Low Pressure Air Refrigeration

ORNL (Oak Ridge, Tennessee); Principal Investigator Name: Dr. Kashif Nawaz

Technical Category 3_B_Building Heating and Cooling
Proposed Funds: Fed: $500,000/ Cost Share: $125,000/ Total: $625,000
Project Duration: 2 years

1. CONCEPT SUMMARY

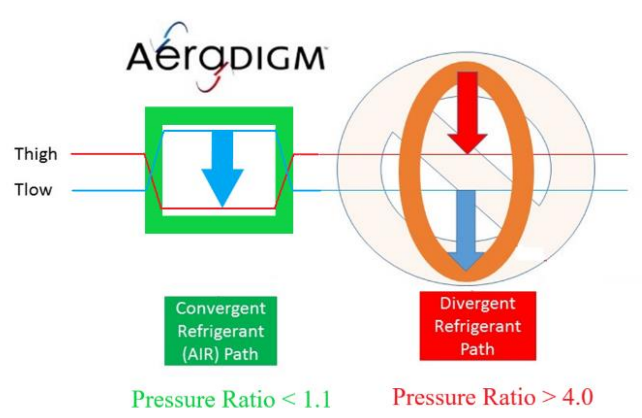
AeraDIGM Inc., an early-stage start-up, introduces a new paradigm for using air as a refrigerant, a natural refrigerant. By separating the energy costs assignable to air movement from the energy costs assignable to running the refrigerant loop, it becomes possible to justify elimination of the refrigerant loop altogether. AeraDIGM's patented approach to heating and air conditioning eliminates two phase refrigerants and the energy consumption attendant to their use in vapor-compression systems. AeraDIGM's non-vapor-compression technology and methods are projected to cut heating, air conditioning, and refrigeration costs by 75% for both air and water sourced heat pumps with greater gains when compared to natural gas and oil heating.

Most crucial for the consideration of ARPA-E is the distinction from all prior assessments that DOE has made, dismissing the use of air as a refrigerant. N.B. The new paradigm eliminates the high pressure ratios required for operation of any refrigerant loop altogether. The uniqueness of key features proposed herein has been confirmed by the worldwide Patent Cooperative Treaty Examiner.

2. INNOVATION AND IMPACT

Problem to be solved: AeraDIGM's overall goal is to deliver heating and cooling at or near the energy budget of fans. The baseline cost of fans moving ambient air across the outside of two separate heat exchanges is now 25% - 35% of air conditioner operating costs. The critical success factor is to move heat with little more than the energy it takes to move the air itself. This will increase the Coefficient of Performance (COP) for refrigeration at the 95 F rating point from its present COP, near 1. AeraDIGM expects to deliver a COP of 20 or better.

Innovative and transformational solution: The new paradigm temporarily changes the pressure of ambient air streams while crossing heat exchangers, moving their temperatures to cross over between the two working temperatures. (Only one of the ambient air streams need be changed in pressure although it would be at a higher pressure ratio. Trade-offs will be investigated as new Fan Replacement modules are developed.) The old paradigm requires much larger pressure changes in order to move the refrigerant between temperatures well outside the two working temperatures. The old paradigm expends more energy at the required pressure ratio of 4 or higher in contrast to the new paradigm which operates near 1.1.

