsored by Johnson Controls Inc., 11/01/17 - 08/31/19, $93,254.
125. "The DC-Power House: Converting a Residential Building from AC to DC Power to Improve Energy Efficiency," sponsored by Center for High Performance Buildings (CHPB) at Purdue, 01/01/18 - 12/31/19, $120,000.
126. "Vapor Compression Refrigeration System for Cold Storage on Spacecrafts," sponsored by Air Squared Inc. via NASA SBIR Phase II Grant, 05/01/18 - 04/30/20, $200,000.
127. "Screw Chiller/Compressor Long-Term Performance Degradation Study (Phase I – Experimental Study)," sponsored by Danfoss Turbocor Compressors, Inc., 06/01/18 - 05/31/19, $165,444, Co-PI: J.E. Braun.
128. "Integrated Electric Vehicle Battery Thermal Management," Cooling Technologies Research Center (CTRC), 01/01/19 - 12/31/19, $40,000, Co-PI, J.A. Weibel.
129. "Theoretical Evaluation of Compressor Technologies for a Low-Pressure Refrigerant," Honeywell, 05/15/18 - 05/31/19, $64,473.
130. "Feasibility Study on 40 kW Linear Air Compressor Technology," Ingersoll-Rand, 02/01/19 - 8/31/19, $63,368, Co-PI: D. Ziviani.

c.) Educational Grants ($2,379,079 total):

1. "NSF Trainee Assistantship for W. Travis Horton", sponsored by NSF, 9/1/96 – 8/31/98, $57,305, PI: R. Viskanta.
2. "ASHRAE Grant-In-Aid for Mr. Luis A. Rivera-Velez", sponsored by ASHRAE, 7/1/97 – 12/31/97, $3,750.
3. "Testing of R-407C and R-410A in Unitary Air Conditioners and Heat Pumps Under Extreme Operating Conditions", sponsored by ASHRAE's Undergraduate Senior Project Grant Program, 9/1/97 - 12/31/97, $5,000.
4. "Operating Expenses of the Purdue Student Branch of ASHRAE", sponsored by UTC Special Grants Program, 9/1/97 – 4/30/98, $1,415, Co-PI: W. Hutzel.
5. Robert and Barbara Popejoy Scholarship and Incentive Award for Melissa A. Myers, 9/1/97 – 12/31/97, $2,000.
6. Willis H. Carrier/ASHRAE Fellowship for Srinivas Pitla, 9/1/97 – 8/31/98, $20,000.
7. "ASHRAE Grant-In-Aid for Mr. Douglas M. Robinson", sponsored by ASHRAE, 7/1/98 - 6/30/99, $9,000.
8. "Testing of Frost Accumulation on Supermarket Display Case Air Coils", sponsored by ASHRAE's Undergraduate Senior Project Grant Program, 9/1/98 - 12/31/98, $4,800.

9. "Operating Expenses of the Purdue Student Branch of ASHRAE", sponsored by UTC Special Grants Program, 9/1/98 – 4/30/99, $1,515, Co-PI: W. Hutzel.
10. Willis H. Carrier/ASHRAE Fellowship for Daqing Li, 9/1/98 – 8/31/99, $20,000.
11. Robert and Barbara Popejoy Scholarship and Incentive Award for Brian S. Borke, 9/1/98 – 12/31/98, $2,000.
12. "ASHRAE Grant-In-Aid for Mr. W. Travis Horton", sponsored by ASHRAE, 7/1/99 - 6/30/00, $7,500.
13. "Supplementing the Operating Expenses of the Purdue Student Branch of ASHRAE", sponsored by Allied Signal Special Grants Program, 9/1/99 – 4/30/00, $500, Co-PI: W. Hutzel.
14. "Supplementing the Operating Expenses of the Purdue Student Branch of ASHRAE", sponsored by UTC Special Grants Program, 9/1/99 – 4/30/00, $500, Co-PI: W. Hutzel.
15. Robert and Barbara Popejoy Scholarship and Incentive Award for Benjamin J. Huttsell, 9/1/99 – 12/31/99, $2,000.
16. "ASHRAE Grant-In-Aid for Mr. Todd M. Harms", sponsored by ASHRAE, 7/1/00 - 6/30/01, $7,500.
17. "Promoting Careers in HVAC&R", sponsored by Honeywell International in support of the Purdue Student Branch of ASHRAE, 9/1/00 – 4/30/01, $825, Co-PI: W. Hutzel.
18. "Promoting Careers in HVAC&R", sponsored by UTC Special Grants Program in support of the Purdue Student Branch of ASHRAE, 9/1/00 – 4/30/01, $825, Co-PI: W. Hutzel.
19. Robert and Barbara Popejoy Scholarship and Incentive Award for Kurt Engelbrecht, 9/1/00 – 12/31/00, $2,000.
20. "Innovation Realization Lab: A New Educational Model for Tom Ortiz," sponsored by NSF, 8/1/00 – 7/31/02, $48,744, PI: M.C. Thursby.
21. "ASHRAE Grant-In-Aid for Mr. Tomas M. Ortiz", sponsored by ASHRAE, 7/1/01 - 6/30/02, $7,500.
22. "Promoting Careers in HVAC&R", sponsored by UTC Special Grants Program in support of the Purdue Student Branch of ASHRAE, 9/1/01 – 4/30/02, $1,000, Co-PI: W. Hutzel.
23. Willis H. Carrier/ASHRAE Fellowship for Bo Shen, 9/1/01 – 8/31/02, $20,500.
24. "Purdue – Karlsruhe Global Education Program", sponsored by Model International Department Grants, Purdue University, 1/1/02 – 12/31/02, $24,815, Co-PIs: E.D. Hirleman, T. Siegmund, J. Matthews.
25. Willis H. Carrier/ASHRAE Fellowship for Jason Hugenroth 9/1/02 – 8/31/03, $20,500.
26. Robert and Barbara Popejoy Scholarship and Incentive Award for Alexander Hamner, 9/1/02 – 12/31/02, $2,000.
27. Robert and Barbara Popejoy Scholarship and Incentive Award for Dustin Ballard, 9/1/02 – 12/31/02, $2,000.
28. GEARE/ME Senior Design Project "Four Person Trailer Carousel", Spring Semester 2004, $5000.
29. "ASHRAE Grant-In-Aid for Mr. Jason Hugenroth", sponsored by ASHRAE, 7/1/04 - 6/30/05, $7,500.
30. "ASHRAE Grant-In-Aid for Mr. Suwat Trutassanawin", sponsored by ASHRAE, 7/1/04 - 6/30/05, $7,500.
31. Robert and Barbara Popejoy Scholarship and Incentive Award for Jason Billings, 9/1/04 – 12/31/04, $1,500.
32. Willis H. Carrier/ASHRAE Fellowship for Derek Hengeveld, 9/1/05 – 8/31/06, $20,500.

33. “Heat Transfer Measurements in Mini-Channel Cold Plate Evaporators”, sponsored by ASHRAE's Undergraduate Senior Project Grant Program, 09/01/06 - 04/30/07, $4,998.
34. “ASHRAE Grant-In-Aid for Mr. Stefan S. Bertsch”, sponsored by ASHRAE, 07/01/06 - 06/30/07, $10,000.
35. “ASHRAE Grant-In-Aid for Ms. Margaret Mathison”, sponsored by ASHRAE, 07/01/06 - 06/30/07, $10,000.
36. “ASHRAE Grant-In-Aid for Mr. Ian Bell”, sponsored by ASHRAE, 07/01/07 - 06/30/08, $10,000.
37. “Global-HUB: A Virtual Community for Global Engineering and Education,” sponsored by National Science Foundation (NSF 0742753-CBET), 10/01/07 - 09/30/08, $140,000, Co-PIs: E.D. Hirleman, Jan Helge Bøhn, Virginia Tech, Deba Dutta, University of Michigan, Juan Lucena, Colorado School of Mines.
38. “ASHRAE Grant-In-Aid for Mr. Craig Bradshaw”, sponsored by ASHRAE, 07/01/09 - 06/30/10, $10,000.
39. “IREE: Developing Globally Competent Engineering Researchers,” sponsored by NSF, 01/15/2010 - 03/31/2011, $959,736, Co-PIs: E. Daniel Hirleman, Brent Jesiek.
40. “ASHRAE Graduate Student Grant-In-Aid for Mr. Christian K. Bach,” sponsored by ASHRAE, 07/01/10 – 06/30/11, $10,000.
41. “Leadership Case Studies: Developing Leadership Capacity in Undergraduate Engineering Students,” sponsored by the College of Engineering “Purdue’s Engineer of 2020 Seed Grant Program”, 06/01/11-05/31/12, $40,000, Co-PIs: Monica Cox, Yating Chang, Beverly Davenport-Sypher.
42. “ASHRAE Graduate Student Grant-In-Aid for Mr. Abhinav Krishna,” sponsored by ASHRAE, 07/01/11 – 06/30/12, $10,000.
43. “ASHRAE Graduate Student Grant-In-Aid for Mr. Stephen Caskey,” sponsored by ASHRAE, 07/01/12 – 06/30/13, $10,000.
44. “Access to Cooperative Education Programs and the Academic and Employment Returns by Race, Gender, and Discipline,” sponsored by National Science Foundation (NSF 1329283-EEC), 8/15/13 - 07/15/16, $304,757, Co-PIs: Matthew Ohland, Joyce Main.
45. “Performance of Finned Heat Exchangers and Heat Sinks after Air-side fouling and Cleaning,” sponsored by ASHRAE's Undergrad Senior Project Grant Program, 8/1/13 - 5/31/14, $5,000.
46. “ASME Scholarship for KCORC Research of Mr. Davide Ziviane,” sponsored by ASME, 04/10/14 – 09/30/14, $13,600.
47. “Internships for Indiana (IFI) Cost Share for OPP – Thrust 3,” sponsored by Lilly Endowment Inc., 11/01/13 – 05/31/19, $523,493.71. Main PI: S.V. Garimella
48. “ASHRAE Graduate Student Grant-In-Aid for Mr. Riley B. Barta,” sponsored by ASHRAE, 08/01/18 – 05/31/19, $10,000, Life Member Club Distinction (one of the top two awardees).
49. “ASHRAE Graduate Student Grant-In-Aid for Mr. Vatsal Shah,” sponsored by ASHRAE, 08/01/18 – 05/31/19, $10,000.
50. “ASHRAE Graduate Student Grant-In-Aid for Mr. Jonathan P. Ore,” sponsored by ASHRAE, 08/01/19 – 05/31/20, $10,000, Life Member Club Distinction (one of the top two awardees).

PAST STUDENT AND SCHOLAR SUPERVISIONS:

a.) Ph.D. Thesis Students Supervised

1. Douglas M. Robinson, Ph.D., “Modeling of Carbon Dioxide Based Air-to-Air Air Conditioners,” graduated May 2000.
2. Yu Chen, Ph.D., “Mathematical Modeling of Scroll Compressors using Refrigerant R-410A,” graduated December 2000 (Co-Advisor: J.E. Braun).
3. W. Travis Horton, Ph.D., “Modeling of Secondary Loop Refrigeration Systems in Supermarket Applications,” graduated May 2002.
4. Joo Seok Baek, Ph.D., “Development of a Carbon Dioxide Based Field Deployable Environmental Control Unit to Replace HCFC-22 or HFC-134a Units,” graduated August 2002 (Co-Advisor: P.B. Lawless).
5. Thomas M. Ortiz, Ph.D., “Development of a new Model for Investigating of the Performance of Carbon Dioxide as a Refrigerant for Residential Air Conditioners,” graduate August 2002.
6. Todd M. Harms, Ph.D., “Charge Inventory System Modeling and Validation for Unitary Air Conditioners,” graduated August 2002 (Co-Advisor: J.E. Braun).
7. Satyam Bendapudi, Ph.D., “Development and Evaluation of Modeling Approaches for Transients in Centrifugal Chillers,” graduated August 2004 (Co-Advisor: J.E. Braun).
8. Jun-Hyeung (Jay) Kim, Ph.D., “Capacity Control of Positive Displacement Compressors,” graduated December 2005.
9. Bo Shen, Ph.D., “Improvement and Validation of Unitary Air Conditioner and Heat Pump Simulation Models at Off-Design Conditions,” graduated May 2006 (Co-Advisor: J.E. Braun).
10. Daqing Li, Ph.D., “Investigation of an Ejector-Expansion Device in a Transcritical Carbon Dioxide Cycle for Military ECU Applications,” graduated May 2006.
11. Jason J. Hugenroth, Ph.D., “Liquid Flooded Ericsson Cycle Cooler,” graduated May 2006. (Co-Advisors: J.E. Braun and G.B. King).
12. Suwat Trutassanawin, Ph.D., “Evaluation of Miniature-Scale Vapor Compression Systems for Electronics Cooling,” graduated August 2006. (Co- Advisor: S.V. Garimella).
13. Anthony F. Black, Ph.D., “Evaluation of Technology Options for Future Coal Based Power Plants,” graduated December 2006. (Co-Advisor: T. Sparrow, Ind. Eng.).
14. Miguel Jovane, Ph.D., “Modeling and Analysis of a Novel Rotary Compressors,” graduated August 2007 (Co-Advisor: J.E. Braun).
15. Abhijit Sathe, Ph.D., “Miniature-Scale Diaphragm Compressors for Electronics Cooling,” graduated August 2008 (Co-Advisor: S.V. Garimella).
16. Stefan S. Bertsch, Ph.D., “Refrigerant Flow Boiling in Mini-Channels,” graduated August 2008 (Co-Advisor: S.V. Garimella).
17. Derek Hengeveld, Ph.D., “Development of a System Design Methodology for Robust Thermal Control Subsystems to Support Responsive Space,” graduated December 2010 (Co-Advisor: J.E. Braun).
18. Ian H. Bell, Ph.D., “Theoretical and Experimental Analysis of Liquid Flooded Compression in Scroll Compressors,” graduated May 2011 (Co- Advisors: J.E. Braun and G.B. King).
19. Margaret M. Mathison, Ph.D., “Modeling and Evaluation of Advanced Compression Techniques for Vapor Compression Equipment,” graduated August 2011 (Co-Advisor: J.E. Braun).
20. Craig R. Bradshaw, Ph.D., “A Miniature-Scale Linear Compressor for Electronics Cooling,” graduated May 2012 (Co-Advisor: S.V. Garimella).
21. Bryce Shaffer, Ph.D., “Performance Analysis of Non-Metallic Dry Running Scroll Compressors,” graduated May 2012.
22. Christian K. Bach, Ph.D., “Refrigerant Side Compensation for Air-Side Maldistribution of Evaporators and its Effect on Performance,” graduated August 2014 (Co-Advisor: J.E. Braun).

