Cut Computer Center Power Usage Effectiveness Below 0.6

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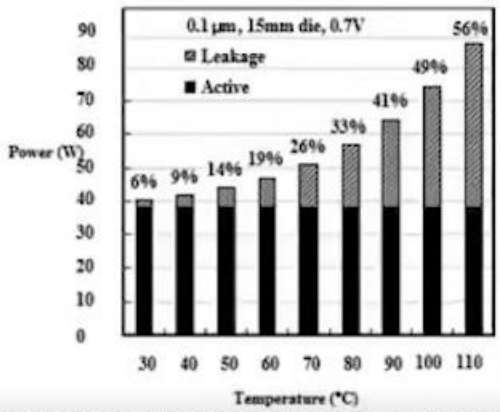
Technical Category 7E Data Centers and Computation
Proposed Funds: Fed: $500,000/ Cost Share: $125,000/ Total: $625,000
Project Duration: 2 years

1. CONCEPT SUMMARY

Placing a heat exchanger or a heat source in a closed plenum between two pumps can generate work equal to 40% of the heat transferred. Patented as "Fan Replacement" (US 9,897,336) the POC comes straight out of the Dresser-Roots COTS Engineering Manual. Fan Replacement delivers 100 Watts of light for 60 Watts. Likewise, Fan Replacement delivers 100 MIPS of computation for 60 MIPS of electricity as we measure it now. And when cooling temperatures are reduced further, leakage can be significantly reduced. How about getting 100 MIPS of computation for 40 or 50 MIPS of electricity? Computer Center Power Usage Effectiveness can be cut from today's average of 2.5 to 0.6. Much lower if computers are cooled at lower temperatures and when the actual cost or running the computer is measured separately from the building it happens to be housed inside.

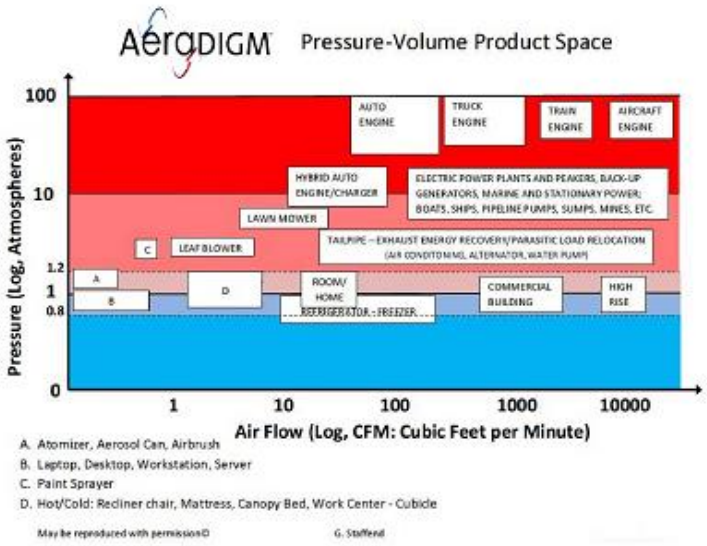


Power Consumption of a die as a function of temperature. Courtesy of Vivek De, Intel.

2. INNOVATION AND IMPACT

- The same air that is used to cool a computer will generate electric power to offset the cost of both cooling and computing. Fan Replacement will also directly control CPU operating temperature (wasted energy and performance).
- United States Patent 9,897,336 granted 20 February 2018 certifies that there has been no commercial or academic investigation of Fan Replacement techniques therein described to capture the work now lost as "free expansion", the air/gas volume changes produced by convective heat transfer. The amount of work done during an adiabatic expansion is determined entirely by the temperature change and the heat capacity.
- The capture of work now lost as "free expansion" can be delivered by introducing Getting All The Work Out (GATWO) techniques throughout the "Pressure vs. Volume Product Space. Tail-pipe exhaust wastes 85%-95% of the energy produced in fuel burning engines. The best "high efficiency furnace" still sends all the power of free expansion straight up the chimney. The performance of every heat pump and air conditioner whether air sourced or geo-thermal can be at least doubled, far more in extreme climates. Eight recently granted patents attest that there are no similar existing or emerging technologies in spite of the fact that the countless established candidates for

improvement and replacement remain uninvestigated throughout the Pressure versus Volume Product Space.

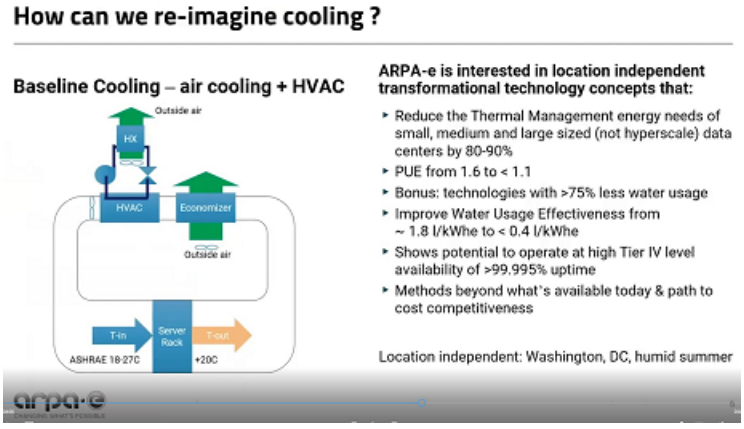


- AeraDIGM, the new paradigm for Getting All The Work Out (GATWO), introduces unprecedented mechanisms to maximize the work obtained from a unit of fuel. Rather than maximizing power (i.e., "power = work/time" Power is the amount of work obtained within a unit of time.) AeraDIGM shifts the focus to maximizing amount of work obtained from any given unit of fuel. Noxious byproducts of combustion are correspondingly reduced or eliminated altogether. The ambient air stream itself becomes the only energy-efficient refrigerant choice. An avalanche of new mechanisms and methods invite research and development throughout the entire Pressure Versus Volume Product Space.