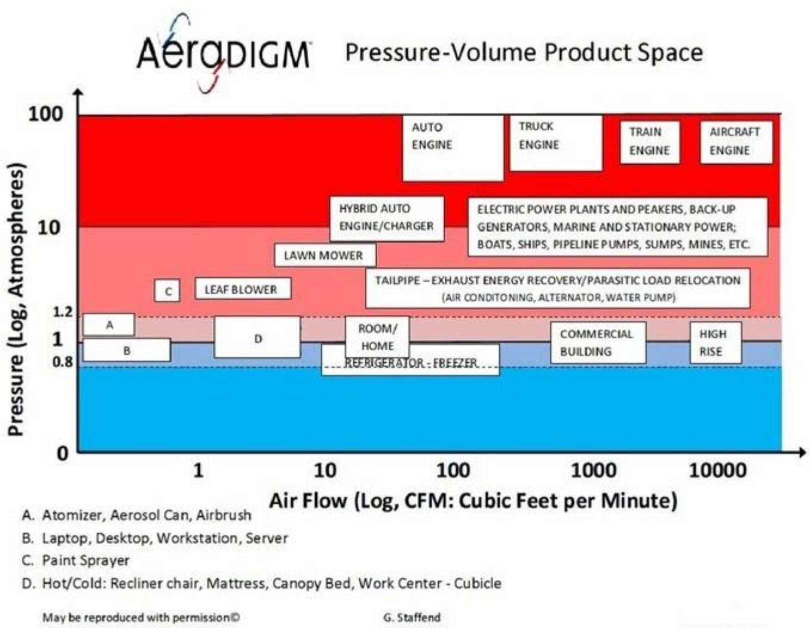


Moreover, the Fan Replacement mechanism which temporarily changes pressure around the heat exchanger also performs the function of a constant pressure heat engine, capturing work otherwise lost in open convection systems as free expansion. No need to burn fuel. Whether cooling or heating, the work produced by adiabatic expansion or contraction depends only on the change in temperature and the heat capacity of the gas.

AeraDIGM Gets All The Work Out (GATWO) regardless of whether the pressure inside the Fan Replacement plenum is established above or below the outside pressure. It's still a heat engine producing work according to the same rules. (The constant pressure heat transfer stipulation only makes it possible to more easily compute the work captured.) In this case the work recovered can be used to offset the energy invested in moving the ambient air and changing its pressure inside the plenum. Call it a 40% rebate. Claim the work in both ambient air streams.

Disruptive potential: ARPA-E funding may be imperative for birthing this disruptive new technology. Entrenched industry interests along with established beliefs in the academic community remain hostile to anything but the slightest incremental extensions of their present ownership. ARPA-E funding will dramatically accelerate the validation of this new technology, a paradigm shift in HVAC methods and practice.

Validation of this new paradigm will eclipse other refrigeration technologies which already pay to move the required mass flow of ambient air across heat exchangers at both working temperatures. Using the same ambient air streams as the refrigerant operating at very low pressure ratios crossing between the working temperatures will yield unprecedented efficiencies. Once the cost of moving air is isolated from the cost of moving heat, AeraDIGM will be acknowledged to have found the irreducible minimum cost method for moving heat between two ambient working temperatures. The Pressure-Volume Project Space reflects potential low pressure applications, all candidates for Getting All The Work Out (GATWO).



Positive impact: Widespread adoption, motivated by savings in purchase cost and especially long-term energy savings, can satisfy 25% of the 2050 Paris climate goals. AeraDIGM saves roughly 75% of the heat pump energy cost by eliminating the refrigerant loop and environmentally harmful and high Global Warming Potential refrigerants altogether. When cooling, because the new paradigm only temporarily raises the temperature of the indoor ambient air stream, AeraDIGM reclaims latent heat losses of 20%-35% which are unavoidable in the sensible heat ration of the old paradigm. In contrast, AeraDIGM delivers a sensible heat ratio of 100%.

Quantitative metrics: Technology Category 3_B_Building Heating and Cooling

Heat Delivery Mechanism	Natural Gas	Heating Oil	Electricity
Due to inefficiencies in combustion and delivery by Furnace or Boiler	$17.6	$26.03	$37
Multiple of AeraDIGM cost	4.4 X	6.5 X	9.25 X
Air Source Heat Pump using vapor-compression technology			$16
Multiple of AeraDIGM cost			4.0 X
Geothermal Heat Pump using vapor-compression technology			$10.94
Multiple of AeraDIGM cost			2.7 X
AeraDIGM Air Source Heat Pump (estimated)			$4
AeraDIGM Geothermal Source Heat Pump (estimated)			$2.74

Based on efficiencies stated by US EIA, underlying fuel data as of 17Dec2015.
AeraDIGM operating cost calculated as 25% of Vapor-Compression.

3. PROPOSED WORK

Final deliverable*:* The overall goal is to deliver heating and cooling air at or near the energy budget of fans. The new paradigm makes air the preferred refrigerant for building heating and cooling. This technology uses both the high-temperature and the low-temperature air streams as independent refrigerants. The new paradigm changes their temperatures to cross temporarily between the two working temperatures. Heat can then flow from "inside" to "outside" streams. The positive displacement pumps which invert the heat exchanger approach temperatures also capture work from the heat transfer that is lost as free expansion in open convection systems. The instant rebate in both ambient air streams is work equal to 40% of heat transferred.