23. Brandon J. Woodland, Ph.D., "Methods of Increasing Net Work Output of Organic Rankine Cycles for Low-Grade Waste Heat Recovery with a Detailed Analysis Using a Zeotropic Working Fluid Mixture and Scroll Expander," graduated Aug. 2015 (Co-Advisor: J.E. Braun).
24. Abhinav Krishna, Ph.D., "Analysis of a Rotating Spool Expander for Organic Rankine Cycle Applications," graduated December 2015.
25. Bin Yang, Ph.D., "Modeling of an Oil-Free Carbon Dioxide Compressor Using Sanderson-Rocker Arm Motion (S-RAM) Mechanism," graduated May 2017.
26. Ammar M. Bahman, Ph.D., "Analysis of Packaged Air Conditioning Systems for High Temperature Climates," graduated May 2018.
27. Harshad Inamdar, Ph.D., "Performance of Finned Heat Exchangers after Air-Side Fouling and Cleaning," graduated in August 2018 (Co-Advisor: S.V. Garimella).
28. Nelson A. James, Ph.D., "Investigation of Chemical Looping for High Efficiency Heat Pumping," graduated in May 2019 (Co-Advisor: J.E. Braun).
29. Stephen L. Caskey, Ph.D., "Analysis of Thermally Connected Residential Appliances" graduated in May 2019.
30. Xinye Zhang, Ph.D., "An Experimental and Numerical Study on Dynamic Characteristics of Linear Compressors," graduated in May 2020.

b.) M.S. Thesis Students Supervised

1. Jonathan D. Douglas, M.S.M.E., "A Cost-Based Method for Comparing Alternative Refrigerants Applied to R-22 Systems," graduated December 1995 (Co-Advisors: J.E. Braun, D.R. Tree).
2. Jason T. LeRoy, M.S.M.E., "Performance Evaluation of Vapor Compression Systems under Extreme Operating Conditions," graduated August 1997 (Co-Advisor: J.E. Braun).
3. Nils P. Halm, M.S.M.E., "Mathematical Modeling of Scroll Compressors using the Refrigerant R-22," graduated December 1997 (Co-Advisors: J.E. Braun, D.R. Tree).
4. Eric B. Skowron, M.S.M.E., "Investigation of Refrigerant/Oil Flow through Suction Accumulators," graduated December 1998 (Co-Advisor: V.W. Goldschmidt).
5. Srinivas S. Pitla, M.S.M.E., "Heat Transfer during In-Tube Cooling of Supercritical CO_2," graduated August 1999 (Co-Advisor: S. Ramadhyani).
6. Bradley F. Marcus, M.S.M.E., "Effects of Application on Reliability and Performance of Unitary Split Systems," graduated December 1999 (Co-Advisor: V.W. Goldschmidt).
7. Matthew C. Comstock, M.S.M.E., "Development of Analysis Tools for the Evaluation of Fault Detection and Diagnostics in Chillers," graduated Dec. 1999 (Co-Advisor: J.E. Braun).
8. Daqing Li, M.S.M.E., "Performance Evaluation of Carbon Dioxide-Based Environmental Control Units," graduated May 2001.
9. Zeqiang Sun, M.S.M.E., "Carbon Dioxide Flow Boiling in Horizontal Tubes," grad. May 2001.
10. Gang Li, M.S.M.E., "Analysis of Refrigerant Flow Control Devices," graduated December 2001 (Co-Advisors: J.E. Braun and S.H. Frankel).
11. Jun-Hyeung Kim, M.S.M.E., "Performance Comparison of a Unitary Split System using Micro-channel and Fin-tube Outdoor Coils," graduated August 2002.
12. Beat Hubacher, M.S.M.E., "Experimental and Theoretical Performance Analysis of Carbon Dioxide Compressors," graduated in December 2003.
13. Yang Li, M.S.M.E., "The Role of Filtration in Maintaining Clean Heat Exchanger Coils," graduated August 2004 (Co-Advisor: J.E. Braun).

14. Rudy Chervil, M.S.M.E., "Energy Efficiency of Poultry Farm Buildings," graduated August 2005 (Co-Advisor: A. Heber and J.E. Braun).
15. Stefan S. Bertsch, M.S.M.E., "Electro Heat Pump for Residential Heating and Cooling Applications," graduated December 2005.
16. Robert A. Leffler, M.S.M.E., "Analysis of Heat Rejection Options for Power Plants," graduated May 2011 (Co-Advisor: S.V. Garimella).
17. Abhinav Krishna, M.S.M.E., "Organic Rankine Cycle with Solution Circuit for Low-Grade Heat Recovery," graduated August 2012 (Co-Advisor: S.V. Garimella).
18. Sugirdhalakshmi Ramaraj, M.S.M.E., "Vapor Compression Cycle Enhancements for Cold Climate Heat Pumps," grad. December 2012 (Co-Advisors: J.E. Braun and W.T. Horton).
19. Yuanpei Song, M.S.M.E., "Modeling and Experimental Validation of a Multi-Port Vapor Injected Scroll Compressor," grad. May 2013 (Co-Advisors.: J.E. Braun and W.T. Horton).
20. Stephen L. Caskey, M.S.M.E., "Cold Climate Field Test Analysis of an Air-Source Heat Pump with Two-Stage Compression and Economizing," graduated December 2013.
21. Nelson A. James, M.S.M.E., "High Temperature Flooded Expansion for Solar Thermal Power Generation," graduated August 2014 (Co-Advisors.: J.E. Braun and W.T. Horton).
22. Ularee Upathumchard, M.S.M.E., "Waste Heat Recovery Options in Natural Gas-Fired Combined Power Plant," graduated December 2014.
23. Supriya Dharkar, M.S.M.E., "CO_2 Heat Pumps for Commercial Building Applications with Simultaneous Heating and Cooling Demand," graduated August 2015.
24. Kunal Bansal, M.S.M.E., "Modeling and Evaluation of Scroll Expanders for a Liquid-Flooded Ericsson Power Cycle," graduated August 2015 (Co-Advisor: J.E. Braun).
25. Nicholas J. Czapla, M.S.M.E., "Performance Testing of a Unitary Split-System Heat Pump Utilizing an Energy Recovery Expansion Device," graduated August 2016.
26. Felipe A. Accorsi, M.S.M.E., "Experimental Characterization of Scroll Expander for Small-Scale Power Generation in an Organic Rankine Cycle," graduated August 2016.
27. Haotian Liu, M.S.M.E., "Performance Analysis of an Updraft Tower System for Dry Cooling in Large-Scale Power Plants," graduated May 2017.
28. Alejandro C. Lavernia, M.S.M.E., "Micro-Scale Waste Heat Recovery from Stationary Internal Combustion Engines by Sub-Critical Organic Rankine Cycle Utilizing Scroll Machinery," graduated May 2018.
29. Cai S. Rohleder, M.S.M.E., "Experimental Analysis of Positive Displacement Compressors for Domestic Refrigerator Freezer and Air Conditioning Application," graduated May 2019.

c.) Non-Theses M.S. Students Supervised

1. Jeffrey A. Duren, M.S.M.E., "Performance of Air Coil Test Facility," graduated Dec. 1996.
2. Andrew E. Causey, M.S.M.E., "Supervisory Control of Scroll Compressor Load Stand," graduated May 1998.
3. Agustin R. Hernandez, M.S.M.E., "Vapor Compression Cycle Application in Electronic Chip Cooling," graduated December 2001.
4. Miguel Jovane, M.S.M.E., "Phase Separator Analysis," graduated August 2002 (Co-major professor: J.E. Braun).
5. Vicente Adum, M.S.M.E., "Analysis of Heat Recovery Heat Exchangers," graduated December 2002.
6. Suwat Trutassanawin, M.S.M.E., "Performance Evaluation of a Transcritical Carbon Dioxide Automotive Air Conditioning System," graduated December 2002.

7. David Bouffard, M.M.E.T., "Air-Source Heat Pump for Nordic Climates," graduated May 2005.
8. Nathanael L. Grauvogel, M.S.M.E., off-campus student – no project, graduated December 2006.
9. Christopher A. Parker, M.S.M.E., "Building Passive Cooling through Night Ventilation," graduated May 2007.
10. Anthony E. Wright, M.S.M.E., "Ignition delay time measurements for exhaust gas/fuel/air mixtures in a rapid compression machine," graduate December 2007.
11. Eric S. Lynch, M.S.M.E., "Fluidized-bed Combustion Analysis," graduated December 2009.
12. Jeffrey D. Munk, M.S.M.E., Off-Campus Professional Education Student, graduated December 2011.
13. Brett Leonard, M.S.M.E., "Clothes Dryer Energy Efficiency Improvements," graduated December 2011.
14. Matthew Vargo, M.S.M.E., "Analysis and Design of Psychrometric Chambers for the new Herrick Labs," graduated May 2011 (Co-major professor: J.E. Braun).
15. Thomas W. Faussett, M.S.M.E., "Performance Testing of a Large Room Cooling System," graduated May 2012.
16. Nicholas Kincaid, M.S.M.E., "Humidity Ratio Detection as a Means of Dryer Cycle Termination," graduated December 2012.
17. Harshad Inamdar, M.S.M.E., "Performance Comparison of Two-Phase Fluids in Heat Pipes for Electronics Cooling," graduated December 2012.
18. Gaurav Kulkarni, M.S.M.E., "MRV of CO_2 Emissions," graduated May 2013 (Co-major prof.: R. Lucht).
19. Brandon Hengesbach, M.S.M.E., "Infra-Red Broil System Development," graduated May 2013 (Co-major prof.: B. Han).
20. Keeley Kabala, M.S.M.E., "Thermal Modeling of Electric Motors," graduated May 2013.
21. Amanda Ruhno, M.S.M.E., "Thermal Modeling of Household Convection Ovens," graduated May 2013.
22. Thomas D. Spicer, M.S.M.E., "Enhanced Moisture Extraction," graduated May 2013.
23. Brent A. Rowland, M.S.M.E., "Sustainability in Industry," graduated December 2013 (Co-major prof.: F. Zhao).
24. Anchalika K. Pathak, M.S.M.E., "Expansion Turbine Analysis for Organic Rankine Cycles," graduated December 2013.
25. Nicholas L. Stuart, M.S.M.E., "Heat Exchanger Performance Optimization," grad. May 2014.
26. Matthew Quock, M.S.M.E., "Heat Exchanger Performance Optimization," grad. May 2014.
27. Chaitanya Wani, M.S.M.E., "Performance Analysis of Organic Rankine Cycle Expanders," graduated May 2015.
28. Nichloas Righetti, M.S.M.E., "Waste Heat Recovery from Residential Ovens," grad. May 2015.
29. Jason Schneemann, M.S.M.E., "Net-Zero Water Use in Residential Homes," grad. May 2015.
30. Joshua Whitman, M.S.M.E., "Countertop Cooking and Chilling Device for Residential Application," graduated May 2015.
31. Xinye Zhang, M.S.M.E., "Performance Improvements of Military Environmental Control Units," graduated May 2015.
32. Xiaoshen Wang, M.S.M.E., "Performance Analysis of Military Environmental Control Units," graduated December 2015.
33. Elizabeth Bourgeois, M.S.M.E., "Pedestal Rainwater Collection System," graduated May 2016.

