1. What is the name of your organization?
University of Notre Dame - The Green Cloud Project

2. Is your organization a non-for-profit and a 501(c)3?
Yes

3. Please provide a single point of contact information for the person responsible for the grant program at your organization.
Karen Pace
940 Grace Hall
574-631-7432
Researc2@nd.edu

4. When was your organization established? If applicable, how many active members do you have?
The University of Notre Dame was founded in 1842. The Green Cloud Project was established in 2008, and currently four faculty members lead the project in collaboration with the City of South Bend and the South Bend Botanical Society. The team also includes system engineers, administrators, and approximately five undergraduate students.

5. Please list your IRS taxid number below, if not included, your grant will not be considered.
350868188

6. What is your organization's URL (website address)?
http://nd.edu/
http://greencloud.crc.nd.edu/

7. Please tell us your organizations mission statement (100 words or less).
The Green Cloud Project is a pioneering renewable energy strategy being developed at the University of Notre Dame that explores novel ways to integrate heat producing, energy hungry computational equipment with buildings to improve overall energy efficiency while promoting partnerships between the University and the local community to reduce energy consumption. By looking beyond known sources of renewable energy, the Green Cloud Project discovers and innovates new ways to reduce our collective energy consumption and carbon footprint while educating students and the community about energy conservation and the possibilities of inventive technologies.

8. Please provide a description of the project you are seeking funding for (400 words or less).
Heat is very useful source of energy; yet it is wasted by one of society's largest producers of heat – data centers (large colonies of consolidated computer equipment). Typically remotely located and air conditioned around the clock in order to maintain prime machine conditions, data centers consume nearly the same amount of energy for cooling as they do simply to operate the computers. Yet computers are only becoming more integrated into the fabric of society, so a

new paradigm is clearly needed. The Green Cloud Project aims to harvest this enormous amount of heat for adjacent buildings that need it, making both more energy efficient.

The Green Cloud Project began as a partnership between the University of Notre Dame and the City of South Bend's Ella Morris/Muessel Ellison Botanical Conservatory to use heat generated by University research computers to offset the high heating costs of the Conservatory. Our current, operational prototype is a small, container-style data center that continuously delivers 80-degree repurposed heat directly into the Conservatory during the coldest months of the year. In its first full operational year, the Green Cloud prototype was projected to offset the heat used by the Conservatory by 15%, helping to save this valued public asset that faced closure due to unsustainable operating costs.

Recognized with a 2009 Uptime Institute award, the Green Cloud Project has expanded to explore the widespread integration of computers with buildings to create heat where it is already needed, exploit cooling where it is already available, and utilize energy when and where it is least expensive. Instead of treating heat from computers as a challenge that must be overcome, we view it as a valuable heat source. Our innovative approach has the potential to boost energy conservation for both our community and worldwide in a very real and measurable way while transforming sustainable building and computing practices. To reach this ambitious goal, we need a platform that improves on our current prototype to generate high quality research data and deliver even greater impact to our local Conservatory.

We propose to use this grant to build a new, more robust Green Cloud prototype to perform as an optimized research test bed and teaching tool. The new, fully instrumented prototype will further improve the energy efficiency of the Conservatory, demonstrate the effectiveness of this new energy conservation concept, and advance its potential for widespread adoption in the design of greener buildings.

9. What is the total dollar amount you are seeking for your organizations project or program?

We request $90,000 for the Green Cloud Project. This will support the design, development, and implementation of a new operational prototype, including $56,426 for capital and construction costs, $29,195 for students and staff involved in the design of the prototype, and $4,379 for overhead costs for the University (an agreed upon rate of 15 % of all costs not including the capital costs of the prototype).

10. Please select what focus area(s) your project addresses (select all that apply)

Renewable Energy and Greener Buildings

11. What metrics and tracking will be used to measure the success of your project or program (e.g. tons of greenhouse gas emissions saved, number of energy efficient affordable homes built, or number of people impacted, etc.)?

An optimized Green Cloud prototype will enable us to directly measure the energy savings achieved by the Conservatory (in both usage and cost) by comparing actual energy use by the Conservatory post-implementation to the average energy use of the facility between 2006-2009. (Because cost can vary with time, energy usage is a better metric for energy performance while

cost is a better metric for practical economic performance.) At the completion of this one year National Environmental Grant, we will be able to report on the energy savings achieved by the new Green Cloud prototype in its initial year, provide the City with projected energy and cost savings for the future, and predict the broader energy savings potential and economic benefits of deploying additional Green Cloud installations in our local community and beyond. Using data collected from the optimized prototype proposed here, we will be able to make very real predictions about the total energy-and-economic impact of expanding this pioneering renewable energy strategy at the local and national scale.

