TOWARD A SUSTAINABLE ECOSYSTEM: HARVESTING THE WASTE HEAT FROM DISTRIBUTED DATA CENTERS FOR OTHER-PURPOSED BUILDINGS

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Executive Summary

The conventional data center is a single building that centralizes the information and communication technology (ICT) hardware of an organization. It requires considerable energy resources to both run the computers and manage the massive amount of heat that they produce – an inherently non-sustainable paradigm as information technology (IT) becomes even more integrated into every day life. We propose an alternative data center vision where the ICT hardware is decentralized and distributed across an entire community or campus. These "distributed" data centers are directly integrated into other-purposed buildings that harvest the heat produced by the ICT equipment for space, water, or process heat. With optimal control of integrated ICT and building systems, these distributed data centers can be operated to reduce the overall energy consumption of the campus. We call this concept Environmentally Opportunistic Computing (EOC), because we aim to take advantage of the inherent thermal byproduct of computing hardware in order to realize environmentally friendly and sustainable infrastructure. **The goal of this research is to optimize harvesting computational waste heat for other-purposed buildings as a path toward a sustainable community ecosystem.** In this work, we will build simulation models validated by an experimental EOC prototype and use them to evaluate and optimize integrating EOC across an entire community or campus. At the outcome of this research, we will be able to determine the most effective and efficient implementation of EOC in order to minimize energy usage and improve an organization's overall sustainability.

Description of Proposed Research

Research Problem and Societal Impact – The United States Environmental Protection Agency (U.S. E.P.A.) estimated that the U.S. spent over $4.5 billion in 2006 to cool and power data centers containing ICT equipment and predicted this cost will increase by 65% over 5 years. Data centers produce 2% of carbon emissions worldwide and already accounts for 3% of U.S. energy consumption. As IT continues to grow as the backbone of our economy, security, and quality of life, these values will continue to rise, and it is clear that a new perspective is needed on how IT resources are managed. Similarly, the United States Department of Energy (D.O.E.) predicted that the expenditures to heat and cool buildings will rise exponentially, reaching as much as $100 billion annually in the next 20 years. As communities (municipalities, campuses, and industrial parks), become more aware of the adverse energy and environmental impact of current practices, there is a real opportunity to redefine the conventional approach to building design, resource management, and IT infrastructure in a meaningful way – leading to a truly sustainable ecosystem.

We propose Environmentally Opportunistic Computing (EOC) as a step toward a sustainable ecosystem, by using the innate heat of IT as energy sources for buildings. Figure 1 shows the basic concept of EOC as a network of distributed data center nodes that are integrated into other-purposed buildings. The waste heat from the ICT equipment can be used as space heat in a commercial building, water heat for a hospital, or process heat in an industrial setting. Fully implemented, EOC nodes would be distributed across a community, and the compute jobs would be sent to the EOC node where either the energy is cheapest or the need for waste heat is greatest. EOC energy savings are envisioned to come from multiple sources. The other-purposed buildings' energy usage would be reduced by the "free" heat from the EOC node, and the cost to thermally manage a large, centralized data center would be removed. Ultimately, EOC is a novel sustainability approach that uses one energy consumption problem to solve another.

Research Plan – Our broad research goal is to optimize how EOC nodes are integrated with buildings and how they are controlled, including communicating with the building heating/cooling controls and the scheduling of computing jobs. For this research project, we will focus on building thermodynamic models to predict energy consumption and use a holistic, lifecycle energy analysis to reveal the basic relationships between the key parameters that define the problem, such as space and material requirements and operating conditions. This project will be guided by three objectives:

(1) Build an experimentally validated thermal model for a representative building-integrated data center that incorporates intelligent ICT control and management for optimal energy efficiency.
(2) Build a detailed thermal model for a representative building that predicts the thermodynamic performance of the building with and without data center waste heat.
(3) Conduct "cradle-to-grave" lifecycle analyses to evaluate the total energy consumption of a representative building with and without an integrated data center including operational, build, and procurement energy expenditures, potential data center savings, and optimization of the integration.

Essential to this project is an EOC prototype we have developed and implemented at a local greenhouse in collaboration with the City of South Bend, IN (Figure 2). In addition to proving the concept of EOC, it provides us with a platform to validate our thermal model and develop job-scheduling algorithms to produce heat for the greenhouse. At the outcome of this research project, we will have an analysis of the efficacy of EOC implementation and a set of tools to conduct more rigorous evaluation of implementation strategies.