34. Allison Graban, M.S.M.E., “Investigation of Hybrid Heat Pump Dryer Condensation Efficiency and its Effects,” graduated May 2016.
35. Todd M. Graham, M.S.M.E., “Development of a Refrigerator Waste Heat Collection System,” graduated May 2016.
36. Domenique R. Lumpkin, M.S.M.E., “Analysis of Air Cycle Heat Pumps,” graduated May 2016.
37. Erica Roberts, M.S.M.E., “Design and Development of an In-Home Hydroponics Appliance,” graduated in December 2016.
38. Suyash D. Bhangale, M.S.M.E., “Design of Expansion Devices,” graduated May 2017.
39. Aaron Linden, M.S.M.E., “In-Home Hydroponics Appliance,” graduated May 2017.
40. Sarah K. Small, M.S.M.E., “Thermally Integrated Thermal Appliances (TIRA) Heat Capture Design,” graduated May 2017.
41. Andria R, Nyenhuis, M.S.M.E., “Rainwater Storage Appliance,” graduated May 2017.
42. Shawn C. Gorman, M.S.M.E., “Net-Zero Energy Home Design,” graduated Dec. 2017.
43. Robert R. Baer, M.S.M.E., “Water Reuse Applications,” graduated May 2018.
44. Ryan Ebstein, M.S.M.E., “ReNEWW House Big Data Project,” graduated May 2018.
45. Sarah M. Galea, M.S.M.E., “Thermally Integrated Res. Appliances,” graduated May 2018.
46. Kylie McCollum, M.S.M.E., “Thermally Integrated Res. Appliances,” graduated May 2018.
47. Grant Ridley, M.S.M.E., “Power Supply Conversion of Residential Appliances,” graduated May 2018.
48. Skylar R. Soto, M.S.M.E., “Net-Zero Waste in Households,” graduated May 2018.
49. Annie M. Wilson, M.S.M.E., “Residential Indoor Air Quality Study,” graduated May 2018.
50. Francisco Montalvo, M.S.M.E., “Global Energy Sustainability,” graduated in December 2018.
51. Xueyang Xu, M.S.M.E, “Performance Evaluation of Scroll Expanders in Organic Rankine Cycles,” graduated May 2019.
52. Alexander R. Auer, M.S.M.E, “Power Supply Conversion of Residential Appliances,” graduated May 2019.
53. Kevin Y. Zhang, M.S.M.E, “Appliance Scheduling Optimization for Demand Side Management,” graduated May 2019.
54. Felix Goemann, M.S.M.E., “Zero Gravity Refrigerator Analysis,” graduated May 2020.
55. Daniel Gossen, M.S.M.E., “Bio-Inspired Robotics,” graduated May 2020.
56. Brooke M. Gundersen, M.S.M.E., “Laundry Water Reuse and Filtration,” graduated May 2020.

d.) Undergraduate Project Students Supervised

1. Matthew T. Tyler, B.S.M.E., Senior Honor's Thesis: “Construction of an Air Coil Test Facility,” graduated December 1995.
2. Matthew C. Comstock, B.S.M.E., Senior Honor's Thesis: “Evaluation of R-290/R-227ea Mixtures as a Non-Flammable and Cost Effective Replacement for R-22,” graduated May 1997 (Co-major professor: J.E. Braun).
3. Edwin B. Sharp, B.S.M.E., ME 497 Project (6 credits): “Testing of Secondary Loop Refrigeration Systems at Medium Temperature Level,” Spring 1997.
4. Jeffrey P. Henkle, B.S.M.E., ME 497 Project (3 credits): “Two-phase Heat Transfer Coefficients of Refrigerant Mixtures,” Spring 1997.
5. Melissa A. Myers, B.S.M.E., ME 497 Project (3 credits): “Testing of R-407C in Unitary Air Conditioners and Heat Pumps Under Extreme Operating Conditions,” Fall 1997.
6. Alexander C.-Y. Wei, B.S.M.E., ME 497 Project (3 credits): “Testing of R-410A in Unitary Air Conditioners and Heat Pumps Under Extreme Operating Conditions,” Spring 1998.

7. Brian S. Borke, B.S.M.E., ME 497 Project (3 credits): "Design of High Efficiency Ground Source Heat Pump System," Fall 1998.
8. Jeff T. Zwick, B.S.M.E., ME 497 Project (3 credits): "Testing of Secondary Loop Refrigeration Systems at Low Temperature Level," Fall 1998.
9. Benjamin J. Huttsell, B.S.M.E., ME 497 Project (3 credits): "Testing of Direct Expansion Supermarket Refrigeration Systems at Low Temperature Level," Fall 1999.
10. Brian W. Pfeiffer, B.S.M.E., ME 497 Project (3 credits): "Performance Evaluation of Alternative Working Fluids for Rankine Power Cycles," Spring 2000.
11. Kurt Engelbrecht, B.S.M.E., ME 497 Project (3 credits): "Testing of Spin Fin and Plate Fin Condensers," Fall 2000.
12. Jee Cha, B.S.M.E., ME 497 Project (3 credits): "Testing of Secondary Loop Supermarket Refrigeration Systems at Low Temperature Level," Fall 2000.
13. Ryan Rogers, B.S.M.E., ME 497 Project (3 credits): "Testing of Microchannel Heat Exchangers in Unitary Equipment," Spring 2002.
14. Dustin Ballard, B.S.M.E., ME 497 Project (3 credits): "Soda-Can Cooler Efficiency Testing," Fall 2002.
15. Alexander Hamner, B.S.M.E., ME 497 Project (3 credits): "Soda-Can Cooler Efficiency Testing," Fall 2002.
16. Beth A. Ritzert, B.S.M.E., ME 497 Project (3 credits): "Performance Evaluation of Fin-Tube Heat Exchangers in Residential Heat Pump Systems," Fall 2002.
17. Adam S. Sultan, B.S.M.E., ME 497 Project (3 credits): "Performance Evaluation of Fin-Tube Heat Exchangers in Residential Heat Pump Systems," Fall 2002.
18. Andrew Burgess, ME 497 Project (3 credits): "Carbon Dioxide-Based Environmental Control Unit," Summer 2004.
19. Jason Billings, ME 497 Project (3 credits): "Testing of an Ericsson Cycle Cooler," Fall 2004.
20. Anita Klimek, SURF Student: "Reliability Testing of Carbon Dioxide Prototype Compressors, Part I," Summer 2005.
21. Anita Klimek, ME 497 Project (3 credits): "Reliability Testing of Carbon Dioxide Prototype Compressors, Part II," Fall 2005.
22. Anita Klimek, ME 497 Project (3 credits): "Reliability Testing of Carbon Dioxide Prototype Compressors, Part III," Spring 2006.
23. Joseph R. Poland, ME 497 Project (3 credits): "Testing of Prototype Carbon Dioxide ECU for Military Applications," Summer 2006.
24. Himani A. Shah, SURF – GEARE Student: "Construction of Minichannel Heat Transfer Test Setup," Summer 2006.
25. Francisco Montalvo, SURF – GEARE Student: "Global Opportunities Fair Setup," Sum. 2006.
26. Joseph R. Poland, ME 497 Project (3 credits): "Testing of Prototype Carbon Dioxide ECU for Military Applications," Fall 2006.
27. Adriana Zegarra, SURF – GEARE Student: "Trends in World Energy Consumption between 1980 and 2004," Summer 2007.
28. Robert Johns, SURF Student: "Investigation of Liquid Flooded Ericsson Cooler and Optimization of the Compressor and Expander for Liquid Flooded Operation," Summer 2007.
29. Eric Bowler ME 497 Project (3 credits): "Compressor Performance Testing using Compressor Calorimeter," Spring 2008.
30. Devin M. Rohan, SURF Student: "Performance of Microchannel and Plate Fin Heat Exchangers after Air-Side Fouling and Cleaning," Summer 2008.

31. Robert A. Leffler, SURF Student: “Performance of Microchannel and Plate Fin Heat Exchangers after Air-Side Fouling and Cleaning,” Summer 2008.
32. Vincent A. Lingle-Munos, SURF Student: “Possibilities of Carbon Dioxide Absorption during Fossil Fuel Combustion,” Summer 2008.
33. Dale J. Szul Jr., ME 497 Project (3 credits): “Compressor Performance Testing using Compressor Calorimeter,” Summer 2008.
34. Devin M. Rohan, ME 497 Project (3 credits): “Performance of Microchannel and Plate Fin Heat Exchangers after Air-Side Fouling and Cleaning,” Fall 2008.
35. Matthew Vargo, ME 497 Project (6 credits): “Performance of Microchannel and Plate Fin Heat Exchangers after Air-Side Fouling and Cleaning” and “Compressor Performance Testing using Compressor Calorimeter,” Fall 2008.
36. Stephen Caskey, ME 497 Project (3 credits): “Radiant Heat Panel and Envelope Construction Analysis Project,” Summer 2009.
37. Nathan Taylor, ME 497 Project (3 credits): “Acoustic Heat Transfer Enhancement,” Sum. 2009.
38. Huan (Helen) Lian, ME 497 Project (3 credits): “Liquid-flooded compressor performance testing,” Fall 2009.
39. Nicholas J. Czapla, ME 497 Project (3 credits): “Testing of Organic Rankine Cycle with Solution Circuit,” Summer 2011.
40. Prateek Tayal, ME 497 Project (2 credits): “Analyzing Refrigerant Mal-Distribution in Evaporators,” Summer 2011.
41. Nicholas J. Czapla, CTRC Fellowship Student, “Organic Rankine Cycle with Solution Circuit,” Fall 2011.
42. Nadim Chakroun, ME 497 Project (3 credits): “Organic Rankine Cycle with Liquid Flooded Expansion,” Fall 2011.
43. Prateek Tayal, ME 497 Project (2 credits): “Analyzing Refrigerant Mal-Distribution in Evaporators (continued from summer 2011),” Fall 2011.
44. Nadim Chakroun, ME 497 Project (3 credits): “Analysis of an Organic Rankine Cycle with Flooded Expansion (continued from fall 2011),” Spring 2012.
45. Prateek Tayal, ME 497 Project (2 credits): “Heating and Cooling Systems Testing (continued from fall 2011),” Spring 2012.
46. Jizhou Xie, ME 497 Project (3 credits): “Transcritical Carbon Dioxide Cycle Modeling-Gas Cooler,” Fall 2012.
47. Manojkumar Lokanathan, ME 497 Project (3 credits): “Modelling & Calculation of a Compressor in a Transcritical CO_2 Refrigeration System,” Fall 2012.
48. Yucheng Chen, ME 497 Project (3 credits): “Transcritical Carbon Dioxide Cycle Modeling-Evaporator,” Fall 2012.
49. Curtis R. McClarin, ME 497 Project (3 credits): “Heat Exchanger Performance Optimization I,” Fall 2013.
50. Curtis R. McClarin, ME 497 Project (3 credits): “Heat Exchanger Performance Optimization II,” Spring 2014.
51. David Revoir, ME 497 Project (3 credits): “Evaluation of Liquid-Flooded Compression with Regeneration in Small Packaged Heat Pumps,” Fall 2014.
52. Branden Elkins, ME 497 Project (3 credits): “Testing of a Liquid-Flooded Scroll Expander,” Fall 2014.
53. Jeffrey Alperovich, ME 497 Project (3 credits): “Performance Analysis of Organic Rankine Cycle Expanders,” Spring 2015.

54. Haotian Liu, ME 497 Project (3 credits): "Tescor Compressor Calorimeter Commissioning," Spring 2015.
55. Alec Smith, ME 497 Project (3 credits): "Tescor Compressor Calorimeter Commissioning," Spring 2015.
56. Jeffrey Alperovich, ME 497 Project (3 credits): "Performance Analysis of Organic Rankine Cycle Expanders," Fall 2015.
57. Riley Barta, ME 497 Project (3 credits): "High Temperature Air Conditioning using Vapor Injected Compression," Fall 2015.
58. Alejandro Lavernia, ME 497 Project (3 credits): "Thermally Integrated Refrigerator-Dishwasher Pair," Fall 2015.
59. Nicholas Salts, ME 497 Project (3 credits): "Heat Pump System Performance with Expansion Work Output Device," Fall 2015.
60. Riley Barta, ME 497 Project (3 credits): "Multi-Temperature Refrigerated Container System (MTRCS) Analysis," Spring 2016.
61. Alejandro Lavernia, ME 497 Project (3 credits): "Organic Rankine Cycle as a Bottoming Cycle for Waste Heat Recovery from Internal Combustion Engines," Spring 2016.
62. Carsten Rabenhorst, ME 497 Project (3 credits): "Testing of Natural Gas Compressors," Spring 2016.
63. Forrest Son, ME 497 Project (3 credits): "Performance Testing of a "Level 1" Unitary Split-System Heat Pump," Fall 2016.
64. Vinayak Gupta, ME 497 Project (3 credits): "Thermal System Analysis," Fall 2016.
65. Xueyang Xu, ME 497 Project (3 credits): "Compressor Performance Analysis," Fall 2016.
66. Cai S. Rohleder, ME 497 Project (3 credits): "Heat Pump Performance Analysis," Fall 2016.
67. Vinayak Gupta, ME 497 Project (3 credits): "Thermal System Analysis II," Spring 2017.
68. Xueyang Xu, ME 497 Project (3 credits): "Compressor Performance Analysis II," Spring 2017.
69. Quan Jun (Jimmy) Sun, ME SURF Student: "Thermal sciences as applied to HVAC&R systems and equipment," Summer 2017.
70. Changkuan (Steven) Liang ME 497 Project (3 credits): "Thermal Science research," Summer 2017.
71. Abdul Raheem A. Shaik, ME SURF Student: "Waste heat recovery from a vented electric clothes dryer utilizing a finned-tube heat exchanger," Summer 2018.
72. Francisco X. Plaza, ME 498 Project (3 credits): "Screw Compressor Performance Study," Spring 2019.
73. Meghavin C. Bhatasana, ME 498 Project (3 credits): "Oil Retention Study," Spring 2019.
74. Jiawei Yang, ME 498 Project (3 credits): "CO2 Refrigeration Cycle Analysis," Spring 2019.
75. Meghavin Bhatasana, ME SURF Student: "Oil Return and Retention in Unitary Split System Gas Lines with HFC and HFO Refrigerants," Summer 2019.
76. Joshua Mason, ME SURF Student: "Conversion of power from AC to DC circuits in homes," Summer 2019.
77. Paige E. Beck, ME 297 Project (3 credits): "Transcritical Carbon Dioxide Cycle for Experimental Comparisons of Expansion Work Recovery Technologies," Spring 2020.

e.) Post-Docs Supervised

1. Douglas M. Robinson, Ph.D. from Purdue University: May 1, 2000 to June 30, 2000.
2. Lorenzo Cremaschi, Ph.D. from University of Maryland: September 1, 2004 to July 31, 2006.
3. Josef Riha, Ph.D. from Technical Univ. of Dresden, Germany: May 1, 2007 to Jan. 10, 2008.