Tracking the breadth and impact of our education and outreach efforts will be another important metric that we will use to measure the success of the new Green Cloud prototype. As part of this grant, the Green Cloud team, led by computer scientist Dr. Paul Brenner, engineering Professor David Go, and architecture Professor Aimee Buccellato, will coordinate opportunities to meet with school groups and visitors to the Conservatory to help educate the community about this pioneering conservation concept, the impact that it has already made in their community, and the implications that this emerging technology may have on our future. We will reach out to schools that serve predominantly low- to-moderate-income families, as we share a common concern that students in these demographics are not always afforded exposure to important energy and environmental issues. Because the Green Cloud Project combines technology and cutting-edge computer science with the environment, we feel this is a promising way to educate the community, K-12 and beyond, about energy conservation and our collective responsibility to solve one of our most pressing environmental problems: energy consumption. We will collect and analyze metrics on the number of tour groups, their ages, and additional relevant demographics, which will help us design unique education and outreach programs, symposia, and research-related curricula.

12. Please breifly describe the scope of your organization and the projects/programs reach (global, national, regional etc.)

The Green Cloud Project is part of the Center for Research Computing at the University of Notre Dame, one of the top education and research institutions in the United States. Although the direct impact of our pioneering concept is local, its potential to reduce energy use and improve sustainable building practices is global. The Ella Morris/Muessel Ellison Botanical Conservatory and the South Bend Parks Department immediately benefit from the energy savings achieved by the current Green Cloud prototype, and so our research has helped to sustain a valuable community asset while educating the local public about energy conservation and new renewable energy sources.

The early success of the Green Cloud technology in a practical environment has already led to presentations at a number of national conferences on computing and architecture. Our work has been recognized by a wide variety of media outlets (including The Economist, Chronicle of Higher Education, and local print and television media). It was honored with the 2009 Green Enterprise IT Award, a national award given by the Uptime Institute, and will be part of the forthcoming Handbook of Energy-Aware and Green Computing. A National Environmental Grant from Wells Fargo will advance this important energy conservation research, enabling our team to continue to discover ways to use repurposed heat to help resource-strapped communities

like ours more effectively manage their energy consumption, while potentially fundamentally changing the way buildings use energy.

13. Does your project have volunteer opportunities, if so, please briefly describe and roles and number of volunteers needed.
The Green Cloud project provides significant volunteer opportunities for University of Notre Dame students to engage with the South Bend community through research activities related to this work. Over the past three years, a number of undergraduate students have conducted research related to the project, augmenting lessons learned in the classroom with involvement in a ground-breaking project that is making a real contribution to the local community. An optimized Green Cloud prototype will require the involvement of at least four students every year to lead outreach efforts, analyze data, and improve Green Cloud operation. Volunteer docents from the South Bend Botanical Society will join our research team in development of additional educational outreach efforts to engage the public about the Green Cloud Project and the importance of energy conservation.

14. What is your project or programs begin and end date?
Upon receipt of the grant, we will commence Phase I: the design, construction, and testing of the new Green Cloud prototype. During Phase II (approximately January 2012-December 2012), we will collect and analyze energy usage data and in Phase III, we will report on the energy savings achieved by the prototype in its initial year, make projections using that data to predict the broader energy savings potential and economic benefits of the technology, and report on the success of our education and outreach activities in each of the three phases.

We see our current unique partnership with the South Bend Botanical Conservatory as the tip of the iceberg for the future of this technology. While funding from a National Environmental Grant will be immediately applied to the design, construction, and installation of an optimized Green Cloud prototype, our work to advance this pioneering energy conservation concept will continue for the foreseeable future based on the direct economic and environmental benefits afforded by the project and continued developmental support from organizations such as Wells Fargo.

15. Please briefly describe any collaboration with other non-governmental organizations, private and public sector partnerships.
In addition to our collaboration with the City of South Bend and the South Bend Botanical Society, the eBay Corporation generously donated computer equipment to support our current Green Cloud prototype. We are active in multiple professional organizations relative to this technology (such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers) but have no current formal collaborations in this regard.

16. Please list your top 5 funders:
University of Notre Dame
City of South Bend
Department of Energy grant for the Northwest Indiana Computational Grid
eBay Corporation (computer equipment donation)

17. Please list other financial institutions that will be participating in the funding of your project.
University of Notre Dame
City of South Bend

18. Have you partnered with Wells Fargo in the past, if yes, please briefly describe (100 words or less).
No, this will be our first partnership with Wells Fargo.

19. Will you be able to provide documentation of the programs or projects success via photos and a return on investment (ROI) statement by November, 2011? Will you also participate as a guest blogger on our Wells Fargo Environmental Forum blogsite?
Yes.