Relation to Sustainable Ecosystems (Topic 27) – This research is directly aligned with the broad goals and aims of the Sustainable Ecosystems research topic (Topic 27) under the Sustainability theme. Our efforts focus not only on improving data center energy performance, but also on the holistic integration of information technology within a community. This research program address issues of data center thermal management, as well as the efficient use of energy for more sustainable infrastructure taking both operational and "cradle-to-grave" lifecycle perspectives. This work also addresses the particular research challenge of campus/city-scale IT infrastructure, proposing an innovative solution to energy resource management using IT not only to control building heating and cooling, but to act as a heat provider as well.

Related Work & References

Related Work – Over the past decade, there has been significant interest in improving the energy efficiency of data centers, and groups like Hewlett Packard Laboratories have made seminal contributions on fundamental analysis and evaluation techniques.[1] Organizations like the U.S. E.P.A.[2], American Society of Heating Refrigeration and Air-Conditioning Engineers[3], and the multi-institution The Green Grid have made significant strides in redefining metrics for data center efficiency, and companies like Yahoo, Inc., Facebook, Inc., and Google, Inc. have recently touted the improved efficiency of their new data centers.[4] Along that vein, a few projects have been implemented that utilize a portion of the waste heat from large data centers for adjacent structures including research laboratories, greenhouses, and office buildings.[5] Our work looks beyond current efforts to incrementally improve the operating efficiency of a single centralized data center or a single building, and instead seeks methods that will more broadly influence the energy efficiency of an entire community.

Our research team has been working on the issue of waste heat utilization as a path toward sustainable data centers and buildings for a number of years[6], growing from theoretical studies of dynamically migrating computing loads in order to control the exhaust heat from servers[7,8] to an in-place, fully realized prototype of an EOC node (Fig. 2).[9-11] Our 6.1 m × 2.4 m × 2.4 m containerized data center is a prototype EOC node that is directly integrated it into a local greenhouse in South Bend's most prominent park. It houses three racks of servers that are linked to the Notre Dame Center of Research Computing's (CRC) network and are actively used to run scientific computations. The EOC node operates on the principle of free air cooling, relying on unconditioned, external ambient air or return air from the greenhouse to cool the servers rather than conditioned, chilled air. Currently, the prototype delivers ~90-100°F steady airflow into the greenhouse, and preliminary estimates predict as much as 10-15 kW in deliverable energy.[9] Concurrently, we have developed both intelligent algorithms to maximize the heat generated by the servers while maintaining them within operational temperatures[12] and preliminary thermal models to predict the temperature in the containerized data center.[13]

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Budget and Resources

Our research team is led by PI Go, a Professor of Mechanical Engineering, and includes Co-PI Buccellato, a LEED-certified Professor of Architecture, and Co-PI Brenner, Associate Director of the CRC. PI Go and Co-PI Brenner currently direct the undergraduate research of two students and Co-PI Buccellato integrates her EOC research into her senior-level design course. For this proposed research program we will hire a graduate student in Mechanical Engineering who will be co-advised by PI Go and Co-PI Buccellato. We request funds for personnel for this research, including fringe benefits, as outlined in Table 1. Co-PI Brenner is not requesting any support but is fully engaged in this research. The total budget is $71,400 including 50% overhead for Year 1.

Table 1. Outline of Research Budget

PI Go	0.5 summer month
Co-PI Buccellato	0.5 summer month
Graduate student	1-year stipend
Undergraduate students (2)	summer undergraduate research stipend

To support this research, the University of Notre Dame also pledges a cost share of $20,000 to upgrade and improve our prototype EOC node, including more temperature sensors, dynamic flow control, and real-time power usage monitoring capability. This upgraded experimental platform will not only be an essential tool for validating and exercising our thermal models, but will also be better able to serve the greenhouse and the City of South Bend.