4. Liu Fang, Ph.D. from University of Hong Kong: October 1, 2006 to September 30, 2008.
5. Jun-Hyeung (Jay) Kim, Ph.D. from Purdue University: February 6, 2007 to December 31, 2008.
6. Ian H. Bell, Ph.D. from Purdue University: May 15 to June 30, 2011 (Co-Advisor: J.E. Braun).
7. Berhane H. Gebreslassie, Ph.D. from Universitat Rovira I Virgili, Tarragona, Spain: August 1, 2010 to October 31, 2011 (Co-Advisor: S.V. Garimella).
8. Craig R. Bradshaw, Ph.D. from Purdue University: June 1, 2012 to July 31, 2012.
9. Christian K. Bach, Ph.D. from Purdue University: June 1, 2014 to July 31, 2014.
10. Davide Ziviane, Ph.D. from Ghent University, Belgium: October 1, 2017 to September 30, 2019 (Co-Advisor: J.E. Braun).

f.) Visiting Research Associates or Visiting Scholars Supervised

1. Jianyi Zhang, Senior Lecturer, Xiamen Fisheries College, China: Oct. 1, 1998 to Sept. 30, 1999.
2. Marc Paredes, Post-B.S. Student, NTB, Buchs, Switzerland: Feb. 1, 1999 to July 31, 1999.
3. Adrian Zingerli, Post-B.S. Student, NTB, Buchs, Switzerland: Feb. 1, 1999 to July 31, 1999.
4. Silke Goebel, Exchange Student, Georg-Simon-Ohm Fachhochschule Nuernberg, Germany: March 1, 1999 to July 31, 1999.
5. Pradeep Bansal, Associate Professor, University of Auckland, New Zealand, August 1, 1999 to December 31, 1999.
6. Georg Rieder, Exchange Student, Georg-Simon-Ohm Fachhochschule Nuernberg, Germany: March 1, 2000 to August 15, 2000.
7. Bock Choon Pak, Associate Professor, Chonbuk National University, Korea, July 20, 2000 to December 31, 2001.
8. Norbert Schmidt, Exchange Student, Technical University of Dresden, Germany, June 1, 2001 to November 30, 2001.
9. Beat Hubacher, Post-B.S. Student, NTB, Buchs, Switzerland: Sept. 1, 2001 to April 15, 2002.
10. Zhichao Wang, Lecturer, Tsinghua University, China: Oct. 1, 2001 to June 30, 2002, and August 1, 2002 to November 7, 2003.
11. Dominik Arnold, Exchange Student, Georg-Simon-Ohm Fachhochschule Nuernberg, Germany: March 15, 2002 to August 15, 2002.
12. Christian Hoffinger, Exchange Student, Georg-Simon-Ohm Fachhochschule Nuernberg, Germany: March 15, 2002 to August 15, 2002.
13. Frank Yi, Project Engineer, Nanjing Aotecar Refrigerating Company, China: October 1, 2002 to September 30, 2003.
14. Stefan S. Bertsch, Post-B.S. Student, NTB, Buchs, Switzerland: August 25, 2003 to December 31, 2003.
15. Marco Corradi, Ph.D. Exchange Student, Padova University, Padova, Italy: November 1, 2003 to May 31, 2004.
16. Gianpietro Piroddi, Post-B.S. Student, NTB, Buchs, Switzerland: Oct. 1, 2004 to May 31, 2005.
17. Thomas Christen, Post-B.S. Student, NTB, Buchs, Switzerland: April 1, 2005 to Dec. 31, 2005.
18. Tahsin Boyman, Professor, HTA Lucerne, Switzerland: April 1 to September 30, 2006.
19. Stefan Schwendener, Post-B.S. Student, NTB, Buchs, Switzerland: May 1 to October 31, 2006.
20. Andrea Vasel, Exchange Student, Fachhochschule Wolfenbuettel, Germany: September 1, 2006 to February 28, 2007.
21. Yang Jun, Project Engineer, Shanghai Hitachi, China: December 1, 2006 to June 30, 2007.
22. Vincent Lemort, Ph.D. Exchange Student, University of Liège, Belgium: January 2 to June 30, 2007.

23. Guido Mendes Barreto, Undergraduate Exchange Student, University of Applied Sciences, Karlsruhe, Germany: September 1, 2007 to February 28, 2008.
24. Li Yutong, Ph.D. Student, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong: June 1, 2008 to August 13, 2008.
25. Zhang Li, Project Engineer, Shanghai Hitachi, China: February 1, 2008 to August 31, 2008.
26. Walid Chakroun, Professor and Department Chair of Mechanical Engineering, Kuwait University, Kuwait: June 1, 2008 to August 31, 2008.
27. Yong Li, Associate Professor, Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, China: September 1, 2008 to February 17, 2009.
28. Ting-Hau Ho, Research Engineer, Sci-Tech Research and Service Co., Chicago: March 1, 2008 to September 30, 2008.
29. Peng Bin, Post-Doc, Department of Mechanical and Electronical Engineering, Lanzhou University of Technology, China: June 1, 2008 to May 31, 2009.
30. Cord Tomforde, Exchange Student, Leibnitz University Hannover, Germany: August 15, 2008 to May 15, 2009.
31. Jan Schiefelbein, IAESTE Student, Technical University of Clausthal, Germany: May 18 to August 7, 2009.
32. Yang Bin, Ph.D. Exchange Student, Department of Refrigeration and Cryogenics, Xi'an Jiaotong University, China: September 1, 2008 to August 31, 2009.
33. Gerhard Frei, Diploma Thesis Student, Europäische Studienakademie Kälte-Klima-Lüftung, Maintal, Germany: May 1 to September 15, 2009.
34. Cao Feng, Associate Professor, Department of Refrigeration and Cryogenics, Xi'an Jiaotong University, China: February 1, 2009 to January 31, 2010.
35. Jiang Long, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2010.
36. Xu Zhenyuan, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2010.
37. Jiang Yu, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2010.
38. Shi Xinjie, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2010.
39. Evgenia Sikorski, Professor, Offenburg University of Applied Science, Germany: March 1 to August 13, 2010.
40. Carolin Dittmer, Diploma Thesis Student, Europäische Studienakademie Kälte-Klima-Lüftung, Maintal, Germany: May 1 to September 7, 2010.
41. Friedrich K.C. Welck, IAESTE Student, Technical University of Clausthal, Germany: May 18 to August 7, 2010.
42. Jian Li, Ph.D. Exchange Student, Department of Refrigeration and Cryogenic Engineering, Xi'an Jiaotong University, China: October 1, 2009 to September 30, 2010.
43. Stefan Surrey, Diploma Thesis student, Leibnitz University Hannover, Germany: September 1, 2010 to February 28, 2011.
44. Philipp Danecker, Diploma Thesis Student, Karlsruhe Institute of Technology (KIT), Germany: September 20, 2010 to March 31, 2011.
45. Tobias Menzi, M.S. Exchange Student, NTB, Buchs, Switzerland: April 1 to July 31, 2011.
46. Mira Weymann, Diploma Thesis Student, Europäische Studienakademie Kälte-Klima-Lüftung, Maintal, Germany: May 1 to September 7, 2011.

47. Fabian Moik, Bachelor Thesis Student, Karlsruhe Institute of Technology (KIT), Germany: September 16, 2011 to December 31, 2011.
48. Weining Wang, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2012.
49. Juncheng Zhu, Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: February 1, 2010 to May 31, 2012.
50. Emeline Georges, M.S. Student, Electromechanical Engineering, University of Liège, Belgium: February 1, 2012 to August 10, 2012 (Co-major professor: J.E. Braun).
51. Timo Mueller, Undergraduate Exchange Student, University of Applied Sciences, Karlsruhe, Germany: April 16, 2012 to July 31, 2012.
52. Andreas Gschwend, M.S. Exchange Student, NTB, Buchs, Switzerland: May 16, 2012 to July 31, 2012.
53. Shuai Deng, Ph.D. Exchange Student, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, China: September 1, 2011 to August 31, 2012.
54. Yijian He, Associate Professor, Institute of Refrigeration and Cryogenics, Zhejiang University, China: January 16, 2012 to December 21, 2012.
55. Frank Mauersberger, Diploma Thesis Student, Europäische Studienakademie Kälte-Klima-Lüftung, Maintal, Germany: May 21, 2012 to September 7, 2012.
56. Steffen Ebling, Diploma Thesis Student, Europäische Studienakademie Kälte-Klima-Lüftung, Maintal, Germany: May 1 to September 9, 2013.
57. Bernhard Vetsch, M.S. Exchange Student, NTB, Buchs, Switzerland: March 1, 2013 to November 30, 2013.
58. Nebojsa Niculovic, Diploma Exchange Student, Leibniz University Hannover, Germany: January 1 to April 30, 2014.
59. Anne Liebold, M.S. Exchange Student, NTB, Buchs, Switzerland: April 14, 2014 to July 31, 2014.
60. Florian Kautz, B.S. Exchange Student, Offenburg University of Applied Science, Germany: March 1 to August 31, 2014.
61. Sebastian Gross-Hardt, B.S. Thesis Exchange Student, Europäische Studienakademie Kälte-Klima-Lüftung (ESaK), Maintal, Germany: May 18 to August 31, 2014.
62. Giulia Marinello, Post-Graduate M.S. Student, KTH Stockholm, Sweden and DTU, Copenhagen, Denmark: November 1, 2012 to October 31, 2014.
63. Bensi Dong, Ph.D. Exchange Student, Beihang University, Beijing, China: November 1, 2013 to October 31, 2014.
64. Emeline Georges, Ph.D. Exchange Student, Electromechanical Engineering, University of Liège, Belgium: February 1 to October 31, 2014 (Co-major professor: J.E. Braun).
65. Davide Ziviane, Ph.D. Exchange Student, Ghent University, Belgium: May 1, 2014 to October 31, 2014.
66. Leona Schmidt-Speicher, Bachelor Thesis Student, Karlsruhe Institute of Technology (KIT), Germany: September 15 to December 19, 2014.
67. Stefan Hotz, Bachelor Thesis Student, Karlsruhe Institute of Technology (KIT), Germany: September 15 to December 19, 2014.
68. Damien Schyns, M.S. Exchange Student, Electromechanical Engineering, University of Liège, Belgium: February 1 to July 31, 2015 (Co-major professor: J.E. Braun).
69. Gabriel Feichter, M.S. Exchange Student, NTB, Buchs, Switzerland: April 13 to July 10, 2015.

70. Kai Roeder, B.S. Thesis Exchange Student, Europäische Studienakademie Kälte-Klima-Lüftung (ESaK), Maintal, Germany: May 1 to August 23, 2015.
71. Thomas Moesch, Diploma Thesis Student, Technical University of Dresden, Germany: June 1 to November 30, 2015.
72. Dr. Yefeng Liu, Associate Professor, University of Shanghai for Science and Technology, China: January 31, 2014 to January 31, 2016.
73. Fabian Schweisthal, B.S. Thesis Exchange Student, Europäische Studienakademie Kälte-Klima-Lüftung (ESaK), Maintal, Germany: May 9 to September 9, 2016.
74. Andreas Hoess, B.S. Thesis Exchange Student, Europäische Studienakademie Kälte-Klima-Lüftung (ESaK), Maintal, Germany: May 1, 2017 to August 31, 2017.
75. Davide Ziviane, Ph.D. Exchange Student, Ghent University, Belgium: February 1, 2016 to September 30, 2017.
76. Nigora Gafur, MS Exchange Student, Karlsruhe Institute of Technology, Karlsruhe, Germany: May 22, 2017 to September 30, 2017.
77. Shijie Zhu, Project Engineer, Nanjing Aotecar New Energy Technology Co., China: Nov. l, 2016 through March 31, 2018.
78. Florian Simon, MS Thesis Student, University of Applied Science, Karlsruhe, Germany: Sept. 1, 2017 through February 28, 2018.
79. Christian Seitz, M.S. Exchange Student, NTB, Buchs, Switzerland: April 9 to July 13, 2018.
80. Robin Weller, B.S. Thesis Exchange Student, Europäische Studienakademie Kälte-Klima-Lüftung (ESaK), Maintal, Germany: May 15, 2018 to August 31, 2018.
81. Francisco Xavier Plaza Calle, B.S. Exchange Student, Universidad San Francisco de Quito, Ecuador: May 21, 2018 to August 3, 2018.
82. Xiaotao Wang, Associate Professor, Technical Institute of Physics and Chemistry, Chinese Academy of Science, Beijing, China: October 15, 2017 through October 15, 2018.
83. Saverio Randi, Ph.D. Exchange Student, Engineering Science, University of Ferrara, Italy: July 1, 2018 – December 31, 2018.
84. Lennart Stania, M.S. Exchange Student, Leibniz University of Hannover, Germany: August 20, 2018 – December 16, 2018.
85. Ralph Kuster, M.S. Exchange Student, NTB, Buchs, Switzerland: March 1, 2019 to June 30, 2019.
86. Fatih Meral, M.S. Exchange Student, Institute of Technical Thermodynamics, University of Kassel, Germany: February 1, 2019 – December 13, 2019.
87. Oliver H. Obst, M.S. Exchange Student, Institute of Technical Thermodynamics, University of Kassel, Germany: February 1, 2019 – December 13, 2019.
88. Wenshan Zhang, Ph.D. Exchange Student, School of Energy and Power Engineering, Xi'an Jiaotong University, P.R. China: January 1, 2019 – December 31, 2019.

g.) Former Advisees hired into Faculty Positions

1. Dr. W. Travis Horton, Associate Professor, School of Civil Engineering, Purdue University, West Lafayette, IN.
2. Dr. Suwat Trutassanawin, Assistant Professor, Mechanical Engineering Department, Mahidol University, Bangkok, Thailand.
3. Dr. Lorenzo Cremaschi, Associate Professor, Department of Mechanical Engineering, Auburn University, Auburn, AL.