20. Please briefly describe what steps you are taking at your organization to be a leader in sustainability for your employees and your partners. (100 words or less)
The Green Cloud project is a pioneering effort at the University of Notre Dame and a model for emerging efficiency and sustainability practices at the University. Notre Dame's Office of Sustainability is dedicated to integrating sustainable projects, like the Green Cloud Project, into University operations, reducing our carbon footprint, reducing waste, and expanding sustainability education through new curriculum, like two recently added minors in Sustainability (College of Science) and Energy Studies (Center for Sustainable Energy, Notre Dame). For more information about the University's commitment the environment and sustainable practices, see the Office of Sustainability's website: www.green.nd.edu.

21. Please tell us why you feel a partnership with Wells Fargo is important to your organization's environmental efforts?
The most innovative changes achieved by industry and the academy have been made possible through partnerships between research entities and companies, like Wells Fargo, that conduct business in visionary ways. Wells Fargo, by the establishment of this grant, has seriously invested in advances in renewable energy, greener building, and serving communities. Wells Fargo sees these advances as not just good but imperative – not only for their own strategic resource management and bottom line, but for practicing a kind of corporate citizenship vital to changing the world for the better.

Because of its size and breadth of assets, Wells Fargo has both the ability and the vision to effect real change for the future of the environment. Wells Fargo's commitment to sustainability initiatives, like the Leadership in Energy and Environmental Design green build program (LEED), and its own funding program dedicated to climate change research, make clear Wells Fargo's genuine commitment to the environment and our collective future.

Wells Fargo is also a recognized leader in energy efficient data centers, capitalizing on "free cooling" from the local climate for their Minneapolis data center and utilizing new virtualization technologies to reduce hardware usage. The Green Cloud Project incorporates and seeks to further advance these principles of free cooling and virtualization, creating broad potential for mutual energy and economic benefit as our ground-breaking energy conservation concept

advances from the prototype to market.

Wells Fargo's support for the development of an optimized Green Cloud prototype will have an immediate and very tangible impact on the environmental and economic sustainability of South Bend's Botanical Conservatory, keeping this treasured resource open and available to our community. The optimized prototype achieved with a National Environmental Grant will enable us to collect critical scientific data to support the viability of our energy conservation concept, increase our potential to advance current sustainable building practices, and expand this important environmental initiative beyond the University and South Bend.

Environmentally Opportunistic Computing:
A Greener Approach to Computers and Buildings

Investigator:
Prof. David B. Go
Assistant Professor, Department of Aerospace and Mechanical Engineering

Co-Investigators:
Dr. Paul Brenner
Associate Director for High Performance Computing, Center for Research Computing
Research Assistant Professor, Department of Computer Science and Engineering

Prof. Aimee Buccellato
Assistant Professor, School of Architecture

Submitting Unit: Department of Aerospace and Mechanical Engineering

Participating Institutions/Organizations:
City of South Bend
Botanical Society of South Bend

Topic Area: Greener Buildings

Total Dollar Amount Sought:
$75,000
- $50,000 fully instrumented EOC prototype node
- $25,000 graduate student

Project Summary

Environmentally Opportunistic Computing (EOC) is a new approach to green buildings that seeks to develop an *energy-efficient and environmentally friendly* relationship between modern computing and current building practices, both of which are highly energy-intensive. Pioneered at the University of Notre Dame, for which we won an Uptime Institute award in 2009, EOC takes high performance computers out of traditional centralized data center and integrates them with existing (or new) buildings. The heat produced by the computers is then used by the building to help offset the operating energy costs of the building – making the building more energy efficient and greener. In current practice, high performance and enterprise computers are maintained in centralized data centers, but because a large collection of computers generates an enormous amount of heat, the data center must be constantly cooled by air conditioning in order to prevent hardware failure. As such, nearly the same amount of energy is required to cool the data center as the energy it takes to simply operate the computers, and all the heat that is generated is expelled into the environment. In 2007, the United States spent nearly $4.5 billion to run and operate data centers, consuming 3% of all U.S. electricity. Given the constant demand by the public for more powerful and functional information technology, these numbers only continue to rise. *As such, computational systems will become more integrated into the fabric of society and crucial to our economy, requiring new innovative, energy efficient, and environmentally friendly building design paradigms*.