Supporting Figures

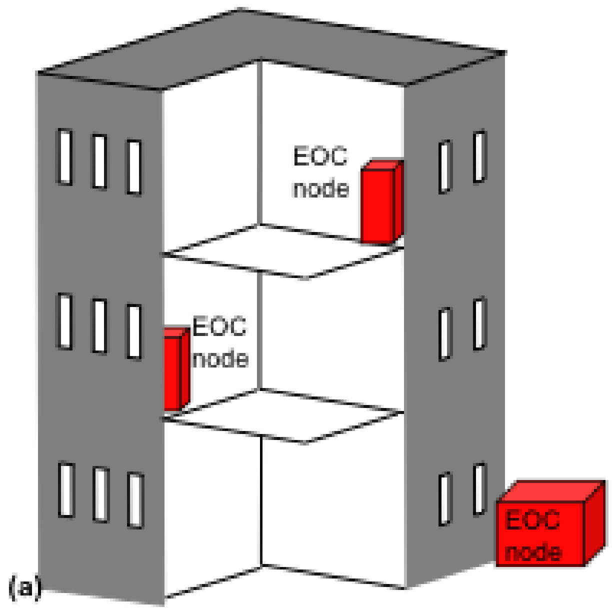

Figure 1: (a) Illustration of potential implementation of Environmentally Opportunistic Computing (EOC) nodes into a multi-level building. Small EOC nodes could be implemented on the raised floors and directly ducted with the heating and ventilation system. A larger EOC node could be placed adjacent to the building and integrated with the centralized heating/ventilation system of the building. (b) Illustration of Environmentally Opportunistic Computing implemented across an entire municipality where individual EOC nodes are integrated with a wide variety of buildings. The computing load is then migrated from node to node based on building need for waste heat and computing availability.

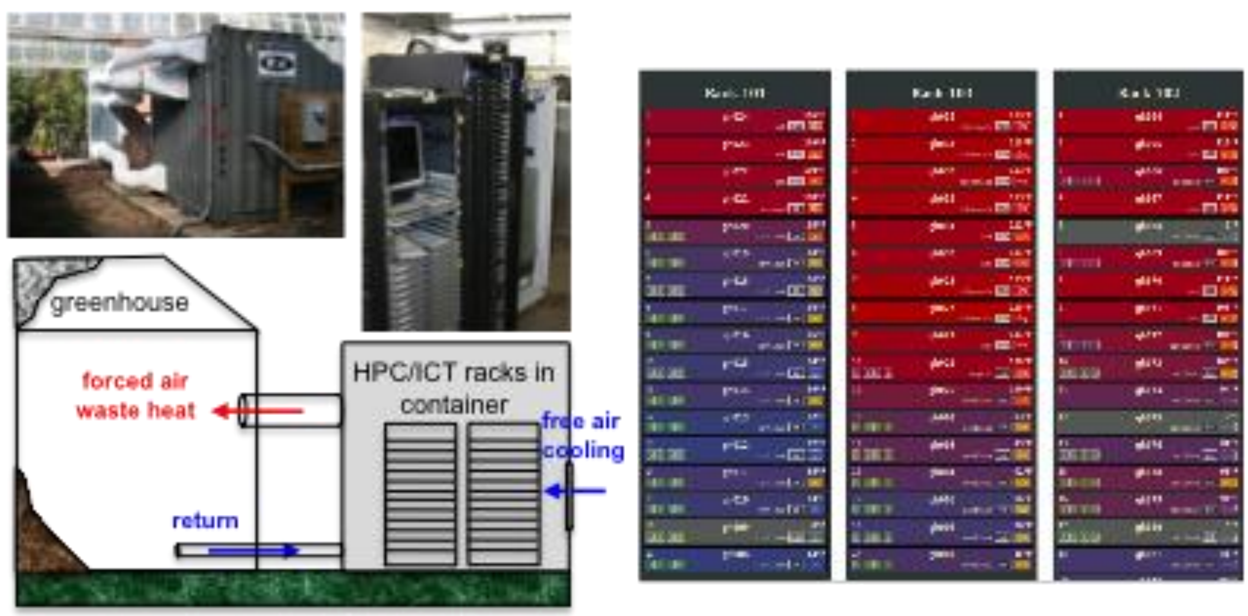

Figure 2: Our prototype EOC node implemented at the local greenhouse in collaboration with the City of South Bend. Photographs show the actual 6.1 m × 2.4 m × 2.4 m containerized data center and server racks as ducted to the greenhouse. Cooling is provided by either circulating ambient outdoor air or return air from the greenhouse through the node and the heat is expelled directly into the greenhouse. On the right are "live" images of the temperature distribution across the three server racks that we use to guide our intelligent scheduling algorithms.