4. Dr. Miguel Jovane, Facultad de Ingeniería Mecánica, Assistant Professor, Universidad Tecnológica de Panamá, Panama.
5. Dr. Stefan S. Bertsch, Professor, Department of Mechanical Engineering, NTB Interstaatliche Hochschule für Technik Buchs, Switzerland.
6. Dr. Margaret M. Mathison, Lecturer, Department of Mechanical Engineering, Iowa State University, Ames, IO.
7. Dr. Jun-Hyeung (Jay) Kim, Assistant Professor of Engineering, Doane University, Crete, NE.
8. Dr. Christian K. Bach, Assistant Professor, Department of Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater, OK.
9. Dr. Craig R. Bradshaw, Assistant Professor, Department of Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater, OK.
10. Dr. Ammar M. Bahman, Assistant Professor, Department of Mechanical Engineering, Kuwait University, Kuwait.
11. Dr. Davide Ziviane, Research Assistant Professor, School of Mechanical Engineering, Purdue University.

CURRENT STUDENT AND SCHOLAR SUPERVISIONS:

a.) Ph.D. Thesis Students Supervision

1. Vatsal M. Shah, Ph.D., ", Oil Return and Retention in Unitary Split System Gas Lines with HFC and HFO Refrigerants," started in January 2016 (Co-Advisor: J.E. Braun).
2. Nicholas P. Salts, Direct Ph.D., "Theoretical and Experimental Evaluation of Twin-Screw Compressors with Internal Rotor Cooling Options," started June 2016.
3. Riley B. Barta, Direct Ph.D., "Experimental and Numerical Analysis of Performance Enhancements to a Multi-Stage Two-Evaporator Transcritical Carbon Dioxide Refrigeration Cycle," started June 2016.
4. Haotian Liu, Ph.D., "Evaluation of Adhesive Bonding in HVAC&R Applications," started in May 2017 (Co-Advisor: J.A. Weibel).
5. Leon P.M. Brendel, Direct Ph.D., "Vapor Compression Refrigeration System for Cold Storage on Spacecrafts," started in August 2017 (Co-Advisor: J.E. Braun).
6. Jonathan P. Ore, Ph.D., "Control Strategies for Energy Use in the DC Nano-Grid House," started in August 2018.
7. Changkuan (Steven) Liang, Direct Ph.D., "Automated Charge Testing of Vapor Compression Cycles," started in June 2019 (Co-Advisor: J.E. Braun).
8. Vanessa Restrepo Perez, Ph.D., "Self-Healing Architectured Interfaces Inspired by the Molecular Unfolding of Proteins," started in August 2019 (Co-Advisor: R. Martinez, IE).
9. Allison R. Graban, Ph.D., "Energy Efficiency of Heat Pump Tumble Clothes Dryers," started in January 2020 (Co-Advisor: J.E. Braun).

b.) Master Thesis Students Supervision

1. Tyler J. Shelly, M.S.M.E., "Integrated Electric Vehicle Battery Thermal Management," started in January 2019 (Co-Advisor: J.A. Weibel).
2. Joseph T. Hedspeth, M.S.M.E., "Vapor Compression System Modeling for Military Applications," started in January 2019 (Co-Advisor: D. Ziviani).
3. Junyan Ren, M.S.M.E., "Dual-Evaporator Organic Rankine Cycle with Spinning Scroll Expander," started in August 2019 (Co-Advisor: D. Ziviani).

4. Andreas Hoess, M.S.M.E., "Performance Analysis and Reliability of Twin-Screw Compressors," started in January 2020 (Co-Advisor: D. Ziviani).

c.) Non-Theses Master Students Supervision

none

d.) Undergraduate Project Students Supervision

1. John L. Folkers, ME 49800 Project (3 credits): "DC Nanogrid House Research," Summer 2020.

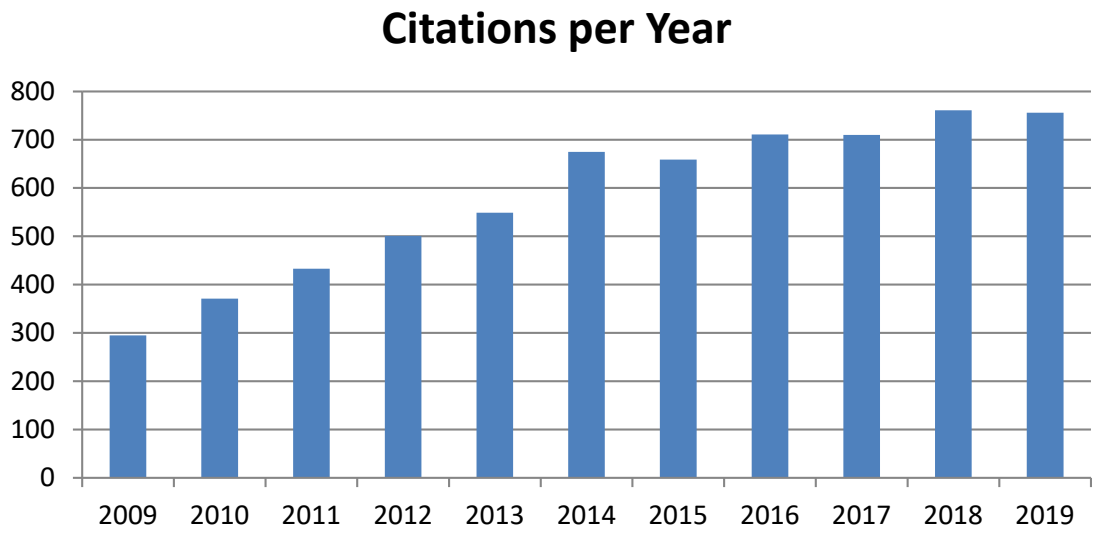
e.) Post-Docs and Research Scientists Supervision

1. Orkan Kurtulus, Ph.D. from Yildiz Technical University, Turkey: January 1, 2012 to present (Co-major professors: S.V. Garimella, 1st year, and J.E. Braun, 2nd year to present).

f.) Visiting Research Associates or Visiting Scholars Supervision

None

GOOGLE SCHOLAR CITATION INDICES (status January 2020):



Citation Indices	All	Since 2015
Citations	7675	3743
h-index	40	30
i10-index	137	80

ARCHIVAL JOURNAL PUBLICATIONS:

1. L.S. Fletcher, G.P. Peterson, C.V. Madhusudana, and E.A. Groll, "Constriction Resistance in Bolted and Riveted Joints," *ASME Transactions, Journal of Heat Transfer*, Vol. 112, No. 4, November 1990, pp. 857-863.
2. E.A. Groll, and H. Kruse, "Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel: R23/DEGDME und CO_2/Aceton" ('Vapor Compression Cycle with Solution Circuit for Environmental Friendly Refrigerants'), *KK DIE KÄLTE und Klimatechnik*,

45. Jahrgang, Gentner Verlag Stuttgart, April 1992, pp. 206-218.
3. E.A. Groll, and R. Radermacher, "Vapor Compression Cycle with Solution Circuit and Desorber/Absorber Heat Exchange," *ASHRAE Transactions*, Vol. 100, Pt. 1, 1994, pp. 73-83.
4. S.W. Inlow, and E.A. Groll, "Analysis of Secondary-Loop Refrigeration Systems Using Carbon Dioxide as a Volatile Secondary Refrigerant," *Int'l J. HVAC&R Research*, Vol. 2, No. 2, April 1996, pp. 107-121.
5. R. Cohen, and E.A. Groll, "Update on Refrigerant Compressors in Light of CFC Substitutes," *Bulletin IIF/IIR*, Tome LXXVI, No. 5, August 1996, pp. 2-19.
6. E.A. Groll, "Modeling of Absorption/Compression Cycles Using Working Pair Carbon Dioxide/Acetone," *ASHRAE Transactions*, Vol. 103, Pt. 1, 1997, pp. 863-872.
7. E.A. Groll, "Current Status of Absorption/Compression Cycle Technology," *ASHRAE Transactions*, Vol. 103, Pt. 1, 1997, pp. 361-374.
8. J.T. LeRoy, E.A. Groll, and J.E. Braun, "Computer Model Predictions of Dehumidification Performance of Unitary Air Conditioners and Heat Pumps Under Extreme Operating Conditions", *ASHRAE Transactions*, Vol. 104, Pt. 2, 1998.
9. S.S. Pitla, D.M. Robinson, E.A. Groll, and S. Ramadhyani, "Heat Transfer from Supercritical Carbon Dioxide in Tube Flow: A Critical Review," *Int'l J. HVAC&R Research*, Vol. 4, No. 3, July 1998, pp. 281-301.
10. D.M. Robinson, and E.A. Groll, "Efficiencies of Transcritical CO_2 Cycles with and without an Expansion Turbine," *Int'l J. Refrig.*, Vol. 21, No. 7, 1998, pp. 577-589.
11. D.M. Robinson, and E.A. Groll, "Heat Transfer Analysis of Air-to-CO_2 Two-Phase Heat Absorption and Supercritical Heat Rejection," *Int'l J. HVAC&R Research*, Vol. 4, No. 4, October 1998, pp. 327-345.
12. J.D. Douglas, J.E. Braun, E.A. Groll, and D.R. Tree, "A Cost-Based Method for Comparing Alternative Refrigerants Applied to R-22 Systems," *Int'l J. Refrig.*, Vol. 22, No. 2, 1999, pp. 107-125.
13. E.N. de Andrade, E.B. Skowron, V.W. Goldschmidt, and E.A. Groll, "Oil Concentration in Liquid Refrigerants: In Situ Measurement", *Int'l J. Refrig.*, Vol. 22, No. 6, 1999, pp. 499-508.
14. J.T. LeRoy, E.A. Groll, and J.E. Braun, "Evaluating the Accuracy of Public Domain Simulation Model PUREZ in Predicting the Performance of Unitary Equipment", *ASHRAE Transactions*, Vol. 106, Pt. 1, 2000, pp. 200-215.
15. D.M. Robinson, and E.A. Groll, "Theoretical Performance Comparison of CO_2 Transcritical Cycle Technology Versus HCFC-22 Technology for a Military Packaged Air Conditioner Application," *Int'l J. HVAC&R Research*, Vol. 6, No. 4, October 2000, pp. 325-348.
16. T.M. Ortiz, E.A. Groll, and B.A. Meyer, "Thermodynamic Analysis of Heat Driven Metal Hydride Cogeneration Cycle", *Int'l J. Thermal Sciences*, Vol. 40, No. 2, 2000, pp. 165 – 172.
17. W.T. Horton, and E.A. Groll, "Analysis of a Medium-Temperature Secondary Loop Refrigerating System," *ASHRAE Transactions*, Vol. 107, Pt. 2, 2001, pp. 459-465.
18. M.C. Comstock, J.E. Braun, and E.A. Groll, "The Sensitivity of Chiller Performance to Common Faults," *Int'l J. HVAC&R Research*, Vol. 7, No. 3, July 2001, pp. 263 – 279.
19. S.S. Pitla, S. Ramadhyani, and E.A. Groll, "Convective heat transfer from in-tube flow of turbulent supercritical carbon dioxide: Part 1 – numerical analysis", *Int'l J. HVAC&R Research*, Vol. 7, No. 4, October 2001, pp. 345-366.
20. S.S. Pitla, E.A. Groll, and S. Ramadhyani, "Convective heat transfer from in-tube cooling of turbulent supercritical carbon dioxide: Part 2 – experimental data and numerical predictions", *Int'l J. HVAC&R Research*, Vol. 7, No. 4, October 2001, pp. 367-382.

