Heat Transfer Projects Including Social Justice Issues

Shirley T. Fleischmann, PhD

School of Engineering, Padnos College

Grand Valley State University

Grand Rapids, MI, 49504

Email: fleischs@gvsu.edu

Abstract: Shelter from the environment is a basic human need. Providing for it is certainly an aspect of consideration of the common good that engineers are obligated to consider by canons of our profession. Heat load analysis is often one of the first topics covered in a typical heat transfer class and provides a perfect springboard to including the greater context surrounding shelter - including social justice issues. The topic of this paper will be a number of projects undertaken by a Heat Transfer class that involved a technical analysis of a particular house or building in the neighborhood of an urban campus and within the context of an urban setting. That context includes issues such as high percentages of rental properties, rising levels of development and displacement of lower income residents, poor energy performance of rental properties leading to disproportionately large electric and gas bills while the houses stay cold in winter and hot in summer. The projects described in this paper have been structured so that students are required to consider the social, economic, environmental, and regulatory embedding for their proposed solutions. This is also in keeping with the new ABET requirements.

"The habit of apprehending a technology in its completeness: this is the essence of technological humanism, and this is what we should expect education in higher technology to achieve. I believe it could be achieved by making specialist studies the core around which are grouped liberal studies which are relevant to those specialist studies. But they must be relevant; the path to culture should be through a man's specialism, not by-passing it...

A student who can weave his technology into the fabric of society can claim to have a liberal education; a student who cannot weave his technology into the fabric of society cannot claim even to be a good technologist."[1]

Lord Ashby, *Technology and the Academics*

Introduction: The projects described in this paper are a result of a particular approach to curriculum design in which context provides a framework. Three questions provide a context for curriculum design: What are we trying to accomplish? To whom are we accountable? How do we motivate students to learn and become proficient in engineering design?

Question 1: What is it that we are trying to accomplish in higher education in engineering?

The goal of engineering education is to prepare students to enter the engineering profession. Because engineering is a profession that is practiced in the context of culture, that preparation must be done in the context of the culture(s) in which engineers will practice their profession. In most cases that culture is strongly driven by technology and that technology is designed and delivered by engineers to a general public that often does not understand the technology or its potential impacts. This places increased responsibility on engineers in two areas: to understand the social and environmental impact of their work - and also to educate non-engineers about the work that they do so that people outside of engineering can provide an informed outside point of view of engineering work. Ultimately the latter is essential to provide the checks and balances necessary to preserve civil society; it is a responsible citizenship issue. It is challenging to craft experiences that will help students to see the potential of their work in the context of responsible citizenship.

Question 2: To whom are we accountable?

We can name many constituencies to whom we are accountable however one stands out in importance for most engineering programs in the United States and that is ABET, our accrediting agency. The new 2019-2020 ABET Criteria can be understood as a mandate to teach engineering within the context of the culture in which it will be practiced.

Question 3: How do we motivate students?

In part, we motivate students by inviting them to share the engineering experience with us…and the engineering experience is one of problem solving. The first homework assignment in Heat Transfer includes a short essay in which students are asked what they hope to gain from this course. Their answers are used to guide my approach to the course. Many students answer that they hope to gain "practical knowledge". When that practical knowledge comes early in the course, it sets the expectation that applications will be the focus throughout. Energy efficiency for buildings with the related social, economic, and environmental consequences have long been a driving interest for me. Each project described in this paper started with a practical problem related to heat transfer in buildings located in the community local to our campus. Solving these problems has direct practical benefits to a population that is somewhat different from the typical student population. Developing relationships that will allow access to the buildings at the same time that trust is developed between the students and the people who will benefit from their work is part of the project. This is not normally addressed in engineering classes and most students need faculty guidance at some level. Preliminary work in relationship building is necessary on the part of the faculty. Students are drawn into the project by posing it as a project that we tackle together as responsible citizens but the students also walk into established relationships. Only then will they be able to see the full impact of their work.

Projects: In this part 3 projects will be described. Each project was handled in the lab where we had more time than in the lecture and, more importantly, the group size was limited to 15 students or less. Each lab section visited the site at least once to take measurements and make observations and every site visit was done with the faculty member.