Grand Vision of EOC

Our grand vision for EOC is to break up the large, centralized data center into smaller, decentralized modules ("nodes") that are then integrated into new or existing infrastructure such as office/commercial buildings, hospitals, industrial campuses, and government facilities. The heat generated by these EOC nodes can then be used as space, water, or process heat for these facilities, lowering operating energy costs. Further, if designed properly, the EOC nodes can operate with no air conditioning, using passive sources such as outside ambient air for "free cooling" or by utilizing aspects of the plumbing/HVAC systems of the parent building with little cost. The energy cost associated with cooling the computers is virtually eliminated, while the generated heat is utilized by the building. As the computers and buildings go through peak usage times, the computing jobs can be migrated from node to node to create heat where it is needed, to exploit cooling where it is available, and to utilize energy when and where it is least expensive, ultimately minimizing the overall energy consumption of an organization, be it a municipality, corporation, or educational institution. *However, to shift the paradigm in data center design, we need to further demonstrate the widespread practicality, utility, and potential of EOC.*

Proposed Project with the City and Botanical Society of South Bend

At the University of Notre Dame, we have implemented EOC in a prototype we call the Green Cloud to help offset the cost to heat the nearby Ella Morris/Muessel Ellison Botanical Conservatory and Greenhouse, establishing a key partnership between our university and our community. Located at the Potawatomi Park in South Bend, IN along with our city zoo, large playgrounds, an outdoor pool, and a number of large pavilions, the Conservatory is a valuable public asset and resource. Unfortunately, the prohibitive cost of running the Conservatory continues to place a strain on the Botanical Society and the City of South Bend, particularly heating the Greenhouse during the fall, winter, and spring, averaging $15,000/month during the peak winter months. Our Green Cloud prototype (http://greencloud.crc.nd.edu/) is a shipping container-style EOC node that houses three racks of high performance computing servers that are

used by Notre Dame faculty for research in areas as diverse as understanding the structure of proteins vital to biological function to discovering new materials for solar cells. During its first winter of operation (2010-2011), the Green Cloud continuously supplied nearly 80°F heat at no cost to the Conservatory and was projected to offset the heating costs by as much as 15%.

Building upon the unique partnership that EOC fosters between our University, the City, and our community, we propose to use this grant to design and build a new, optimized EOC node that will (a) further improve the energy efficiency of the Conservatory, (b) demonstrate the efficacy of this new energy conservation concept and the potential for widespread integration of EOC into the built environment, and (c) serve as an educational tool to engage the broader community as well as students at Notre Dame. With this grant, we will design a fully instrumented EOC node housing 3-5 racks of servers connected to the Notre Dame network and integrated with the Conservatory. The instrumentation will enable us to keep accurate track of the energy produced by the computers and to optimize their performance in order to maximize the waste heat delivered to the Conservatory. The node will be designed in keeping with the existing character of the Conservatory and Potawatomi Park and will be configured to easily educate the public and student groups about energy-efficient buildings and computers (such as displays showing current energy usage and savings). We will also link the performance of the node to our website so that the public can learn about the principles of waste heat recovery from real time measurements while tracking computational activity from node to node. For instance, the website will have a page that shows the location of the server currently hosting the website at that very moment, its energy consumption, and the heat it produces for the Conservatory. Students in Dr. Brenner's Student Engineers Reaching Out and Prof. Buccellato's Environmental Stewardship through Interdisciplinary Research and Design courses have already begun to incorporate and test the EOC concept in their undergraduate course work. This new, fully instrumented and optimized EOC node will provide the students and the research with a full-scale experimental laboratory to increase our collective understanding of this highly practical emerging technology while pushing the envelope in greener building technologies.

Ongoing Efforts at the University of Notre Dame

The Green Cloud project is the first EOC prototype of its kind, and it has received significant attention from the press with articles in The Economist, Chronicles of Higher Education, and the local news, as well as numerous academic publications. The Conservatory is one of the community's few public resources for low and moderate-income community members to experience nature and learn about botanical conservation. As such, there is significant excitement in the community about maintaining the livelihood of the Conservatory as well as making the City and community as a whole more energy efficient. However, our broad vision for EOC reaches beyond our early success at the Conservatory. Notre Dame is currently designing a state-of-the-art water ecology research center that will be singular in its ability to host research related to the impact of land use, invasive species, and climate change on water resources. Prof. Buccellato, who is leading the design of the facility, has begun to study the implementation of EOC into the research and education buildings in the context of her undergraduate design course. Additionally, the City of South Bend is eager to expand our institutional/municipal partnership through the implementation of EOC at the municipal wastewater treatment plant to assist in the pre-treatment or drying of solid waste. This grant would help us to further our vision and expand EOC into new applications, bringing greater awareness not only to our immediate community but the larger computing community, leading to a transformation in the way we think about data centers, green buildings, energy, and the environment.

