Using IR Thermal Imaging to Engage Students in Campus Energy Awareness

Robert E. Choate[1], Thomas A. Choate[2]

Abstract – As many universities throughout the country are seeking to reduce energy losses inherent in decades-old buildings on their campuses, infrared thermography provides an avenue for determining which structures are in the most need of repair and specific areas of the structures that are most vulnerable to heat loss during the heating season and heat gain during the cooling season through the building envelope. An academic building on Western Kentucky University's campus, Grise Hall (GH) completed in 1966, was initially selected for this assessment since it was scheduled to have repairs performed to its Heating Ventilation and Air Conditioning System in fall 2010 and spring 2012, and weatherization repairs in summer 2012. Grise Hall is a five-story, brick and block building with multiple personnel entry and egress points on three floors. The structure contains multi-use, office, classroom, and auditorium spaces located on interior and exterior walls. The intent of the study was to provide before and after thermographic images to assess the impact of the building repairs. Particular focus on Grise Hall was a known issue of exfiltration due to poor air balancing and subsequent loss of significant conditioned air through the enclosure resulting in possibly higher energy costs. A resetting of a large window wall at the 2nd floor building entry lobby was required, and "ballooning" of the roof membrane due to "high" interior pressures had been previously noted by the Department of Facilities Management. This paper will outline the building envelop measures and student training methodologies and learning outcomes.

Keywords: Thermography, Student Engagement, Energy Awareness, Sustainability

INTRODUCTION

In 2009-2010, Western Kentucky University announced it was taking a major step toward reducing energy consumption and making a positive impact on the environment. Kentucky Governor Steve Beshear and WKU President Gary Ransdell presented a comprehensive Energy Policy for Western Kentucky University outlining individual and university responsibility for energy management. Dr. Ransdell added that the policy is a significant part of a larger effort toward sustainability at WKU. "This effort will engage the entire campus community and includes changes in the way we live, learn, work and do business," he said. "Recognizing that universities are the places where innovative solutions are born, the WKU campus is being used as a living laboratory for energy efficiency and conservation efforts. Through this policy and other efforts, we are encouraging students, faculty and staff to apply ideas and research to advance sustainability."

Concurrent with the unveiling of this energy policy, the Department of Facilities Management (DFM) contacted the Department of Engineering with an inquiry regarding available energy auditing resources. DFM had developed a plan to address energy management issues across campus through the implementation of a building weatherization repair. The plan attacked the obvious areas of concern of energy losses/gains primarily through infiltration and exfiltration via failed window and door sealing components. The engineering department proposed the use of infrared thermography observation and differential pressure measure between the interior and exterior of the buildings scheduled for repair to assess the benefits of the repairs. A before and after observation approach was suggested to verify the benefit of the repairs. It was also decided that rather than faculty and staff performing the measurements that students would be trained and tasked with these building envelop measure responsibilities.

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[1] Western Kentucky University, 1906 College Heights Blvd, Bowling Green, KY 42101 robert.choate@wku.edu

[2] Vanderbilt University, 2201 West End Avenue, Nashville, TN 37240 thomas.a.choate@vanderbilt.edu

Infrared thermography [1, 2, 3] can provide an awareness of qualitative energy losses through a "visual" assessment of building envelop integrity. Thermographic inspection of building exterior walls and roof surfaces can be readily applied to the evaluation and assessment of exterior wall, window and door seal, and roof performance and associate energy loss in areas found to have thermal anomalies noted in the thermal images. Of particular interest for this student-centric study are thermal imaging's abilities to "visualize" convective energy loss due to air leakage from the building during the cooling season and into the building during the heating season. When coupled with a system to measure or alter the pressure of the interior conditioned space, an effective and quantitative means of assessing which structures are in the most need of weatherization repairs can be demonstrated. Excessive air leakage in the building envelop is known to be a major contributor to the energy consumed in conditioned buildings. Air exchange is needed to maintain a healthy indoor space, but excessive loss of conditioned air or gain of external unconditioned air through air infiltration or exfiltration is often acerbated by failing door and window seals.