Innovation	Impact: Technology Category 7_E Data Centers and Computation
Fan Replacement - convective heating	Work captured from resulting volume increase depends on the temperature difference and heat capacity alone. (Output pump acting in generator mode.)
Fan Replacement – convective cooling	Work captured from volume decrease depends on the temperature difference and heat capacity alone. (Input pump acting as generator while gating reduction in pressure to plenum.)
Reduce approach air temperature to computer components.	Reduction in leakage current directly increases the number of instructions processed for the same amount of energy. (MIPS per amp increases.)

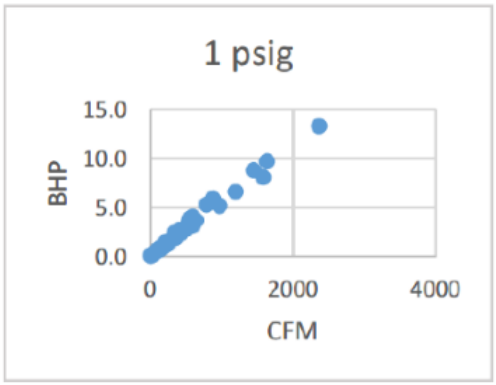
3. PROPOSED WORK

- The end of project goal is the measurement and validation of a commercializable prototype which shall be extendable from one-to-many data center computer racks. By isolating the "computer operation and cooling" issues from the building and location issues we will provide the basis for delivering "best case" PUE, deliverable reliably regardless of building and climate. Our "rack by rack" module is fed outside air



directly. After passing through the computer rack, the air may be exhausted, recirculated, or used to warm or replace building air. In every setting, this model can be expected to outperform arpa-e's model for "cooling re-imagined".

- In spite of the many alternative pump designs and methods already available or suggested for future development, the only Commercial Off The Shelf pumps known to provide efficiency above 90% at the very low pressure differentials so manifestly adequate and desirable for this application are Roots blowers, reliably available for 150 years. Because they are engineered for much higher pressures and flows than are needed here, it will be appropriate to modify them or replace them in later production runs, but they are well suited for the demonstration of computer rack cooling/energy recovery.
- Our success in this demonstration is supported by the published "Engineering Manual" performance data of Commercial Off The Shelf (COTS) pump and blower manufacturers of various sorts. Present technology is predicated on the use of fans to move air on both sides of the refrigerant loop. The energy cost of moving air is a separate problem from the energy cost of the refrigerant loop. Once the energy cost of the refrigerant loop is translated into the energy cost of cooling the same air that we are already compelled to move, the cost of cooling that same air becomes a trifle. For example, Figure 2 shows the scatter diagram from the URAI[5] data sheet across a broad range of pumps. As can be seen, the energy required to move the air regardless of pump is about 180CFM/BHP at 1PSIG. Subtracting comparable energy costs for a range of fans moving the same mass flow of air and further subtracting the energy cost of adiabatic heating 1PSIG from the base of 68°F shows pumping efficiency in the neighborhood of 90% for delivering heat. All this is based on pumps that are designed and manufactured to withstand much higher pressures. Even before design optimization for low pressure and high volume operations, the needs of a driving pump may already be demonstrated by Commercial Off The Shelf (COTS) engineering manuals.



- As much as we believe we have anticipated all eventualities, the glaring fact remains that this has never been done before. The AeraDIGM Design Review completed by one of the world's premier design improvement organizations, Munro & Associates, already 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 weight of cast metal rotors is concerning when the exit pump must be driven at pressures ranging from 1-3 PSIG, so considerable engineering time will be devoted to delivering some variant of the baseline Roots Blower for laboratory testing. Provided that our proposal is funded, this initial work of the Design Review may be extended with Munro & Associates to provide a more thoroughgoing down-select from the options most likely to maximize pump performance at both the entry to and the exit from the computer rack.

  - There is no physical system level data validating the concept except by analysis of existing papers and data generated independently.
  - First risk is at the subsystem level (two blower) configuration; can this concept capture work as air is returned to atmospheric pressure?
  - To mitigate this risk, this project defines a set of acceptance criteria based upon performance of an existing system (to be defined early in the project).
  - Second risk is the capability to validate the claims for efficiencies impacting cost as related to performance; are the performance levels similar to those claimed and supported by devices which are both readily manufacturable at the requisite level of quality and at a price in line with market expectations?
- As much as we believe the instant recovery of computer operating costs in the neighborhood of 40% will provide irresistible incentive to manufacturers and customers alike, the configuration and replacement of intra-enclosure fans remains a challenge along with the higher first cost, whether blowers are configured rack-by-rack or row-by-row. The availability of raised flooring to provide easy access to outside air along with the provision of exhaust and/or selectable recirculation is yet to be dealt with.

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.