Project 1: Elementary School

In one year the heat transfer project started with an article in the local newspaper about an elementary school where snow sifted into the windows when the wind blew against them. Finding it hard to believe that such conditions existed in an elementary school not far from our campus, I visited the school and spoke with the principal. The story was accurate. The single pane glass in many of the windows had been replaced with Plexiglas and were poorly glazed. It was entirely possible to open up a ¼ inch crack by gently pushing on the Plexiglas. After a conversation with the principal we agreed to have my heat transfer class visit the school to do an energy analysis but also to talk with the principal about the many other problems faced by this physically neglected school in a low-income neighborhood. We rotated activities on site. While half of the class surveyed the classrooms, the other half of the class conducted hands-on activities with the children in the gym. These were the children who would directly benefit from a better energy management solution for their school. We found that in most classrooms only one of the double-hung windows worked – and then only for fire-egress purposes. Single pane glass had been replaced by Plexiglas because it was less expensive and less likely to shatter. Later decisions about the glass cleaner caused crazing on the Plexiglas so most of the replaced panes were no longer transparent - and the wood was in such poor shape that it was almost impossible to create an effective seal when replacing the pane.

We used a thermal imaging camera and discovered that there was no insulation in the attic and that above the ceiling of the second floor there was a 3-4 foot high empty space between the ceiling and the flat roof. In the winter this was cold but in the summer it was unbearably hot – driving the staff to work in the basement in the summer. A new (over-sized) boiler had been installed and at the same time the school system had decided to save on energy costs by setting all the thermostats back on Friday afternoon and setting them up again on Monday morning. With such a poorly functioning thermal envelop the school was cold enough that students wore their coats inside on Monday and Tuesday, were comfortable on Wednesday, and were overly hot by Thursday and Friday. Clearly, there was much room for improvement in the energy management for this building. The engineering students were required to model the building to show the effect of their suggested improvements. This was the technical part and also the easy part.

I was grateful to the principal for the time he spent explaining some of the other problems faced by the school. The neighborhood included many houses with absentee landlords who rented rooms by the day or even by the hour. Loud music interfered with classroom instruction (especially with such poor windows) and the drug traffic and prostitution were significant problems. These were issues for city policy and policing…and certainly not problems that most of my students had encountered in their elementary school years.

Windows, lack of insulation, and other energy-related problems were not the only physical problems. The building was simply in poor physical shape. As a class we held a series of roundtable discussions about what we could recommend. Some of the students wanted to know why the parents didn't just show up on the week-ends and fix the problems. Certainly that is what their parents would have done. It was sobering to realize that as poor as the physical condition of the school was, the condition of many of the rental homes where the students lived was possibly worse. The reality of single parenting on the economic edge was something that my students had never considered. Most of my students came (and still come) from a middle to upper economic class environment. There are expectations based on life experience that come with this environment. Taking charge of a situation requires an expectation of control, a knowledge of resources required, and an ability to obtain those resources. Just the simple example of painting where it was badly needed could serve as an example of the disconnect in understanding. How much does a gallon of paint cost? Should that gallon of paint take priority over meeting the most basic needs of food and shelter? We were discussing the problems of poverty with a group of students most of whom had never seriously encountered it. The most stunning conversation was with the group that included a foreign student who had come from a poor village in Africa. He listened for a while and then said, "You, in America, have no idea what poverty is like". He then described how he grew up. Needless to say, the students in this class learned far more than just heat transfer in this project. The technical problem opened the door to the context of poverty and the many aspects of really solving these problems.