The campus-wide energy policy and the weatherization repair plan were viewed by the authors as an opportunity to truly realize Dr. Ransdell's vision of "a living laboratory for energy efficiency and conservation" for students, faculty and staff. The initial building undergoing significant projects, HVAC system renovation and weatherization, selected for the initial study was:

Building: Grise Hall

Date Built: 1966

Cost of Construction: $1.6 million

Architects: R. Ben Johnson and Associates of Owensboro

Named for: Finley C. Grise, Dean of the University 1927-1959

Currently houses: The Gordon Ford College of Business; Government; Sociology

History - Grise Hall was once used to accommodate the departments and offices of the Bowling Green College of Commerce and some of the offices of the Departments of Education and Psychology. The 140,000 square foot building includes a 5 story central complex, an office wing, a classroom-laboratory wing, and an auditorium lecture extension. It has 65 classrooms, 159 offices for faculty and staff, an auditorium that seats 450, and 14 laboratories.

BUILDING ENVELOP MEASUREMENTS

CASE STUDY: GRISE HALL

In addition to the repairs outlined in the weatherization repair plan, the Department of Facilities Management had identified a significant cause of the air imbalance in Grise Hall (GH) and planned to address this issue by the reinstallation and/or commissioning of return air handlers in the HVAC systems of the building. This air pressure imbalance was readily noted in GH when, after entering both the 1st and 2nd floor lobbies, the single bank and vestibule type doors, respectively, remained open due to building positive pressure differential with the outside. Significant air flow velocity and airborne noise were also evident in the large passageways and doorways leading from adjacent areas such as hallways and stairwells into the 1st and 2nd floor lobbies with their door panels. Therefore, in addition of thermographic images, differential pressure measurements were performed in an attempt to quantify the exfiltration rates.

Thermograms of several door and window panels were taken by a student energy auditor from the department of engineering. Figure 1 shows interior and exterior photographs of the vestibule type door and window panel of the main floor lobby, which are the primary entry doors for the building. This six door and ten single pane window panel faces southward. Visual inspection indicated that the window glazing and caulking was in obvious need of repair due to oxidation and UV exposure. Similarly, door seals and sweeps were either damaged or missing, resulting in loss of an air seal around their perimeter.

Figure 1 Photographs of the GH Main Lobby Vestibule Type Door and Window Panel - Interior and Exterior

An overview thermogram and photograph pair for this door and window panel is shown in figure 2. The impact of the air imbalance and the compromised door and window seals is apparent in the infrared thermogram, which shows the patterns of conditioned air leaking around the compromised seals and from the center exterior door, which consistently failed to close completely due to the excessive interior building pressure.

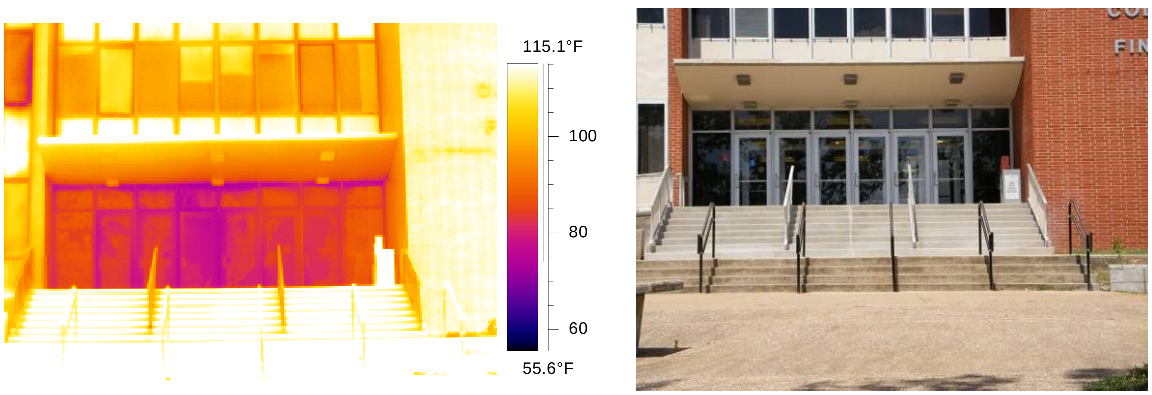

Figure 2 Thermogram and Photograph Pair of GH Main Lobby Vestibule Type Door and Window Panel

The compromised window seal is shown in the close-up images and photographs of the upper right corner of the entryway overhang in figures 3 and 4. A patterning of light and dark striations is particularly apparent in the higher contrast gray palette image in figure 4. This “visualized” air leakage pattern shows the convective cooling of the exterior surfaces by the conditioned air from the interior building space, resulting in possibly significant energy loss from the building space possibly compromising human comfort in the occupied space.

