Engaging students in the complex issues surrounding data center thermal management

Eric Daney, Downingtown Area School District & Villanova University

Serve as K-12 Science Curriculum Leader for the Downingtown Area School District in addition to teaching 9th Universal Physics at the Downingtown STEM Academy.

Received National Science Foundation Grant for Research Experience for Teachers to work in the Villanova University Center for Energy-Smart Electronic Systems

Dr. Aaron P. Wemhoff, Villanova University

Aaron Wemhoff is an Assistant Professor in the Department of Mechanical Engineering at Villanova University. He earned his PhD from UC Berkeley in 2004, and he previously worked as a staff engineer at Lawrence Livermore National Laboratory.

Dr. Gerard F. Jones, Villanova University

Following a several year period as a project engineer for Mobil Oil Corporation in Paulsboro, New Jersey, Jerry Jones joined the University of Pennsylvania, receiving his MS in 1975 and PhD in 1981. Jones was a technical staff member with Los Alamos National Laboratory (LANL) in New Mexico until 1987. His research activities included experiments, analysis, and simulations on thermal systems, including solar and geothermal energy conversion. He consulted with LANL on a wide array of technical topics from 1990 until 2006.

Jones joined the Department of Mechanical Engineering at Villanova University in 1987 where he currently holds the rank of professor. In 2008, after serving as department chairman for six years, he assumed the position of Associate Dean, Academic Affairs where he was responsible for day-to-day running of the undergraduate engineering program of 850 students in five engineering majors. In 2012, he took the position of Sr. Associate Dean for Graduate Studies and Research. His undergraduate teaching has included numerous courses in heat transfer, fluid mechanics, thermodynamics, analysis and design, gravity-driven water networks, and laboratories. His graduate courses are heat conduction, convection, computational fluid dynamics, advanced fluid dynamics, and solar thermal energy conversion.

Among his research interests are heat transfer in composite materials, high-performance heat exchangers for electronics cooling, and thermal management of power production and dissipation systems. His most recent research has focused on optimization of multi-scale thermal structures using Constructal theory.

Dr. Jones is a fellow of the American Society of Mechanical Engineers, has served actively on the ASME Computational Heat Transfer committee for many years, and is a past president and secretary of the Villanova Chapter of Sigma Xi, the Scientific Research Society. Since 2005, he has been a member of the Committee on Science and the Arts (CS\&A) of the Franklin Institute of Philadelphia which selects its annual Franklin Medal award winners, and starting in 2011 is a member of the executive committee of the CS\&A. He has advised nearly 20 Masters and Ph.D. candidates, served on more than 35 M.S. and Ph.D. thesis committees, and has published more than 80 archival journal and conference proceedings publications. His book, Gravity-Driven Water Flow in Networks: Theory and Design (Wiley, 2010) is an outgrowth of student-focused, service-learning efforts in Central America begun in 2004 with two colleagues in the ME Department at Villanova. Since this time, he has traveled extensively with students on more than a dozen international trips while engaging many students in leadership positions.

Engaging Students in the Complex Issues Surrounding Data Center Thermal Management (Work in Progress)

Abstract

Data centers consumed 1.5% of the electricity produced in the United States in 2007. This consumption, coupled with diminishing access to fossil fuels, provides scientists and engineers of this generation and the next with the challenge of making better use of available energy. This paper provides the foundation for a project-based learning module that will be implemented this coming spring for 200 ninth-grade students at the Downingtown STEM Academy. The project will focus on educating students about the function of the data center in their everyday lives and the energy consumption issues that are central to the design of next-generation data centers. Throughout this learning process students will be asked to research and develop new and innovative ways of addressing the issue. Student teams will present their responses to the essential question in progressively more detailed methods to garner feedback for reflection, revision, and further study. The culminating submission will be a video documentary developed, filmed, and edited by the team. These presentations will be included in a grade-wide live and online showcase of findings and recommendations, allowing students to share their findings and recommendations both locally and globally. Providing a learning opportunity that focuses on the current data center energy usage challenge, and the emergent technologies being used to address it, will connect students to a deeper understanding of the inner workings of the data center and its place in modern society.