Purple House

This project came out my association as a board member and president of the board for a local not for profit community development organization. The organization owned a small house near our campus that was rented to a neighborhood family. The energy costs to heat the house were exorbitant; in December of 2004 the gas bill was for 415 CCF of gas. This was for a small house with a total of 4 radiators supplied with a gas-fired boiler. The organization paid the energy bills for the house and along with late or missing rent payments it was clear that the situation was economically not sustainable. Through a partnership with a local cellulose insulation manufacturer we were able (in a lab section) to do blower door tests and infra-red imaging of the house. We found evidence to confirm our suspicion that the house had no insulation anywhere (something true of most of the houses in this neighborhood). In the process of gathering this data students were also introduced to the low-income neighborhood that surrounds our campus. The required part of the project was to model the house temperature as a function of time assuming hollow walls, single-pane windows, the measured air infiltration rate, and 160˚F radiator surfaces when the outside temperature was 32˚F. Calculations were to be repeated for just insulating the walls and attic and adjusting the infiltration rate. Obtaining the data required for the modeling required students to spend time in the neighborhood and at the house. There was a family living there so our interactions also involved respecting the family's privacy.

In addition to the technical model each student was required to complete an essay in which they discussed the problem of un-insulated high energy requiring houses as a social justice issue. Most of the houses in this neighborhood are not insulated and most are rental units. In very cold weather many families must decide between heating the house and eating. These are families that cannot afford high energy bills yet they carry the largest economic burden and the houses are often not comfortable. The energy inefficiency also wastes energy and adds to environmental burden. A list of questions was posed for students to consider as they started to tackle this problem. With the models we found that the equilibrium steady state temperature of the house would be around 60˚F or colder with an outside temperature of 32°F. With the thermostat set at 70˚F (or higher as we observed-a different social problem), the boiler would run continuously. This would explain the high gas usage. Adding insulation and decreasing the infiltration rate dropped the heating load to 1/7 of the original load.

Figure 1 shows a typical result of the modeling showing clearly the effect of high infiltration and very little insulation.

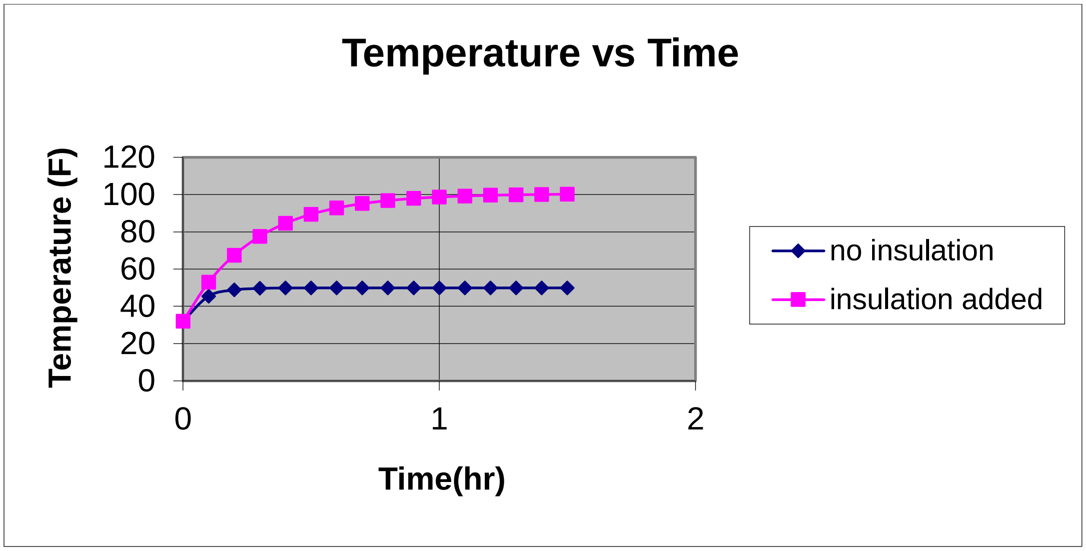

Figure 1: Temperature in a house as a function of time for no insulation and high infiltration as compared to the insulated case and low infiltration.