21. Bansal, P.K., Braun, J.E., and E.A. Groll, "Improving the Energy Efficiency of Conventional Tumbler Clothes Drying Systems," *Int'l J. Energy Research*, Vol. 25, No. 15, 2001, pp. 1315-1332.
22. M.C. Comstock, J.E. Braun, and E.A. Groll, "A Survey of Common Faults for Chillers," ASHRAE Transactions, Vol. 108, Pt. 1, 2002, pp. 819-825.
23. Y. Chen, N.P. Halm, E.A. Groll, and J.E. Braun, "Mathematical Modeling of Scroll Compressors Part I: Compression Process Modeling," *Int'l J. Refrig.*, Vol. 25, No. 7, 2002, pp. 731-750.
24. Y. Chen, N.P. Halm, E.A. Groll, and J.E. Braun, "Mathematical Modeling of Scroll Compressors Part II: Overall Scroll Compressor Modeling," *Int'l J. Refrig.*, Vol. 25, No. 7, 2002, pp. 751-764.
25. S.S. Pitla, E.A. Groll, and S. Ramadhyani, "New correlation to predict the heat transfer coefficient during in-tube cooling of turbulent supercritical carbon dioxide", *Int'l J. Refrig.*, Vol. 25, No. 8, 2002, pp. 887-895.
26. Braun, J.E., Bansal, P.K., and E.A. Groll, "Energy Efficiency Analysis of Air Cycle Heat Pump Dryers," *Int'l J. Refrig.*, Vol. 25, No. 9, 2002, pp. 954-965.
27. T.M. Harms, E.A. Groll, and J.E. Braun, "Accurate Charge Inventory Modeling for Unitary Air Conditioners," *Int'l J. HVAC&R Research*, Vol. 9, No. 1, January 2003, pp. 55-78.
28. J.-H. Kim, and E.A. Groll, "Performance Comparisons of a Unitary Split System Using Microchannel and Fin-Tube Outdoor Coils," *ASHRAE Tran.*, Vol. 109, Pt. 2, 2003, 11 pages.
29. T.M. Harms, D. Li, E.A. Groll, and J.E. Braun, "A Void Fraction Model for Annual Flow in Horizontal Tubes," *Int'l J. Heat and Mass Transfer*, Vol. 46, 2003, pp. 4051-4057.
30. T.M. Harms, J.E. Braun, and E.A. Groll, "The Impact of Modeling Complexity and Two-phase Flow Parameters on the Accuracy of System Modeling for Unitary Air Conditioners," *Int'l J. HVAC&R Research*, Vol. 10, No. 1, January 2004, pp. 5-20.
31. Y. Chen, J.E. Braun and E.A. Groll, "Modeling of Hermetic Scroll Compressors: Model Development," *Int'l J. HVAC&R Research*, Vol. 10, No.2, April 2004, pp. 129-152.
32. Y. Chen, E.A. Groll, and J.E. Braun, "Modeling of Hermetic Scroll Compressors: Model Validation and Application," *Int'l J. HVAC&R Research*, Vol. 10, No.3, July 2004, pp. 307-329.
33. G. Li, J.E. Braun, S.H. Frankel, E.A. Groll, and Z. Wang, "Application of CFD Models to Two-Phase Flow in Refrigerant Distributors," *Int'l J. HVAC&R Research*, Vol. 11, No.1, January 2005, pp. 45-62.
34. S. Bendapudi, J.E. Braun, and E.A. Groll, "A Dynamic Model of a Centrifugal Chiller System - Model Development, Numerical Study and Validation," Paper No. 4754, *ASHRAE Transactions*, Vol. 111, Pt. 1, 2005, pp. 132-148.
35. B.C. Pak, E.A. Groll and J.E. Braun, "Impact of Fouling and Cleaning on Plate Fin and Spine Fin Heat Exchanger Performance," *ASHRAE Transactions*, Vol. 111, Pt. 1, 2005, pp. 496-504.
36. J.S. Baek, E.A. Groll, and P.B. Lawless, "Piston-Cylinder Work Producing Expansion Device in a Transcritical Carbon Dioxide Cycle, Part I: Experimental Investigation," *Int'l J. Refrigeration*, Vol. 28, No. 2, 2005, pp. 141-151.
37. J.S. Baek, E.A. Groll, and P.B. Lawless, "Piston-Cylinder Work Producing Expansion Device in a Transcritical Carbon Dioxide Cycle, Part II: Theoretical Model," *Int'l J. Refrigeration*, Vol. 28, No. 2, 2005, pp. 152-164.
38. B. Shen and E.A. Groll, "A Critical Review of the Influence of Lubricants on the Heat Transfer and Pressure Drop of Refrigerants, Part I: Lubricant Influence on Pool and Flow Boiling," *Int'l*

J. HVAC&R Research, Vol. 11, No. 3, July 2005, pp. 341-359.
39. B. Shen and E.A. Groll, "A Critical Review of the Influence of Lubricants on the Heat Transfer and Pressure Drop of Refrigerants, Part II: Lubricant Influence on Condensation and Pressure Drop," *Int'l J. HVAC&R Research*, Vol. 11, No. 4, October 2005.
40. D. Li and E.A. Groll, "Transcritical CO_2 refrigeration cycle with ejector-expansion device," *Int'l J. Refrigeration*, Vol. 28, No. 5, 2005, pp. 766-773.
41. J.S. Baek, E.A. Groll, and P.B. Lawless, "Theoretical Performance of Transcritical Carbon Dioxide Cycle with Two-Stage Compression and Intercooling," Proc. IMechE, Vol. 219, Part E: *J. Process Mechanical Engineering*, Special Issues Paper, 2005, pp. 187- 195.
42. J. Zhang and E.A. Groll, "Survey of the Design of Refrigeration Plants for Public Refrigerated Warehouses," *ASHRAE Transactions*, Vol. 111, Pt. 2, 2005, 7 pages.
43. B. Shen, J.E. Braun, and E.A. Groll, "A Method for Tuning Refrigerant Charge in Modeling Off-Design Performance of Unitary Equipment," *Int'l J. HVAC&R Research*, Vol. 12, No. 3, 2006, pp. 429-450.
44. S. Trutassanawin, E.A. Groll, S.V. Garimella, and L. Cremaschi, "Experimental Investigation of a Miniature-Scale Refrigeration System for Electronics Cooling," *IEEE Transactions on Components and Packaging Technologies*, Vol. 29, No. 3, 2006, pp. 678-687
45. Li, Y., Braun, J.E. and Groll, E.A., "The Impact of Fouling on the Performance of Filter-Evaporator Combinations," *Int'l J. Refrigeration*, Vol. 30, No. 3, 2007, pp. 489-498.
46. Li, Y., Braun, J.E. and Groll, E.A., "The Impact of Filter Type on the Performance of Packaged Air Conditioners," *Int'l J. Refrigeration*, Vol. 30, No. 3, 2007, pp. 506-514.
47. Kim, J.-H., and Groll, E.A., "Review of Recent Advances toward Transcritical CO_2 Cycle Technology," *Int'l J. HVAC&R Research*, Vol. 13, No. 3, 2007, pp. 499-518.
48. Allert, B.I., Atkinson, D.L., Groll, E.A., and Hirleman, E.D., "Making the Case for Global Engineering: Building Foreign Language Collaborations for Designing, Implementing, and Assessing Programs," (MS#1009), *Online Journal for Global Engineering Education*, Vol. 2, Issue 2, 2007.
49. Hugenroth, J., Braun, J.E., Groll, E.A., and King, G.B., "Thermodynamic Analysis of a Liquid-Flooded Ericsson Cycle Cooler," *Int'l J. Refrigeration*, Vol. 30, No. 7, 2007, pp. 1176-1186.
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11. Sikorski, E., and Groll, E.A., "Vergleichende Analyse des europäischen Wärmepumpenmarkts," Beiträge aus Forschung und Technik 2011, Institut für Angewandte Forschung (AIF), Hochschule Offenburg, ISSN 1866-9352.
12. Groll, E.A., "Ejector Technology," Editorial, *Int'l J. Refrig.*, Vol. 34, No. 8, 2011, pp. 1543-1544.
13. Groll, E.A., "Compressor Technology," Editorial, *Int'l J. Refrig.*, Vol. 36, No. 7, 2013, pp. 1793-1795.
14. Baxter, V.D., Groll, E.A., and Shen, B., "Air Source Heat Pumps for Cold Climate Applications: Recent U.S. R&D Results from IEA HPP Annex 41", Article in Federation of European Heating, Ventilation, and Air Conditioning Associations (REHVA) European HVAC Journal, September 2014, pp. 14-18.

PUBLISHED REPORTS:

1. E.A. Groll, and H. Kruse, "Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel, 2. Statusbericht" ('Vapor Compression Cycle with Solution Circuit for Environmental Friendly Refrigerants, 2. Statusreport'), *Statusbericht des Deutschen Kälte- und Klimatechnischen Vereins*, Nr. 6, 2. Statusseminar, Bonn, October 11, 1990, pp. 29-32.
2. E.A. Groll, and H. Kruse, "Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel, 3. Statusbericht" ('Vapor Compression Cycle with Solution Circuit for Environmental Friendly Refrigerants, 3. Statusreport'), *Statusbericht des Deutschen Kälte- und Klimatechnischen Vereins*, Nr. 7, 3. Statusseminar, Bonn, April 18, 1991, pp. 23-29.

3. E.A. Groll, and H. Kruse, "Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel, 4. Statusbericht" ('Vapor Compression Cycle with Solution Circuit for Environmental Friendly Refrigerants, 4. Statusreport'), *Statusbericht des Deutschen Kälte- und Klimatechnischen Vereins*, Nr. 8, 4. Statusseminar, Bonn, October 24, 1991, pp. 99-105.
4. E.A. Groll, and H. Kruse, "Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel, Abschlussbericht" ('Vapor Compression Cycle with Solution Circuit for Environmental Friendly Refrigerants, Final Report'), published in "Untersuchung alternativer Anlagenschaltungen und Arbeitsstoffe zur Lösung des FCKW-Ozon-Problems" ('Investigations of Alternative Cycles and Working Fluids to Solve the CFC-Ozone-Problem'), *Forschungsbericht des Deutschen Kälte- und Klimatechnischen Vereins*, Nr. 35, Universität Hannover, Institut für Kältetechnik und Angewandte Wärmetechnik, May 1992.
5. E.A. Groll, "Experimentelle und theoretische Untersuchungen von Kompressionkältemaschinen mit Lösungskreislauf" ('Experimental and Theoretical Investigations of Vapor Compression Cycles with Solution Circuit'), *Forschungsbericht des Deutschen Kälte- und Klimatechnischen Vereins*, Nr. 44, Dissertation, Universität Hannover, Institut für Kältetechnik und Angewandte Wärmetechnik, February 1994.
6. J.D. Douglas, J.E. Braun, E.A. Groll, and D.R. Tree, "A Cost-Based Method for Comparing Alternative Refrigerants Applied to R-22 Systems," Master Thesis, Herrick Labs 95-21, Report No. 2200-1, 1995.
7. J.T. LeRoy, E.A. Groll, and J.E. Braun, "Capacity and Power Demand of Unitary Air Conditioners and Heat Pumps Under Extreme Temperature and Humidity Conditions," Master Thesis, Herrick Labs 97-25, Report No. 3220-2, 1997.
8. J.T. LeRoy, E.A. Groll, and J.E. Braun, "Capacity and Power Demand of Unitary Air Conditioners and Heat Pumps Under Extreme Temperature and Humidity Conditions," Final Report ASHRAE RP-859, Herrick Labs 97-26, Report No. 3220-3, 1997.
9. N.P. Halm, E.A. Groll, J.E. Braun, and D.R. Tree, "Mathematical Modeling of Scroll Compressors," Master Thesis, Herrick Labs 97-31P, Report No. 3147-1, 1997.
10. A.E. Causey, E.A. Groll, and J.E. Braun, "Compressor Load Stand: Commissioning and Control Strategies," Herrick Labs 98-12, Report No. 3147-2, 1998.
11. E.B. Skowron, V.W. Goldschmidt, E.A. Groll, "Investigation of Refrigerant/Oil Flow through Suction Accumulators", Master Thesis, Herrick Labs 98-20P, Report No. 2879-1, 1998.
12. D.M. Robinson, and E.A. Groll, "Performance Comparison of Transcritical CO_2-Technology with CFC-, HCFC-, and HFC-Technology", Final Report, Herrick Labs 99-2, Report No. 1495-1, 1999.
13. S.S. Pitla, S. Ramadhyani, and E.A. Groll, "Heat Transfer From In-Tube Cooling of Supercritical Carbon Dioxide", Master Thesis, Herrick Labs 99-10, Report No. 3139-1, 1999.
14. J. Zhang, and E.A. Groll, "Energy Efficiency Survey and Recommendations for Public Refrigerated Warehouses," Final Report, Herrick Labs 99-14, Report No. 220, 1999.
15. B.F. Marcus, E.A. Groll, V.W. Goldschmidt, "Effects of Applications on Reliability and Performance of Unitary Split Systems", Master Thesis, Herrick Labs 99-23P, Report No. 3256-1, 1999.
16. S.S. Pitla, D.M. Robinson, A. Zingerli, E.A. Groll, and S. Ramadhyani, "Heat Transfer and Pressure Drop Characteristics during In-Tube Gas Cooling of Supercritical Carbon Dioxide", Final Report ASHRAE 913-RP, Herrick Labs 2000-10, Report No. 3613-1, 2000.
17. D.M. Robinson and E.A. Groll, "Modeling of Carbon Dioxide Based Air-to-Air Air Conditioners", Ph.D. Thesis, Herrick Labs 2000-7, Report No. 1644-1, 2000.