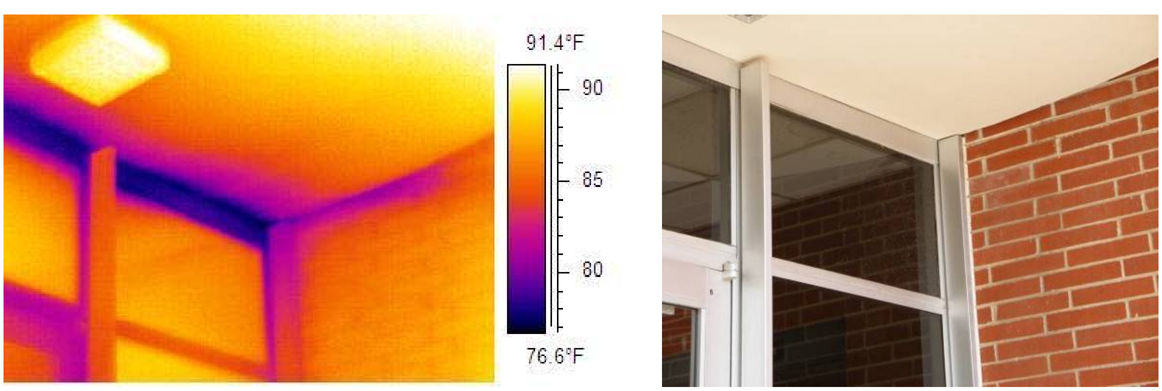

Figure 3 Thermogram and Photograph Pair of Main Lobby Overhang

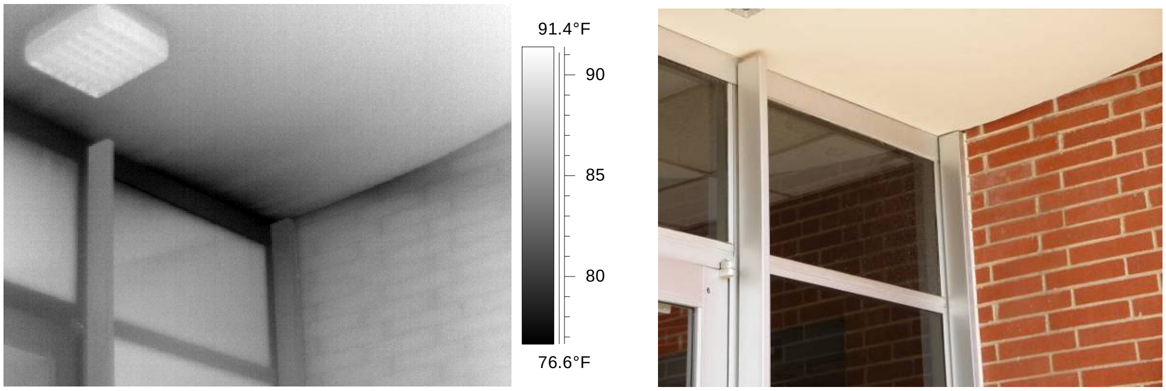

Figure 4 Thermogram and Photograph Pair of Main Lobby Overhang

The single bank doors on the westward facing 2nd floor lobby were also evaluated for air leakage. This panel consists of four doors and eight single pane windows. The overall physical condition of this panel was similar to the main entryway door panel with obvious seal performance degradation due to age and weather exposure. As stated previously, doors in this panel would also not completely close due to the air imbalance. The entire door and window panel had been reset in the structure when it was dislodged due to the air pressure imbalance.

Figure 5 shows a thermogram and photograph pair of the door and window panel with apparent air leakage pattern similar to the vestibule type door on the 1st floor lobby. Figure 6 provides detailed images of the upper and lower sections of the panel. As with the vestibule type door panel, cooler conditioned air leakage around the compromise door and window seals is convectively cooling the adjacent overhang and wall exterior surfaces as shown in figures 5 and 6 thermograms.