Metrics for Measuring Success

Our metrics for measuring success will be a direct measurement of the energy expenditures (usage and cost) by the Conservatory over the course of a year as compared to the average from 2006-2009. (Because cost can modulate with time, energy usage is a better metric for energy performance while cost is a better metric for practical economic performance.) By November 2011, we will be able to report on energy savings from our current prototype during the fall, winter, and spring of 2010/2011; and at the completion of this one year National Environmental Grant, we will be able to report on the initial energy savings because of the new EOC node proposed here. We will also be able to report on projected savings over the foreseeable future.

A second metric will measure our education efforts. Prof. Go, Dr. Brenner, and Prof. Buccellato will seek opportunities to meet with school-groups on field trips to the Conservatory to help educate community youth about this exciting work and the implications it will have for their future. In particular, we will reach out to schools that serve predominantly low- to moderate-income families, as we share concern that students in these demographics are not always given exposure to or inspired by important energy and environmental issues – and the role that they too can play in solving these problems in the future. Our EOC work at the Conservatory give the students an opportunity to get out of the classroom and see how ideas, like EOC, can contribute to reducing energy consumption in their community and elsewhere. Because EOC combines technology with the environment, we feel this is a promising way to help inspire and educate today's youth. For these efforts, we will report on the number of school groups, their ages, and demographics, allowing us to measure of the impact of our outreach.

While these are direct metrics, we will also use the EOC node for scientific measurements to validate our current models of EOC. Our aim with these models is to predict the energy and economic efficacy and benefits of scaling EOC. Therefore, an indirect metric will be predictions on the total energy and economic impact of expanding EOC throughout the local and national communities.

Partnering with Wells Fargo

We view this work as having two objectives. First, the development of this second, optimized EOC node will have an immediate impact on the both the energy and economic sustainability of the Conservatory, keeping this valuable resource open and available to our community. Second, a fully instrumented EOC node will give us the scientific data that proves the viability of the EOC approach to data centers, helping us to expand and further this important environmental initiative. We have already begun interacting with key technical partners to promote EOC, including the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), who have created guidelines on best practice for data center energy efficiency, the Uptime Institute, a leading organization guiding data center practices, and various members in academia and national laboratories. We have published our EOC work at multiple conferences and in an upcoming Handbook of Energy-Aware and Green Computing.

A partnership with Wells Fargo would enable us to not only help our community but also grow EOC and create positive exposure for our approach to greener buildings and data centers. Wells Fargo is a recognized leader in energy efficient data centers, capitalizing on "free cooling" from the local climate for their Minneapolis, MN data center and new virtualization technologies to reduce hardware usage. EOC is built upon these principles of free cooling and virtualization, so there is opportunity for mutual benefit as EOC goes forward. We envision not only a National Environmental Grant to make our community Conservatory more efficient, but also a synergistic relationship with Wells Fargo that allows us to continue to grow and expand EOC.

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Email: dgo@nd.edu
Website: http://www.nd.edu/~dgo/

Education and Training

• University of Notre Dame (Notre Dame, IN)	Mechanical Engineering	B.S.	2001
• University of Cincinnati (Cincinnati, OH)	Aerospace Engineering	M.S.	2004
• Purdue University (West Lafayette, IN)	Mechanical Engineering	Ph.D.	2008

Appointments

- Assistant Professor, Department of Aerospace and Mechanical Engineering, University of Notre Dame, 2008-present
- Graduate Research Assistant, School of Mechanical Engineering, Purdue University, 2004-2008
- Research Intern, Mobile Platforms Group, Intel Corporation, 2007
- Engineer, Edison Engineering Development Program, General Electric Aircraft Engines, 2001-2004

Awards

- Air Force Office of Scientific Research Young Investigator Program, 2010

Publications – Closely Related

1. Brenner, P.; Thain, D.; Buccellato, A.P.C.; Go, D.B., 2011, "Environmental Opportunistic Computing," in Handbook of Energy-Aware and Green Computing (ed. by I. Ahmad and S. Ranka) – in press
2. Buccellato, A.P.C.; Brenner, P.; Go, D.B.; Jansen, R.; Ward, E.M., 2011, "Environmentally Opportunistic Computing: Computation as Catalyst for Sustainable Design," ASHRAE Winter Conference, ASHRAE2011-86119, Las Vegas, NV.
3. Witkowski, M.; Brenner, P.; Jansen, R.; Go, D.B.; Ward, E.M., 2010, "Enabling Sustainable Clouds via Environmentally Opportunistic Computing," IEEE International Conference on Cloud Computing Technology and Science, Indianapolis, IN.
4. Go, D.B.; Sen, M., 2010, "On the condition for thermal rectification using bulk materials," *Journal of Heat Transfer*, 132:124502.
5. Go, D.B.; Maturana, R.A.; Garimella, S.V.; Fisher, T.S., 2008, "Enhancement of external forced convection by ionic wind," *International Journal of Heat and Mass Transfer*, 51:6047-6053.