18. Y. Chen, E.A. Groll, and J.E. Braun, "Mathematical Modeling of Scroll Compressors", Ph.D. Thesis, Herrick Labs 2000-17P, Report No. 3147-1, 2000.
19. Z. Sun and E.A. Groll, "CO_2 Flow Boiling Heat Transfer in Horizontal Tubes", Master Thesis, Herrick Labs 2001-8, Internal Report No. 229, 2001.
20. D. Li and E.A. Groll, "Theoretical and Experimental Investigation of Carbon Dioxide Based Air Conditioning System", Master Thesis, Herrick Labs 2001-7, Report No. 1644-1, 2001.
21. G. Li, J.E. Braun, E.A. Groll, and S. Frankel, "A Numerical and Experimental Investigation of Refrigerant Flow Control Devices", Master Thesis, Herrick Labs 2001-19P, Report No. 5372-1, 2001.
22. W.T. Horton and E.A. Groll, "Modeling of Secondary Loop Refrigeration Systems in Supermarket Applications," Ph.D. Thesis, Herrick Labs 2002-3, Report No. 5271-1, 2002.
23. J. S. Baek, E. A. Groll, and P. B. Lawless, "Development of a Carbon Dioxide Based Field Deployable Environmental Control Unit to Replace HCFC-22 or HFC-134a Units," Ph.D. Thesis, Herrick Labs 2002-10, Report No. 1662-1, 2002.
24. T. M. Harms, E. A. Groll, and J. E. Braun, "Charge Inventory System Modeling and Validation for Unitary Air Conditioners," Ph.D. Thesis, Herrick Labs 2002-13, Report No. 5288-2, 2002.
25. J.-H. Kim, and E.A. Groll, "Performance Comparisons of a Unitary Split System Using Microchannel and Fin-Tube Outdoor Coils," Master Thesis, Herrick Labs 2002-14, Report No. 5707-1, 2002.
26. T. M. Ortiz, and E. A. Groll, "Development of a New Model for Investigation of the Performance of Carbon Dioxide as a Refrigerant for Residential Air Conditioners," Ph.D. Thesis, Herrick Labs 2002-17, Report No. 1275-1, 2002.
27. B. Hubacher, E. A. Groll, "Measurement of Performance of Carbon Dioxide Compressors," Final Report (ARTI Project 611-10070), Herrick Labs 2002-24, Report No. 0140-1, 2002.
28. J.-H. Kim, and E.A. Groll, "Microchannel Heat Exchanger Defrost Performance and Reliability," Final Report (ASHRAE 1195-RP), Herrick Labs 2003-13, Report No. 5707-2, 2003.
29. T. M. Ortiz, D. Li, and E. A. Groll, "Evaluation of the Performance Potential of CO_2 as a Refrigerant in Air-To-Air Air Conditioners and Heat Pumps: System Modeling and Analysis", Final Report (ARTI Project 610-10030), Herrick Labs 2003-20, Report No. 1275-2, 2003.
30. B. Shen, and E.A. Groll, "Critical Literature Review of Lubricant Influence on Refrigerant Heat Transfer and Pressure Drop," Final Report (ARTI Project 611-20080), Herrick Labs 2003-21, Report No. 1249-1, 2003.
31. B. Hubacher, and E. A. Groll, "Experimental and Theoretical Performance of Carbon Dioxide Compressors," Master Thesis, Purdue University, Herrick Labs 2003-24, Report No. 0140-2, 2003.
32. L. Yang, J.E. Braun, and E.A. Groll, "The Impact of Fouling on the Performance of Filter-Evaporator Combinations and Rooftop Air Conditioners," Master Thesis, Purdue University, Herrick Labs 2004-13, Report No. 0106-1, 2004.
33. J.-H. Kim, and E.A. Groll, "Analysis of a Bowtie Compressor with Novel Capacity Modulation," Ph.D. Thesis, Purdue University, Herrick Labs 2005-14, Report No. 3572-1, 2005.
34. S.S. Bertsch, and E.A. Groll, "Theoretical and Experimental Investigation of a Two-Stage Heat Pump Cycle for Nordic Climates," Master Thesis, Purdue University, Herrick Labs 2005-13P, Report No. 7031-1, West Lafayette, Indiana, 2005.
35. B. Shen, E.A. Groll, and J.E. Braun, "Improvement and Validation of Unitary Air Conditioner

and Heat Pump Simulation Models at Off-Design Conditions," Ph.D. Thesis, Herrick Labs 2006-1, Report No. 6304-1, 2006.
36. B. Shen, E.A. Groll, and J.E. Braun, "Improvement and Validation of Unitary Air Conditioner and Heat Pump Simulation Models at Off-Design Conditions," Final Report ASHRAE 1195-RP, ASHRAE, Inc. 1791 Tullie Circle, NE, Atlanta, GA 30329, 2006.
37. D. Li, and E.A. Groll, "Investigation of an Ejector-Expansion Device in a Transcritical Carbon Dioxide Cycle for Military ECU Applications," Ph.D. Thesis, Purdue University, Herrick Labs 2006-4, Report No. 0401-1, 2006.
38. S. Trutassanawin, E.A. Groll, and S.V. Garimella, "A Miniature-Scale Refrigeration System for Electronics Cooling," Ph.D. Thesis, Purdue University, CTRC Report #2006-02, 2006.
39. A.A. Sathe, E.A. Groll, and S.V. Garimella, "Miniature-Scale Diaphragm Compressor for Electronics Cooling," Ph.D. Thesis, Purdue University, CTRC Report #2008-01, 2008.
40. S. S. Bertsch, E.A. Groll, and S.V. Garimella, "Refrigerant Flow Boiling in Microchannel Evaporators," Ph.D. Thesis, Purdue University, CTRC Report #2008-03, 2008.
41. F. Liu and E.A. Groll, "Recovery of Throttling Losses by a Two-Phase Ejector in a Vapor Compression Cycle," Final Report, ARTI Project 10110-01, Arlington, Virginia, August 2008.
42. J. Poland, E.A. Groll, and W.T. Horton, "Energy and Performance of Secondary Coolant Low-Temperature Refrigeration Systems," Final Report ASHRAE 1484-RP, ASHRAE, Inc. 1791 Tullie Circle, NE, Atlanta, GA 30329, 2010.
43. Baxter, V. D., E. A. Groll, O. A. Abdelaziz, B. Shen, G. Groff, K. Sikes, and G. Khowailed, 2013, "IEA HPP Annex 41 – Cold Climate Heat Pumps: Task 1 Report – Literature and Technology Review – United States", ORNL Report, ORNL/TM-2013/472.
44. Baxter, V. D., E. A. Groll, and K. Sikes, 2013, "IEA HPP Annex 41 – Cold Climate Heat Pumps: Summary Interim Report", ORNL Report, ORNL/TM-2015/6.

SEMINARS AND INVITED LECTURES:

1. "Two Stage Vapor Compression Heat Pump with Solution Circuits: Catering to Simultaneous Chilling and Water Heating Needs," seminar presentation, 14th Industrial Energy Technology Conference, Houston, TX, April 22, 1992.
2. "Transcritical Cycle using pure Carbon Dioxide as the Refrigerant," seminar presentation, Workshop on Natural Refrigerants, Challenges and Opportunities, University of Maryland, College Park, MD, April 13, 1994.
3. "Carbon Dioxide in Mixture Applications," seminar presentation, Workshop on Natural Refrigerants, Challenges and Opportunities, University of Maryland, College Park, MD, April 13, 1994.
4. "Tests with R290/R600 Mixtures in Domestic Refrigerator/Freezer", seminar presentation, IIR Conf. on New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hannover, Germany, May 12, 1994.
5. "Research Activities at the Ray W. Herrick Laboratories at Purdue University", Tech Session presentation, Central Indiana ASHRAE Chapter Meeting, Indianapolis, IN, April 11, 1995.
6. "Ammonia Vapor Compression and Secondary Loop Refrigeration Systems for Supermarket Applications," seminar presentation, Seminar 17: Ammonia Coil Design Considerations, 1995 ASHRAE Annual Meeting, San Diego, CA, June 27, 1995.
7. "Ammonia – Secondary Loop Refrigeration System as a Replacement for HCFC-22 in Supermarket Applications," seminar presentation, 1995 International CFC and Halon

Alternatives Conference, Washington, D.C., October 24, 1995.

8. "Alternative Refrigerants in the USA with Respect to Vapor Compression Technology," invited lecture, Matsushita Electric Industrial Co., Ltd., Kusatsu Shiga-Ken, Japan, March 12, 1997.
9. "Thermal Systems Research at the Ray W. Herrick Laboratories at Purdue University," invited lecture, Matsushita Electric Industrial Co., Ltd., Kusatsu Shiga-Ken, Japan, March 13, 1997.
10. "Performance Comparison of Secondary Fluids," seminar presentation, Seminar 31: Experience with Secondary Coolants, 1997 ASHRAE Annual Meeting, Boston, MA, July 1, 1997.
11. "Secondary Refrigerant Developments and Use in Europe", seminar presentation, Seminar 31: Experience with Secondary Coolants, 1997 Annual ASHRAE Mtg., Boston, MA, July 1, 1997.
12. "The Potential of Using Carbon Dioxide in Refrigerant Mixtures for Refrigeration Applications," invited seminar presentation, Univ. of Illinois at Urbana-Champaign, April 23, 1998.
13. "Research on the Transcritical Carbon Dioxide Cycle at the Herrick Laboratories," invited lecture, UT Carrier Corporation, Syracuse, NY, June 6, 1998.
14. "What is ASHRAE?" Invited seminar presentation, Deutsche Kälte und Klima Tagung 1998, Wuerzburg, Germany, November 19, 1998.
15. "Secondary Loop Refrigeration Systems for Supermarket Applications," invited seminar presentation, Saint Louis ASHRAE Chapter Meeting, St. Louis, MO, January 11, 1999.
16. "Research on the Transcritical Carbon Dioxide Cycle Technology at the Ray W. Herrick Laboratories," invited lecture, The Trane Company, La Crosse, WI, July 16, 1999.
17. "Recent Applications of the Transcritical CO_2 Cycle Technology," invited seminar, 3rd International Congress on Refrigeration – Evolutions of Refrigeration Systems, Congress Centre Milanofiori, Assago (Milano), Italy, February 13, 2001.
18. "Heat Transfer Coefficient of Supercritical CO_2 during In-Tube Forced Convection Cooling," invited lecture, University of Paderborn, Germany, February 15, 2001.
19. "ASHRAE sponsored Research Activities at the Ray W. Herrick Laboratories", invited seminar presentation, Central Indiana ASHRAE Chapter Meeting, Indianapolis, IN, Nov. 13, 2001.
20. "Recent Developments in Automotive Air Conditioning Compressors," invited lecture, Nanjing Aotecar Refrigerating Company, Nanjing, China, Sept. 20, 2002.
21. "Research on the Transcritical Carbon Dioxide Cycle Technology at the Ray W. Herrick Laboratories," invited lecture, Visteon, Plymouth, MI, Nov. 22, 2002.
22. "Industrie-Kooperationen und Drittmitteleinwerbung an der Purdue Universität im Bereich der Kälte- und Klimatechnik" (Industry Cooperation and Research Support at Purdue University in the Area of Refrigeration and Air Conditioning), invited lecture, University of Applied Science, Karlsruhe, Germany, May 8, 2003
23. "Performance and Reliability of Microchannel Heat Exchangers in Unitary Equipment," invited lecture, University of Padova, Italy, June 11, 2003.
24. "Kältetechnik: Gestern, Heute und Morgen" (Refrigeration: Past, Present and Future), invited lecture, University of Karlsruhe, Germany, July 24, 2003.
25. "The Science of Refrigeration: Past, Present and Future," invited seminar, University of Notre Dame, September 16, 2003.
26. "Performance Testing of Carbon Dioxide Compressors," invited lecture, LG Electronics,

Chong-won, Korea, October 15, 2003.

27. "Use of Scroll Compressors in Automotive Air-Conditioning," invited seminar, 4th International Automobile Air Conditioning Conference, Tianjin, China, October 17, 2003.
28. "Heat Transfer and Pressure Drop Characteristics of Supercritical CO_2 during In-Tube Forced Convection Cooling", invited lecture, Ruhr-University of Bochum, Germany, May 18, 2004.
29. "HVAC&R Research Activities at the Ray W. Herrick Laboratories at Purdue University" invited seminar, LG Electronics, Chong-won, Korea, July 28, 2005.
30. "Modeling of Unitary Air Conditioners and Heat Pumps," invited seminar, LG Electronics, Chong-won, Korea, July 28, 2005.
31. "Performance and Reliability of Microchannel Heat Exchangers as Outdoor Coils in Unitary Heat Pumps," invited seminar, LG Electronics, Chong-won, Korea, July 28, 2005.
32. "Mathematical Modeling of Scroll Compressors," invited seminar, LG Electronics, Chong-won, Korea, July 29, 2005.
33. "Recent Advances with respect to the Transcritical CO_2 Cycle Technology," invited seminar, LG Electronics, Chong-won, Korea, July 29, 2005.
34. "Miniature-Scale Refrigeration Systems (MSRS) for Electronics Cooling," invited seminar, LG Electronics, Chong-won, Korea, July 29, 2005.
35. "Latest Developments with Respect to Refrigeration Compressors," invited lecture, IZW-IEA Symposium on Innovations in Refrigeration, Air Conditioning and Heat Pumping Technologies for the Reduction of CO_2 Emissions, IKK Hannover, Germany, Nov. 1, 2005.
36. "Experimental Performance of a Two-Stage Unitary Heat Pump with Economizing for Northern U.S. Climates", seminar presentation, Seminar 7: What System Components are Used Today in Unitary Air Conditioners, and What Changes Will Get Us to the Next Efficiency Level, 2007 ASHRAE Winter Meeting, Dallas, TX, January 28, 2007.
37. "Measurements of Flow Boiling Heat Transfer Coefficients in a Mini-Channel Evaporator for Electronics Cooling", seminar presentation, Seminar 50: Recent Developments in Microchannel Heat Transfer and Fluid Flow, 2007 ASHRAE Winter Meeting, Dallas, TX, January 30, 2007.
38. "Recent Research of Novel Compression Concepts for Refrigeration Applications," invited graduate seminar presentation, Texas A&M University, October 24, 2007.
39. "Performance of Microchannel Heat Exchangers as Outdoor Coils in Unitary Heat Pumps," seminar presentation, Seminar 28: Improving Performance in Air to Refrigerant Heat Exchangers, 2008 ASHRAE Winter Meeting, New York City, NY, January 21, 2008.
40. "Recent Research of Novel Compression Concepts for Refrigeration Applications," invited seminar presentation, KTH Stockholm, Sweden, June 4, 2008.
41. "ASHRAE sponsored Research Activities at the Ray W. Herrick Laboratories", invited seminar presentation, Fort Wayne Indiana ASHRAE Chapter Meeting, Ft. Wayne, IN, January 20, 2009.
42. Research Activities at the Ray W. Herrick Laboratories", seminar presentation, Harbin Institute of Technology, Harbin, China, May 22, 2009.
43. "Evaluation of a Novel Liquid-Flooded Ericsson Cycle Cooler for Vending Machine Applications," seminar presentation, Seminar 25: HVAC&R Research, 2009 ASHRAE Annual Meeting, Louisville, KY, June 22, 2008.
44. "ASHRAE sponsored Research Activities at the Ray W. Herrick Laboratories", invited seminar presentation, Central Indiana ASHRAE Chapter Meeting, Indianapolis, IN, October 13, 2009.
45. "State of the Art and Latest Research with Respect to Refrigeration Compressors," invited presentation at AiCARR Refrigeration Seminar, University of Padua, Italy, April 16, 2010.