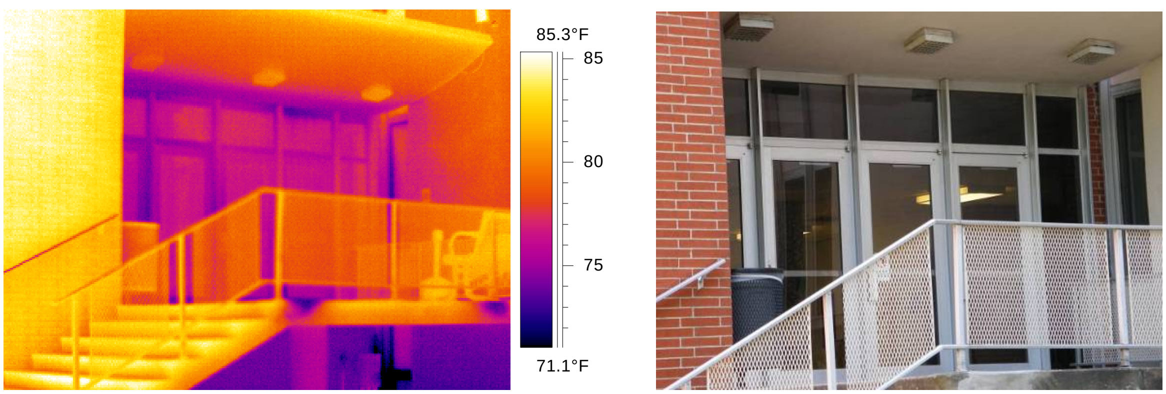

Figure 5 Thermogram and Photograph Pair of GH 2nd Floor Lobby Single Bank Door and Window Panel

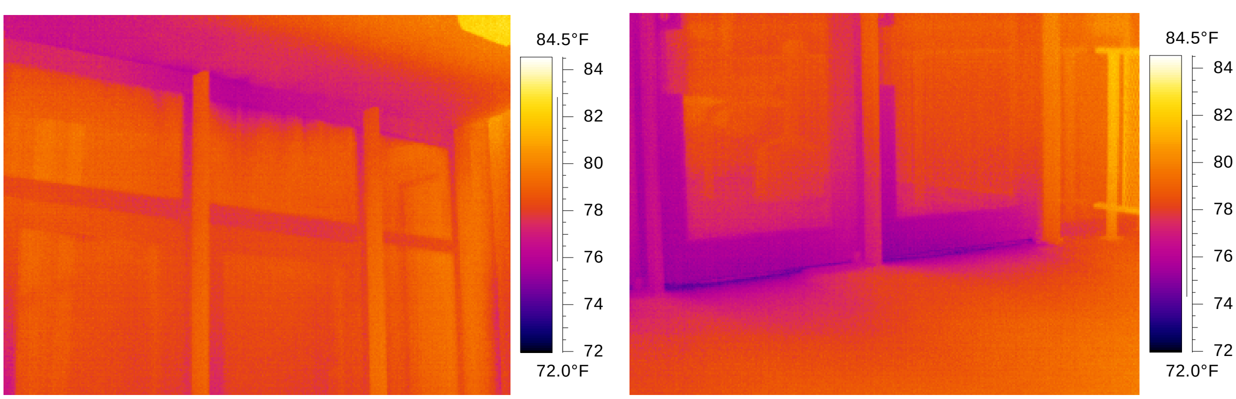

Figure 6 Thermograms of Upper and Lower Sections of GH 2nd Floor Lobby Single Bank Door and Window Panel

Based on the observed air imbalance, a differential pressure survey was also performed in an attempt to quantify the exfiltration rate. The HVAC system in GH consists of four air handling units (AHU's). A test and balance analysis report [4] indicated that the total conditioned air in the cooling mode delivered by these AHU's is approximately 93,000 CFM. The return air under the cooling mode load condition is approximately 63,500 CFM. Per the report, the building should also be at a slightly positive differential pressure condition of approximately 0.05 inches of H_2O (12.5 Pa) relative to outside pressure when operated in this mode.

Given the surrounding grounds, ingress to and egress from GH is available on three of its five floors without the need for a lift. Therefore, this access to single bank and vestibule type doors on the 1st, 2nd and 4th floors made an inside to outside building differential pressure survey feasible without any building modifications. As shown in Table 1, the differential pressure survey at these limited locations in the building envelope measured approximately 2.5 to 3.0 times larger than the expected differential pressure during cooling season operating conditions.