Publications – Other

1. Chetwani, N.; Cassou, C.A.; Go, D.B.; Chang, H.-C., 2010, "High-frequency AC electrospray ionization source for mass spectrometry of biomolecules," *Journal of the American Society of Mass Spectrometry*, 21:1852-1856.

2. Tirmuala, R.; Go, D.B., 2010, "An analytical formulation for the modified Paschen's curve," *Applied Physics Letters*, 97:151502.
3. Go, D.B.; Pohlman D.A., 2010, "A mathematical model of the modified Paschen's curve for breakdown in microscale gaps," *Journal of Applied Physics*, 107:103303.
4. Guajardo-Cuellar, A.; Go, D.B.; Sen, M., 2010, "Evaluation of heat current formulations for equilibrium molecular dynamics calculations of thermal conductivity," *Journal of Chemical Physics*, 132:104111.
5. Go, D.B.; Garimella, S.V.; Fisher, T.S.; Mongia R.K., 2007, "Ionic winds for locally enhanced cooling," *Journal of Applied Physics*, 102:053302.

Synergistic Activities

- Advised 15 undergraduate research projects including seven women (two from an all women's college), one Hispanic student (a woman), two African-American students from historically black colleges and universities (one woman), and four students from disciplines other than Mechanical or Aerospace Engineering (two Chemistry, one Chemical Engineering, one Education)
- Formally engage in interdisciplinary research by officially advising the M.S. research of one woman student (K. Isbell) whose degree will be awarded through the Department of Chemistry and Biochemistry
- Engaged local K-12 students through an invited lecture (Trinity School at Greenlawn, South Bend, IN, 2008) and lead coordinator of St. Joseph Valley Regional MATHCOUNTS Competition (University of Notre Dame, 2009-2011)
- Keynote Speaker, Minority Engineering Program Honors Dinner (University of Notre Dame, 2009)
- Webmaster, IEEE Components, Packaging, and Manufacturing Technology Society, Thermal Management and Thermo-Mechanical Design TC (2007-present)

Collaborators

Dr. Paul Brenner (University of Notre Dame), Prof. Aimee Buccellato (University of Notre Dame), Prof. Hsueh-Chia Chang (University of Notre Dame), Prof. Timothy S. Fisher (Purdue University), Prof. James Friend (Monash University), Prof. Suresh V. Garimella (Purdue University), Prof. Michael Lemmon (University of Notre Dame), Dr. Mark MacDonald (Intel Corporation), Dr. Rajiv K. Mongia (Intel Corporation), Prof. Mihir Sen, (University of Notre Dame), Prof. Douglas Thain (University of Notre Dame), Prof. Leslie Yeo (Monash University)

Ph.D. Advisors

- Timothy S. Fisher, Professor, Purdue University
- Suresh V. Garimella, R. Eugene & Susie E. Goodson Professor, Purdue University

Post-Doctoral and Graduate Student Advisees

- Dr. Ming Tan (2010/2011) ***Total Post-Doctoral Scholars: 1***
- A. Guajardo-Cuellar (2011), R. Tirumala (Ph.D. in progress), Y. Li (Ph.D. in progress), P. Rumbach (Ph.D. in progress), D. Taller (Ph.D. in progress), S. Balagopal (M.S. in progress), K. Isbell (M.S. in progress) ***Total Graduate Students: 5***

Paul R. Brenner, PhD, PE

Work: 111 Information Technology Center, Notre Dame IN 46556 Phone: (574)-210-7979
Home: 1617 East Washington, South Bend IN 46617 Email: paul.r.brenner@nd.edu

PROFESSIONAL PREPARATION

University of Notre Dame, Notre Dame, IN 1998
B.S. Civil Engineering – Cum Laude

The Ohio State University, Columbus, OH 2000
M.S. Materials Science and Engineering
Field of Research: Intermetallic Mechanical Behavior and Dislocation Mechanisms

University of Notre Dame, Notre Dame, IN 2007
Ph.D. Computer Science and Engineering
Field of Research: Computational Biophysics and High Throughput Distributed Systems

APPOINTMENTS: RESEARCH, ENGINEERING, AND MANAGEMENT

Center for Research Computing, The University of Notre Dame, Indiana 2007 - Present
Associate Director for High Performance Computing
Research Assistant Professor, Department of Computer Science and Engineering
• Advance computation based research through HPC system design, deployment, operation, and support
• Conduct HPC research and grant development to grow computational infrastructure and capabilities
• HPC user training: hands-on instruction, collaborative documentation, & operational communications