I. Introduction

Energy literacy plays a vital role in K-12 education; future generations need to develop behavioral patterns to eliminate or reverse harm to the environment and maximize the use of available energy resources. The definition of energy literacy[1], though vague, encompasses the knowledge of (1) available energy resources, including advantages and disadvantages, and (2) the influence everyday actions have on these resources. Energy literacy also includes attaining a knowledge base sufficient to affect an individual's behavioral aspects toward energy conservation.[2,3] In general, K-12 students have expressed concerns regarding energy-related problems but lack knowledge and behavior toward addressing these problems.[2] For example, Bayraktar et al.[4] reported that most fourth-grade students in their survey were not aware of the impact that insulation or "energy-star" rated appliances had on energy consumption.

To address this issue, several studies have been developed to create K-12 curricula related to energy sustainability. Chen et al.[5] developed one such framework that is focused on energy conservation and reduction of carbon emissions. They found that the top priorities in the framework should be in the area of civic responsibility, with reduced emphasis on low-carbon lifestyle, energy concepts, and reasoning of energy issues. Darwish and Agnello[6] have proposed a model for integration of sustainability into existing K-12 classes:

- In the science curriculum, they propose having students understand the steps required to transition from unsustainable to sustainable construction.
- In the math curriculum, they propose having students perform calculations of energy and nonrenewable resource usage.
- In the language arts curriculum, they propose the integration of green building case studies.
- In the social studies curriculum, they propose the instruction of energy economics and carbon footprint.
- In the arts curriculum, they propose having students define green construction.

Several universities have provided demonstrations and workshops to promote energy literacy among K-12 students. For example, the University of Florida has stated that a large set of instructional materials is available for K-12 teachers regarding solar energy.[7] Calvin College in Grand Rapids Michigan has created a LEED-certified center that contains a wind turbine and solar photovoltaic systems for local K-12 visitors.[8] Clarkson University in upstate New York created a number of projects in areas of solid waste re-use, renewable energy systems, and water quality for 8^{th}-grade students.[9] Arkansas Tech has hosted a two-week workshop for K-12 teachers with a focus on comparing various energy sources and provided in-class demonstrations featuring water turbines, fuel cells, and photovoltaics.[10] Finally, the Villanova Department of Mechanical Engineering has hosted approximately 60-80 girl scouts on the annual Girl Scout Day, where the middle school-aged girls learn sustainability concepts through activities such as concentrated solar energy and photovoltaics.[11]

One aspect of energy literacy that has not yet been explored on the K-12 level lies in green data centers. Data centers consumed 1.5% of U. S. energy in 2007[12], of which one-third to one-half was spent on cooling systems[13]and thus was not directly related to the flow of information to and from the data center, which is its sole function. Based on the large fraction of energy consumed by them, research on improving the energy efficiency of data centers can have an impact on the nation's overall energy portfolio. Therefore, the NSF-funded Energy Smart Electronic Systems center was developed for the purpose of improving the energy efficiency of data centers. The advancement and application of engineering science and technologies, such as studies to reduce rates of exergy destruction and the use of advanced heat exchangers and thermodynamic cycles to extract and re-use waste heat, are considered in this project.[14, 15] As part of this effort, the unique opportunity to relay concepts pertaining to energy efficient use of electronics to K-12 students was undertaken through a Research Experience for Teachers (RET) grant. This study was therefore developed through a collaborative effort by Villanova University Engineering and the Downingtown STEM Academy, a local high school in Chester County, PA that received a score of 101.4 out of 100 on the Pennsylvania School Performance Profile, the highest in the state among all public, charter, cyber charter, and technical high schools.[16]

This paper is the culmination of studies done through the NSF RET grant and lays out the framework of instruction for a project-based unit focused on the structure and function of data centers as well as their energy consumption. This project plans to be included as the culminating project for the established study of energy and energy consumption undertaken in the Universal Physic and Introduction to Engineering courses.