Table 1: Building Envelope Differential Pressure Before Measurements

Measurement Location and Description	**Differential Pressure**	**Observations**
1st Floor - South Facing Single Bank Stairwell Door	0.124 inches of H_2O (30.9 Pa)	Door closure in ~4s.
1st Floor - North Facing Single Bank Stairwell Door	0.128 inches of H_2O (31.9 Pa)	Door closure in ~6s.
1st Floor - Air Lock Passage to Exterior - South Facing Vestibule Type Door	0.129 inches of H_2O (32.1 Pa)	Door remains open.
2nd Floor – West Facing Single Bank Landing Door	0.144 inches of H_2O (35.9 Pa)	Door remains open.
4th Floor – North Facing Single Bank Door	0.145 inches of H_2O (36.1 Pa)	Door remains open

It was discovered that some of the return air handlers had been deactivated and some removed in an effort to "save energy". Under these conditions, this air imbalance created on average a measured positive differential pressure condition of ~0.134 inches of H_2O (33.4 Pa). The excessive pressure differential created significant air leakages through compromised seals in the building envelop [5], and subsequently, higher energy consumption.

When the return air handlers were reactivated and reinstalled where necessary to save energy, the building was revisited by student energy auditors, and thermograms and differential pressure measurements were repeated. The compromised window seal shown in figure 4 is shown on the revisit in figure 7.

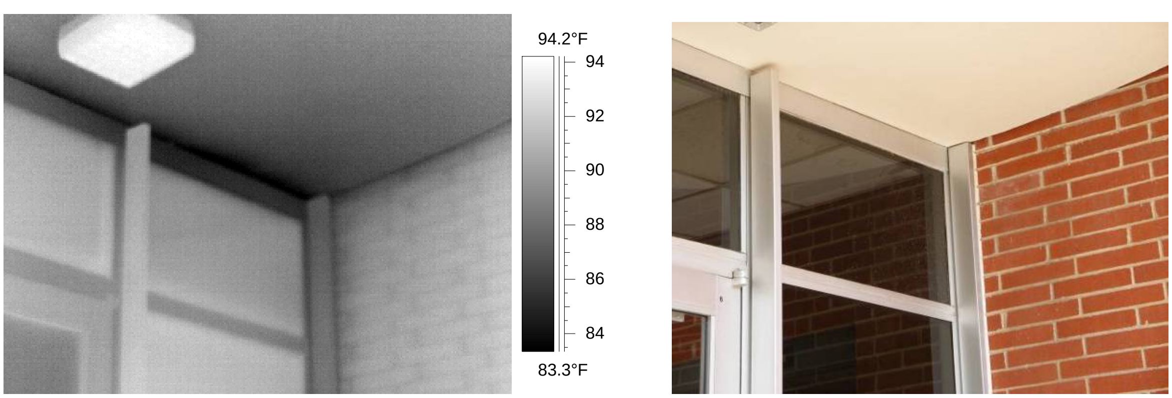

Figure 7 Thermogram and Photograph Pair of Main Lobby Overhang After Return AHU Modifications

A minimal "visualized" air leakage pattern is evident of the overhang in this new thermogram, which indicates a significant reduction in the convective cooling of the exterior surfaces by the conditioned air from the interior building space. The differential pressure measurements under these operating conditions were also repeated by the student energy auditors and are provided in Table 2.

Table 2: Building Envelope Differential Pressure After Return AHU Modifications

Measurement Location and Description	Differential Pressure
1st Floor - South Facing Single Bank Stairwell Door	0.029 inches of H_2O (7.2 Pa)
1st Floor - North Facing Single Bank Stairwell Door	0.031 inches of H_2O (7.7 Pa)
1st Floor - Air Lock Passage to Exterior - South Facing Vestibule Type Door	0.028 inches of H_2O (7.0 Pa)
2nd Floor – West Facing Single Bank Landing Door	0.039 inches of H_2O (9.7 Pa)
4th Floor – North Facing Single Bank Door	0.040 inches of H_2O (10.0 Pa)

Under these conditions, this air imbalance created on average a measured positive differential pressure condition of ~0.033 inches of H_2O (8.2 Pa). This pressure differential was consistent with the original building AHU balance report. Further modifications are planned on the HVAC system in spring 2012 and the weatherization repairs for the building are scheduled for the summer 2012. When these improvements are completed, infrared thermograms and differential pressure measurements will be repeated by future student energy auditors to assess the impact of these final building repairs.