46. "Trends in Compressor Development," invited colloquium presentation, Schaufler Honorary Colloquium – The Art of Compression, Sindelfingen, Germany, April 13, 2011.
47. "The School of Mechanical Engineering at Purdue University: Where do we go from here?" Seminar presentation, School of Mechanical Engineering, Purdue University, April 27, 2011.
48. "The Undergraduate GEARE Program," Innovation in Curriculum Panelist, ABET Annual Meeting, Baltimore, Maryland, October 27, 2011.
49. "Cold Climate Heat Pump Projects at Purdue University & the Living Lab at the new Herrick Labs Building," invited dinner presentation, IEA Heat Pump Program Executive Committee Meeting, Atlanta, GA, November 9, 2011.
50. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Northern Indiana ASHRAE Chapter Meeting, South Bend, IN and Munster, IN, January 19, 2012.
51. "Analysis of Novel Compression Concepts," invited seminar presentation, Clemson University, March 14, 2012.
52. "Research on Cold Climate Heat Pumps," invited seminar presentation, Texas A&M University, April 4, 2012.
53. "Personal Experiences with Academic Career Development Activities," invited panel presentation, Annual Conf. of Engineering Deans Institute, April 15-18, 2012, Kauai Marriott Resort, Kauai, HI.
54. "Developing Global Engineering Competency Skills through Participation in the Undergraduate GEARE Program," invited seminar presentation, ABET Symposium, St. Louis, MO, April 21, 2012.
55. "Developing Global Engineering Competency through Participation in the Undergraduate GEARE Program," invited panel presenter, STEM Workshop, Washington DC, April 26, 2012.
56. "Cold Climate Heat Pump Research at the Ray W. Herrick Labs," invited seminar presentation, IEA Heat Pump Program Symposium, Chillventa Congressing, October 8, 2012.
57. "Novel Compressor Technologies for Net Zero Energy Buildings," invited seminar presentation, IEA Heat Pump Program National Team Meeting, Chillventa Congressing, October 9, 2012.
58. "Developing a Campus Portfolio of Global Engineering Competency Programs," invited panel presentation, 15th Annual Colloquium on International Engineering Education, Newport, Rhode Island, November 1, 2012.
59. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Fort Wayne Indiana ASHRAE Chapter Meeting, Fort Wayne, IN, January 8, 2013.
60. "Review of Novel Compression Concepts for HVAC&R Applications," Distinguished Lecture, Tyler Texas ASHRAE Chapter Meeting, Tyler, TX, January 24, 2013.
61. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Bluegrass ASHRAE Chapter Meeting, Lexington, KY, February 6, 2013.
62. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Nashville ASHRAE Chapter Meeting, Nashville, TN, March 12, 2013.
63. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, ASHRAE Region VI CRC, La Crosse, WI, May 3, 2013.
64. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Long Island ASHRAE Chapter Meeting, Long Island, NY, May 14, 2013.
65. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Cleveland ASHRAE Chapter Meeting, Cleveland, OH, January 15, 2014.
66. "Review of Novel Compression Concepts for HVAC&R Applications," Distinguished Lecture,

Central Indiana ASHRAE Chapter Meeting, Indianapolis, IN, February 11, 2014.

67. "Review of Novel Compression Concepts for HVAC&R Applications," Distinguished Lecture, South Dakota ASHRAE Chapter Meeting, Sioux, SD, March 5, 2014.
68. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Iowa ASHRAE Chapter Meeting, Des Moines, IA, March 6, 2014.
69. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Akron ASHRAE Chapter Meeting, Fairlawn, OH, March 28, 2014.
70. "Recent Research on CO_2 Heat Pump Systems and Components," invited seminar presentation, Shanghai Jiao Tong University, Shanghai, China, July 24, 2014.
71. "Novel Compression and System Concepts for Cold Climate Air-Source Heat Pumps," invited seminar presentation, University of Shanghai for Science and Technology, Shanghai, China, August 5, 2014.
72. "Update on Refrigerants: Past, Present and Future," invited seminar presentation, University of Shanghai for Science and Technology, Shanghai, China, August 6, 2014.
73. "University Cooperation with Industry and ME Curriculum," invited seminar presentation, University of Shanghai for Science and Technology, August 7, 2014.
74. Performance of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Seminar Presentation, 2015 ASHRAE Winter Conference, Chicago, IL, January 27, 2015.
75. "Performance of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Invited Graduate Seminar Presentation, Kansas State University, Manhattan, KS, September 30, 2015.
76. "Organic Rankine Cycles Experimentation and Analysis," Seminar Presentation at Eaton Corporation, Detroit, MI, January 4, 2016.
77. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, New Mexico ASHRAE Chapter Meeting, Albuquerque, NM, January 19, 2016.
78. "Center for High Performance Buildings (CHPB)," Seminar Presentation, Central Indiana ASHRAE Chapter Meeting at Purdue University, West Lafayette, IN, March 8, 2016.
79. "Review of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Distinguished Lecture, Evansville ASHRAE Chapter Meeting, Evansville, IN, April 12, 2016.
80. "The School of Engineering Education at Purdue University: Laying the Educational Foundation for the Future," Seminar Presentation, School of Engineering Education, Purdue University, April 14, 2016.
81. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Malaysia ASHRAE Chapter Meeting, Kuala Lumpur, Malaysia, March 16, 2017.
82. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Thailand ASHRAE Chapter Meeting, Bangkok, Thailand, March 21, 2017.
83. "Review of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Distinguished Lecture, Thailand ASHRAE Chapter Meeting, Bangkok, Thailand, March 21, 2017.
84. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Hong Kong ASHRAE Chapter Meeting, Hong Kong, China, March 23, 2017.
85. "Review of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Distinguished Lecture, Hong Kong ASHRAE Chapter Meeting, Hong Kong, China, March 23, 2017.

86. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, ASHRAE Akron/Canton Chapter Meeting, Akron, Ohio, April 21, 2017.
87. "Review of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Distinguished Lecture, Long Island ASHRAE Chapter Meeting, Long Island, NY, May 9, 2017.
88. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, Chile ASHRAE Chapter Meeting, Santiago De Chile, June 20, 2017.
89. "Review of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Distinguished Lecture, South Dakota ASHRAE Chapter Meeting, Sioux Falls, SD, April 4, 2018.
90. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, ASHRAE Research Triangle Chapter Meeting, Durham, NC, January 9, 2019.
91. "PDSim: A Generalize Modeling Platform to Predict the Performance of Positive Displacement Compressors," Invited Seminar, Institute of Refrigeration, London, UK, February 7, 2019.
92. "Update on Refrigerants: Past, Present and Future," Invited Seminar, Oak Ridge National Lab, Oak Ridge, TN, March 25, 2019.
93. "Update on Refrigerants: Past, Present and Future," Distinguished Lecture, ASHRAE East Tennessee Chapter Meeting, Knoxville, TN, March 27, 2019.
94. "Recent Developments in Refrigeration and Air-Conditioning Compressors," Invited Seminar, Honor Colloquium, The Schaufler Foundation, April 5, 2019.
95. "Towards High Efficient, Intelligent, and Flexible Building Technologies and their Equipment," Invited Seminar, University of Liège, Liège, Belgium, June 3, 2019.
96. "Towards High Efficient, Intelligent, and Flexible Building Technologies and their Equipment," Invited Seminar, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P.R. China, July 15, 2019.
97. "Improving Vapor Compression System Efficiency through Advanced Vapor Compression Technologies," Invited Seminar, Department of Building Science, School of Architecture, Tsinghua University, Beijing, P.R. China, July 15, 2019.
98. "Improving Vapor Compression System Efficiency through Advanced Vapor Compression Technologies," Invited Seminar, Int'l Summer School, Shanghai Maritime University, Shanghai, P.R. China, July 16, 2019.
99. "Towards High Efficient, Intelligent, and Flexible Building Technologies and their Equipment," Invited Seminar, Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, P.R. China, July 18, 2019.
100. "Purdue University College of Engineering Undergraduate Education Activities Update," Invited Seminar, School of Energy and Power Engineering," University of Shanghai for Science and Technology, Shanghai, P.R. China, July 18, 2019.

KEYNOTE PRESENTATIONS:

1. "Recent Advances in the Transcritical CO_2 Cycle Technology," Keynote Lecture, 18th Nat'l & 7th ISHMT-ASME Heat and Mass Transfer Conf., IIT Guwahati, India, Jan. 6, 2006.
2. "Compressor Research at the Ray W. Herrick Laboratories," Keynote Lecture, 50 Years Anniversary Celebration, Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, Shanghai, China, April 13, 2006.
3. "Recent Research of Novel Compression Concepts for Refrigeration Applications," Keynote

Lecture, 22nd Int'l Congress of Refrigeration, Beijing, China, August 25, 2007.

4. "Experimental Investigation of Local Heat Transfer Coefficient for Refrigerant Flow Boiling in Microchannel Cold Plate Evaporators," keynote lecture, 22nd Int'l Congress of Refrigeration, Beijing, China, August 25, 2007.
5. "Novel Compression and System Concepts for Cold Climate Air-Source Heat Pumps," Keynote Lecture, 5th International Conference on Cryogenics and Refrigeration, ICCR2013, Hangzhou, China, April 7, 2013.
6. "Recent Research of Advanced Scroll Compressors and Expanders for Vapor Compression and Organic Rankine Cycles," Plenary Speaker, Int'l Conf. on Compressors and Coolants, Smolenice, Slowakia, September 2, 2013.
7. "Recent Research of Novel Compression Concepts for Vapor Compression Heat Pumping, Air Conditioning and Refrigeration Systems," Keynote Speaker, Int'l Conf. on Compressors and their Systems, City University London, UK, September 9, 2013.
8. "Recent Research of Novel Compression Concepts for Vapor Compression Heat Pumping, Air Conditioning and Refrigeration Systems," Plenary Speaker, Int'l Conf. on the Future of the Refrig. and Air Conditioning Industry – Are You Ready? Guangzhou, China, April 13, 2014.
9. "Novel Compression and System Concepts for Cold Climate Air-Source Heat Pumps," Plenary Speaker, Int'l Conf. on the Future of the Refrigeration and Air Conditioning Industry – Are You Ready? Guangzhou, China, April 14, 2014.
10. "The experience of Cooperation between US University with Industry," Keynote Speaker, Nat'l Conf. on New Technologies in Refrigeration, Chengdu, China, July 30, 2014.
11. "Novel Compression and System Concepts to Achieve High-Efficiency Heat Pumps," Keynote Speaker, Nat'l Conf. on New Technologies in Refrigeration, Chengdu, China, July 31, 2014.
12. "Performance of Novel Compression Concepts for Heat Pumping, Air Conditioning and Refrigeration Applications," Keynote Speaker, XII. International HVAC+R & Sanitary Technology Symposium, Istanbul, Turkey, April 1, 2016.
13. "PDSim: A Generalized Simulation Tool for Predicting the Performance of Fixed Volume Ratio Expanders," Keynote Speaker, The 4th Annual Engine Organic Rankine Cycle Consortium Workshop, Troy, MI, Nov. 16, 2017.
14. "Improving Vapor Compression System Efficiency through Advanced Vapor Compression Technologies," Keynote Speaker, 9th Int'l Conf. on Compressors and Refrigeration (ICCR 2019), Xi'an, P.R. China, July 11, 2019.
15. "Past, present and future of refrigeration: Pathways to the next generation heating and cooling technologies," Keynote Speaker, 2020 IIR Rankine Conf., Virtual Event, Glasgow, Scotland, July 29, 2020.