II. The Framework

The Essential Question

The question that is the central focus of the learning in this unit and is to be addressed by each student team by the culmination of the project is: How can data centers make better use of infrastructure to improve efficiency in energy consumption?

Project Aims

Project aims are the intangible outcomes of a learning experience that cannot be directly measured. The aim for this unit of study is to raise awareness of the moral, ethical, social, economic, and environmental implications of using science and technology.

Learning Objectives

To be able to fully answer the essential question and the address the project aim each student will need to meet the three learning objectives listed below.

1. Describe the role of the data center in the functioning of the web
2. Identify inherent concerns in data center thermal management
3. Describe current and possible future strategies to address data center thermal management concerns.

Foundational Learning Modules

The Foundational Learning Modules drive the introduction of core content to meet the objectives as well as promoting the development of deeper questions to focus student learning. Completed versions of these modules will be posted for public access.

1. Energy Consumption (Source to Device) – This learning module will ask students to explore the various methods of generating electricity and its consumption in data centers, as well as other industries and the private sector.

2. Heat Generation from our Personal Electronic Devices – Students will use a thermocouple temperature probe to track the heat generation of their personal devices as they complete different web-based tasks. This experiment will be followed up with an exploration of what is being done inside their devices to manage that heat generation.

3. Exploring the Role of the Data Center – Students will explore online resources and connect with industry professionals to determine the role of a data center in society.

4. Efficiency Measures in the Data Center Management – Students will familiarize themselves with current measures of data center efficiency and develop their own measures of efficiency within a data center based on information that would be readily available for them in a data center.

5. Introduction to Thermodynamic Laws – Students will be introduced to the Laws of Thermodynamics and asked to explore how these laws are integrated into the design of specific components of the data center.

6. Visualization of Data Center Thermal Management (CFD Modeling) – Students will be introduced to the visual model representations of heat movement constructed using computational fluid dynamics. Data from these representations will be used as evidence to support student claims of areas for improvement.

Project-Based Learning Opportunity

Project-Based Learning as defined by the Buck Institute for Education, the foremost experts in the area, requires that "students go through an extended process of inquiry in response to a complex question, problem, or challenge. While allowing for some degree of student 'voice and choice,' rigorous projects are carefully planned, managed, and assessed to help students learn key academic content, practice 21st Century Skills (such as collaboration, communication & critical thinking), and create high-quality, authentic products and presentations."[17] To meet those criteria, student teams will address the essential question with knowledge gained in the Foundational Learning Modules as well as further research into a specific focus topic.

To appropriately address a focus topic, students will be expected to define the energy consumption and thermal management issues that are relevant, provide insight into current strategies to address these issues, as well as brainstorm other cost effective means of addressing these issues in an international community.

Focus topics include addressing:

- Urban planning in the 21st century
- Building level look at data center thermal management
- Server rack level look at data center thermal management
- Server level look at thermal management
- Processor chip level look at thermal management
- Thermal management in web-connected devices
- Waste heat recovery and uses

- Exploratory experiment focused on thermal management at Downingtown STEM Academy.

Student Outcomes

Student teams will present their responses to the essential question and learning objectives in three progressively more detailed methods. This process will allow students to refine their ideas, recommendations, and presentations through feedback and reflection

The first presentation will be a written overview/outline of the teams' findings as well as a proposal of their recommendations for future methods to address the issue. This submission will lay out the foundation of the teams' ideas and information for communication.

The second submission will be a presentation made before classmates, teachers, and industry members. This will be a second opportunity for students to receive feedback and make revisions to what they will include in their final presentation.

The final submission will be a video documentary developed, filmed, and edited by the team. These presentations will be included in a grade-wide live and online showcase of findings and recommendations that will enable students to share their findings and recommendations both locally and globally.

Assessment of Learning Objectives

In an effort to create meaningful and useful assessment and self-monitoring tools for students, a rubric will be designed at the outset of each new step of the unit. These rubrics will be designed as a collaborative effort between students and teachers so that they provide clear descriptors of the expectations for each particular assessment criterion. A well-designed rubric that includes language and expectations that are familiar to both students and teachers can act as a guide to help students establish where they are along their path to mastering the identified content.