U.S. Air Force Reserves, Engineering Officer (Traditional Reservist) 1998 - Present

434th Air Wing Civil Engineering Squadron, Grissom ARB, Indiana *2009 - Present*
Engineering Squadron Commander
• Command 145 USAF engineers and technicians to meet operational engineering tasks

U.S. DSRC High Performance Computing Center, Wright Patterson AFB, Ohio *2005 - 2009*
HPC Infrastructure Planning and Design Consultant
• Research and evaluate developing HPC technologies with multi megawatt infrastructure impacts

445th Air Wing Civil Engineering Squadron, Wright Patterson AFB, Ohio *1998 - 2009*
Engineering, Mobility, & Training Officer
• Directed analysis, design, & execution; OIC of Operations ($85 million) Bagram, Afghanistan

McGill AirClean Corporation, Columbus, Ohio 2000 - 2003
Manager Civil/Structural Engineering
• Managed structural engineers, designers, and manufacturing planners for efficient project completion

APPOINTMENTS: TEACHING

University of Notre Dame, Notre Dame, IN 2003 – Present
Research Assistant Professor (2007 – Present), Graduate Research Assistant (2003 – 2007)
• Instructor – Data Structures, Undergraduate Research, CSE Service Learning (CBR)

Columbus State Community College, Columbus, Ohio 2001 - 2003
Adjunct Faculty – Core Physics Sequence

PROFESSIONAL CERTIFICATION/ORGANIZATIONS

Registered Professional Engineer, Ohio
Member - Association for Computing Machinery (ACM)
Member - American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

Paul R. Brenner, PhD, PE

RECENT RELATED PUBLICATIONS WITH UNDERGRADUATE STUDENTS*

A. Buccellato, P. Brenner, D. Go, R. Jansen*, E. Ward*
Environmentally Opportunistic Computing: Computation as Catalyst for Sustainable Design
ASHRAE Winter Conference, 2011

P. Brenner, R. Jansen*, D. Go, D. Thain
Environmentally Opportunistic Computing: Transforming the Data Center for Economic and Environmental Sustainability. 1st IEEE Green Computing Conference, 2010

M. Witkowski, P. Brenner, R. Jansen*, D. Go, E. Ward*
Enabling Sustainable Clouds via Environmentally Opportunistic Computing
2nd IEEE International Conference on Cloud Computing Technology and Science, 2010

M. Lammie*, P. Brenner, D. Thain
Scheduling Grid Workloads on Multicore Clusters to Minimize Energy and Maximize Performance
10th IEEE/ACM International Conference on Grid Computing (Grid) 2009

P. Brenner, C. R. Sweet, D. VonHandorf*, and J. A. Izaguirre
Accelerating the Replica Exchange Method Through an Efficient All-pairs Exchange
Journal of Chemical Physics, 2007

RECENT RELATED PUBLICATIONS

P. Brenner, D. Thain, A. Buccellato, and D. Go
Environmentally Opportunistic Computing. Book Chapter in Handbook of Energy-Aware and Green Computing, Chapman and Hall/CRC Press, Taylor and Francis Group LLC. *In Press*

P. Brenner, D. Thain, D. Latimer
Grid Heating Clusters: Transforming Cooling Constraints into Thermal Benefits
Uptime Institute – IT Lean, Clean, & Green Symposium, Green Enterprise IT Awardee, 2009

RECENT SYNERGISTIC ACTIVITIES AND AWARDS

Mentors Notre Dame's "Student Engineer's Reaching Out" Team	2004 - Present
Uptime Institute – IT Lean, Clean, & Green Symposium, Green Enterprise IT Awardee	2009
• Paper: "Grid Heating Clusters: Transforming Cooling Constraints into Thermal Benefits"	
Notre Dame Rev. William A. Toohey Award for Service and Social Justice	2008
Notre Dame CSC Ganey Research Grant Recipient	2006
National Engineering Week – New Faces in Engineering Nominee	2004

CURRENT RESEARCH

- Transformative technology for energy efficient high performance computing & data center operation
- Novel utilization of autonomous and heterogeneous resources for high performance computing
- Active service learning & community based research for undergraduates in science and engineering
- Accelerated parallel sampling algorithms for Monte Carlo based simulation methods

CURRENT COLLABORATORS

- University of Notre Dame: Kevin Barry, Aimee Buccellato, David Go, Jesus Izaguirre, Jeff Kantor, Mike Lemmon, Jaroslaw Nabrzyski, Christopher Sweet, Timothy Stitt, and Doug Thain
- Poznan Supercomputing and Networking Center, Poznan, Poland: Michal Witkowski