STUDENT TRAINING AND LEARNING OUTCOMES

Building science thermography requires the knowledge and understanding of where and how heat transfers and air flows throughout a building. The first author is currently a Certified Building Science Thermographer with previous Level II Thermographer Certification. With the support of the Infrared Training Center (ITC) at FLIR Systems [1], the world's largest thermography training organization, student energy auditors were required to successfully complete a primer or first course in thermography and an infrared camera basics operations course before beginning their building investigations. Aspiring student energy auditors, now with eyes that can observe in both the visible and IR spectra, had learned and can now apply the following to estimate the energy efficiency of selected campus buildings:

- How to use an infrared camera
- Basics of building construction designs, terminology and materials
- Heat transfer physics as it specifically applies to buildings
- Indoor and outdoor building inspection methods
- Typical thermal patterns associated with traditional building defects
- Basics of building science, including stack effect, moisture control, and principles of air control heating and cooling
- Avoiding mistakes: hot spots versus reflections and direct versus indirect readings
- Safe building inspection methods and techniques
- How to report infrared analysis findings with IR reporting software
- Photo documentation techniques, including 35 mm, digital and video
- Interpreting thermograms using heat transfer concepts

The above knowledge and skills are not typically obtained through a mechanical engineering curriculum. They complement the engineer science coursework and baccalaureate engineering degrees of these energy auditors. With these competencies, it was observed during the course of these building energy audits, student confidence continuously increased. Additional engagement and ownership that the students took on these projects enhanced student learning through their participation in the creative process: identifying new problems and creating solutions. The vision of Dr. Ransdell of the WKU campus being used as a living laboratory was being realized in the Department of Engineering, and particularly in the Mechanical Engineering program, through its project-based engineering education approach. Student engagement in relevant and applied projects has been the core of the Mechanical Engineering program [6] since its inception with similar noted at other institutions [7, 8, 9]. Often these projects impact other departments, programs or research centers on campus. For students, this is definitely a more engaging activity than the traditional courses and labs, which have students going through pre-defined assignments and procedures. During the investigations of the respective buildings, the students were all thoroughly engaged in the energy audit at hand, and in each case, the time allocated was always exceeded without any complaint from the student energy auditors. The student feedback has consistently been favorable.

SUMMARY

In summary, infrared thermography in the hands of student energy auditors form a viable research tool in "visualizing" university campus building envelope deficiencies by providing quick assessment and presenting very discernible images. This technique has been shown to effectively visualize air exfiltration in a university multipurpose building. The opportunity to apply infrared thermography to a campus-wide weatherization repair plan will provide the Department of Facilities Management with assessments of the benefits of their plan and identify additional areas of focus. The Department of Engineering, its faculty and students, will benefit through the application of the technique to identify and verify the solutions to energy management issues associated with building envelopes. The University as a whole is the ultimate winner in this process through lower operating costs, greater cooperation between faculty and Facilities Management staff, and vested student interest in developing their knowledge and skills through their participation in the campus living-laboratory environment. Other artifacts include papers documenting the technical merits of the various projects and issues uncovered by the students, learning outcomes of the independently directed research and pedagogical implications. And, with respect to the student involvement in these building energy audits, it was determined at the onset that project success would rely heavily upon student technical capabilities. Thus, a training methodology was developed in cooperation with ITC at FLIR Systems. After properly trained, students participated in every aspect of these projects and collected all building envelop measures. Overall, the efforts of the students contributed significantly to the success of this project.

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Robert E. Choate

Robert Choate teaches thermo-fluid and professional component courses in Mechanical Engineering, including Thermodynamics, Fluid Mechanics, Sophomore Design and the ME Senior Project Design course sequence. Prior his appointment at WKU, he was a principal engineer for CMAC Design Corporation, designing thermal management solutions for telecommunication, data communication and information technology equipment.

Thomas A. Choate

Thomas Choate graduated from The Gatton Academy of Mathematics and Science in Kentucky in May 2010. He is currently attending Vanderbilt University and majoring in economics and mathematics. His research interests include sustainability and identifying sustainability indicators for small communities along with assessing their economic impact.