Outside of the traditional grading structure, a pre-instruction, during instruction and post-instruction formative assessment will be administered to collect data on student progress toward the learning goals.

III. Concluding Remarks

This version of the project will be the first time that energy management, specifically data center thermal management, will be included in the course content. Previously, energy conservation was tackled at a more conceptual level as opposed to a practical application of knowledge to real-world problems.

Partnerships between the STEM Academy and Villanova as well as other businesses partners will be essential in accessing data and field experts to interact with the participating students. We expect that these interactions with experts, as well as authentic data, will make this application-based exploration more engaging for students.

IV. Bibliography

1. Pearson, G.; Young, A. T. (2002) Technically Speaking: Why all Americans Need to Know More about Technology. *National Academy Press*: Washington, DC.
2. DeWaters, J.; Powers, S.; Graham, M. (2007) Developing an Energy Literacy Scale. Presented at *2007 ASEE Annual Conference*.
3. DeWaters, J. E.; Powers, S. E. (2011) Energy Literacy of Secondary Students in New York State (USA): a Measure of Knowledge, Affect, and Behavior. *Energy Policy, 39(3)*, 1699-1710.
4. Bayraktar, T.; Williamson, K.; Bayraktar, I. (2006) Connecting Elementary School Students to Energy Concepts and New Technologies. Presented at *2006 ASEE Annual Conference*.
5. Chen, K. L.; Huang, S. H.; Liu, S. Y. (2013) Devising a Framework for Energy Education in Taiwan Using the Analytic Hierarchy Process. *Energy Policy, 55*, 396-403.
6. Darwish, M. M.; Agnello, M. F. (2009) Sustainability or Green: Challenges and Changes for Educators and the Engineering Curriculum. Presented at *2009 ASEE Annual Conference*.
7. Goswami, Y. (2001) Present Status of Solar Energy Education. Presented at *2001 ASEE Annual Conference*.
8. Heun, M.; VanderLeest, S. (2008) Why a Liberal and Multidisciplinary Education is Needed to Solve the Energy Crisis. Presented at *2008 ASEE Annual Conference*.
9. DeWaters, J.; Powers, S. (2006) Improving Science Literacy Through Project-Based K-12 Outreach Efforts that Use Energy and Environmental Themes. Presented at *2006 ASEE Annual Conference*.
10. Krohn, J. L.; Apple, S. C. (2003) Energy and the Environment: An Energy Education Course for High School Teachers. Presented at *2003 ASEE Annual Conference*.
11. Fleischer, A. S., Wemhoff, A. P., Ural, A., O'Brien, J. C., Alaways, L. W. (2010). Development and Execution of a Successful Mechanical Engineering Outreach Program for Middle School Girls. Proceedings of the Northeast Regional American Society of Engineering Education Conference.
12. Brown, R.; Masanet, E.; Nordman, B.; Tschudi, B.; Shehabi, A.; Stanley, J. (2007) *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*. Washington, DC.
13. Greenberg, S.; Mills, E.; Tschudi, B.; Rumsey, P.; Myatt, B. (2006) Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers. 2006 *ACEEE Summer Study on Energy Efficiency in Buildings*, p. 76-87.
14. K. Ibrahimi, G. F. Jones, and A. S. Fleischer, “A Review of Data Center Cooling Technology, Operating Conditions and the Corresponding Low-Grade Waste Heat Recovery Opportunities,” Renewable and Sustainable Energy Reviews, Vol. 31, 622 (2014).
15. K. Ebrahimi, G. F. Jones, A. Fleischer, “A Review of Challenging Issues in the Integration of Absorption Refrigeration and Organic Rankine Cycle into a Data Center Cooling System,” 14th IEEE ITHERM Conf., 2014.
16. Pennsylvania Department of Education. (2014) School Performance Profile: Downingtown STEM Academy. Retrieved from http://paschoolperformance.org/Profile/27561
17. Buck Institute for Education. (2014) *What is PBL?* Retrieved from http://www.bie.org/about/what_is_pbl/