Alternative approaches: Considerable investments in Computational Fluid Dynamics (CFD) modeling have reached a dead end. After years of work with Solidworks , they finally admitted that their tools will not handle the required shapes. Dassault Systems cannot promise that their far more costly tools will deliver sufficient accuracy. Continuing our partnership with the recognized laboratory at ORNL for experimentation is the best known route to gain reliable data.

Background that supports the proposed approach: The AeraDIGM Design Review completed by industry recognized premier design improvement organization, Munro & Associates, provides suggestions and safeguards for assuring that the driven pump will recover the work of compression as air is returned to (or received from) atmospheric pressure. The heavy cast metal rotors of COTS Roots Blowers can be re-engineered for pressures of 1-3 PSIG. Extensively documented: www.aeradigm.com, US8424284, US8596068, US9897336, US10612800

Technical challenge: The most significant challenge comes from the Department of Energy in "Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies" by Navigant Consulting, March 2014. Thermoelastic technology, presenting an opportunity to save 2.75 Quads/year was at the top of their list, while the Brayton Heat Pump, was at the bottom of their list due to well understood inefficiencies of pumps operating at pressure ratios near 4. All refrigeration technologies therein reviewed can be characterized as "divergent" refrigeration, including Brayton-Joule. Only the new paradigm, convergent air cycle refrigeration proposed by AeraDIGM for pressure ratios near 1.1 will eliminate vapor-compression subsystems and the energy cost attendant to their pressure ratios.

Key technical risks: A simple sequence of experiments has been formulated to validate Fan Replacement and Convergent Refrigeration using COTS Roots Blowers, certified over 150 years to deliver needed performance as compressors. The heavy machined castings which support high compression are far less desirable when seeking efficiency in capturing the work of expanding gas. So the 150 year old design will be "cloned" or "skinned" to produce 3D printed light-weight equivalents, expected to perform better at very low pressures. One variant is widely used for metering gas flows. It may capture work at low pressures. Experiments needed.

Technical risk and mitigation: The technical risk relates to the reconfiguration of this or similar pumps into a configuration more conveniently packaged for commercial use as a "drop in" replacement for common commercial HVAC units on today's market. A number of tempting designs have been identified but they must be built and tested.

Techno-economic challenges: Simply stated, even a pair of re-engineered "light weight" Roots Blowers is expensive relative to the fan it will replace. The cost of a pair of single vane pumps mounted on the same shaft will not compete with a fan blade. But they will beat the cost of complex compressors now used to move refrigerants at a pressure ratio of 4. The techno-economic challenge is to avoid an increase in "first costs" regardless of how much the operating cost and lifetime expenditure may compare to HVACR. ARPA-E is needed to validate, baseline, and accelerate development lower cost high performance Fan Replacement pumps.

4. TEAM ORGANIZATION AND CAPABILITIES

Management: Dr. Kashif Nawaz, ORNL; Gilbert Staffend, AeraDIGM

AeraDIGM: Overall responsibility for this project including external interactions

ORNL: Thermal Analysis and prototype testing, analysis of results, and final report

Centrepolis C3 Accelerator, Lawrence Technological University; coordination of design, build, control activities and securing matching funds from State of Michigan and other sources.

Munro Associates: Potential Design and Build activity

Dr. Kashif Nawaz serves as Group Leader for Multifunctional Equipment Integration and Senior Research Scientist for the Technology Directorate: Buildings and Transportation Science. His laboratories include testing HVAC Systems and components. Dr. Nawaz continues to serve as Chairman of the ASHRAE Technical Committee on Thermodynamics and Psychrometrics. Dr. Nawaz was PI for a similar DOE proposal with AeraDIGM in 2017. It was not funded.

Gilbert Staffend has 8 patents detailing GATWO features extensively. Previously responsible for engineering and manufacturing systems and their improvement at Ford (including Climate Control, Engines, Computer Centers), Honeywell Computer Integrated Manufacturing across all divisions, and AlliedSignal (including Garrett TurboChargers).

Dan Radomski, now Director of LTU's C3 Accelerator has supported the evolution of AeraDIGM concepts in many roles, initially as a Manager at NextEnergy.

Jim Newman is Owner and Managing Partner of Newman Consulting Group, LLC, an EPA Energy Star(r) and Rebuild Michigan(r) Partner. He is a Certified Energy Manager, a LEED Accredited Professional, an Operations and Performance Management Professional, a Building Energy Assessment Professional, and a Fellow of the Engineering Society of Detroit (ESD) and of ASHRAE. He has more than 50 years of experience in HVAC design and manufacturing.