GRADUATE ADVISORS

- Master's Thesis: Dr. Michael J. Mills, The Ohio State University
- PhD Dissertation: Dr. Jesus Izaguirre, The University of Notre Dame

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PROFESSIONAL PREPARATION

University of Notre Dame, Notre Dame, Indiana — 2000
Bachelor of Architecture

Harvard University, Cambridge, Massachusetts — 2005
Master of Design Studies
History and Theory of Architecture

Accredited Professional — 2009
Leadership in Energy and Environmental Design (LEED)

TEACHING APPOINTMENTS

School of Architecture, University of Notre Dame — 2008 – present
Assistant Professor

Institute of Classical Architecture & Classical America
Assistant Director, Intensive Professional Program in Classical Architecture — 2005
Member, Academic Faculty, Academic Programs Committee — 2005-2008

PROFESSIONAL PRACTICE

Partner, Buccellato Design, PLLC, South Bend, IN — 2001 – present
Associate & Project Manager, G. P. Schafer, Architect, PLLC, New York — 2002 – 2008
Project Architect, John B. Murray Architect, LLC, New York — 2001 – 2002
Graduate Architect, Curtis & Windham Architects, Houston, Texas — 2000 – 2001

AWARDS

Educator of the Year, University of Notre Dame School of Architecture — 2010-2011
Initiation Grant, Faculty Research Support Program, Office of Research, University of Notre Dame — 2010-2011

PUBLICATIONS – RELATED

Buccellato, A., "Quantifying Sustainable Design: Select Case Studies." Proceedings of the 2011 Building Enclosure Sustainability Symposium. California Polytechnic University, Pomona: April 2011.

Brenner, P., Thain, D., **Buccellato, A.,** Go, D., Chapter 44: Environmentally Opportunistic Computing: Toward Sustainable Enterprise and HPC Data Centers. Handbook of Energy-

Aware and Green Computing. Chapman and Hall/ CRC Press, Taylor and Francis Group, LLC. *In Press*.

Buccellato, A., Brenner, P. and Go, D., "Environmentally Opportunistic Computing: Computation as Catalyst for Sustainable Design." To be published in the proceedings of the 2011 ASHRAE Winter Conference: Net Zero Design. ASHRAE: January 2011.

Buccellato, A., "Responsible Technology: The Green Scale Research Project." Proceedings from The Creating_Making Forum 2010. The University of Oklahoma: November 2010.

Buccellato, A., "Doing Better With What We Have," Proceedings from the Third Building Technology and Educators Society Conference: Assembling Architecture (BTES '09), Albuquerque, New Mexico, 2009.

Buccellato, A., "Human Happiness and the Built Environment," Tenth Annual Fall Conference of the University of Notre Dame's Center for Ethics and Culture: The Summons of Freedom, Notre Dame, Indiana, 2009.

Synergistic Activities

- **Director**, The Green Scale Research Project: Quantifying Truly Sustainable Design Advancing the study of building technology and sustainable design through quantitative analysis of traditional construction materials, methods, and design principles, including Life Cycle Analysis, Embodied Energy, Embodied Water, and the development of analysis tools to assess the more qualitative aspects of traditional design and urbanism
- **Co-investigator/ Project Designer**, St. Patrick's Environmental Ecosystem Center – Notre Dame (SPEEC-ND), a new experimental research and education facility funded by the Notre Dame Environmental Change Initiative 2011 in partnership with the St. Joseph County Public Parks Department
- **Member**, Development Staff, the Green Cloud supercomputing project
- **Associate Editor**, d3 Dialogue: International Journal of Architecture and Design, NYC
- **Contributor**, "Views from the Top: Expert Opinions on Traditional Building and Design," Web-blog, *Traditional Building Magazine,* 2009.

Collaborators and Affiliations

Paul Brenner, University of Notre Dame, Kevin Buccellato, University of Notre Dame and Buccellato Design, PLLC, Gary Lamberti, University of Notre Dame, Dewitt Latimer, University of Notre Dame, Michael Lemmon, University of Notre Dame, David Lodge, University of Notre Dame, David B. Go, University of Notre Dame, Jennifer Tank, University of Notre Dame, Douglas Thain, University of Notre Dame

Graduate Advisors

K. Michael Hayes, Graduate School of Design, Harvard University
Christine Smith, Faculty of Arts and Sciences, Harvard University

Thesis Advisor

Crystal V. Olin, University of Notre Dame, M.Arch. 2010
Stephanie Wahl, University of Notre Dame, M. Arch. 2010
Timothy Casper, University of Notre Dame, M. Arch. 2011