<u>The Importance of Reflection as Part of the Project</u>

This was a real problem involving real people and using the expertise developed in the class. It was well received by the students. As the reflection part of the project I set aside the lab period in which I handed back the graded reports as a discussion session. It can be awkward to discuss social issues in an engineering class but it helps to begin with a technical discussion. We had discussed parts of the model before but now we did a complete review. For the social justice discussion I had taken notes on each of the students' comments. I asked certain selected students to read their comments as a way to begin discussion and fortunately there was a sufficient range of opinion to facilitate an excellent discussion. This approach – asking selected students to read their comments – works very well because students can begin in the safety zone of simply reading what they have written beforehand. There is great value in students making the social connections themselves. As one of the students noted, "At first I thought this was an easy problem, but then I found out that it was not". This led into a deeper discussion of alternatives and the conclusion that we would need to learn even more before we could propose a long term solution to the problem of energy in-efficient housing.

Another approach to discussion is to note one main comment from each student's essay. In the discussion you can go through the entire class list and for each student, say "this is what I understood from your essay… Did I understand you correctly and do you have anything to add?" My experience with both approaches is that wonderful discussion occurs and it is evident that students have learned far more than just the technical aspects of the project. To enhance the mood for discussion refreshments are helpful and moving the discussion into a conference room – or at least creating a conference table by moving lab table together is helpful.

As a purely voluntary part of this project the insulation company volunteered to teach a student team how to do retro-fit insulation with cellulose and to teach us on the house that we modeled. Most of the class did volunteer and we were able to completely fill the walls with insulation and also eventually insulate the attic. We have not repeated the blower door test but we were able to see the fill level of insulation in the walls using the thermal imaging (infra-red) camera. We also distributed a short description of what we were doing to the neighbors who were curious. This provided an opportunity to explain engineering work to a non-technical audience. In December of 2005 the gas bill for the house dropped to 85 CCF of gas. The project continues to be a topic in my heat transfer classes.

Having a required and a voluntary part worked very well. All students were required to immerse themselves in a real engineering problem to a certain degree. Some of the students who might not have volunteered before became interested enough to step forward and volunteer, but those who were uncomfortable with continued interaction could dis-engage in the voluntary part. All students saw the way in which engineering expertise could improve the quality of life for real people that they met. Even the students who did not volunteer had the benefit of the required experience and they saw how important this kind of work was to someone on the faculty. As they saw tangible benefits many students became motivated to learn even more than what was required.

<u>This Year's Project:</u>

The project this year is a heat load analysis for a rental house owned by a local not for profit housing organization. The house was built in the late 1800's as were many of the houses in the neighborhood. There are 3 apartments – 2 on the second floor and one large apartment on the ground floor. The ground floor apartment is undergoing major renovation and is currently not occupied while both second floor apartments are occupied. Each apartment has its own electric meter but there is only one gas meter for the entire house. Currently a gas-fired boiler provides hot water heat and one water heater services all three apartments. Each apartment kitchen has a gas stove. Because there is only one gas meter, the housing organization pays the gas bill. With the major renovation they would like to find an equitable way to bill each apartment for natural gas usage. One solution might be to know the demand for each apartment and split the bill accordingly. Another might be to have 3 separate gas meters along with 3 separate furnaces and water heaters. The latter plan would require removal of the current heating system and a major addition of equipment and infrastructure. The renovation – which provides access to the basement and all the walls on the ground floor since the walls have been torn down to the studs – makes such a major change possible. There is no insulation in the walls and the attic is lightly insulated. Some of the windows have been updated. Like many of the houses built in the late 1800's it has balloon framing which is highly susceptible to fire.

The house is in a neighborhood that is undergoing rapid change. It is near the city center. The city is pushing to add up to 10,000 living units downtown. Developers have moved in and have been able to purchase many properties – especially in the wake of the 2008 downturn in the economy. New apartments and many of the renovations are offered at market rate which is far above what the average current resident of the neighborhood can afford. The housing organization offers affordable rentals and this particular apartment would be suitable for a family. Such rentals are becoming hard to find. The neighborhood has always been a blue-collar neighborhood with many immigrant families. It is currently a lively, healthy neighborhood but not a wealthy one. The current trend is to push the lower income families out as rental and purchase prices become unaffordable. This threatens the character of the neighborhood as it displaces the current population. As a not-for-profit organization, financial resources are tight and the organization is committed to stewardship of economic, social, and environmental resources. Within this context, what should be the organization's plan for this house? Is there an approach that would allow for equitable division of the gas bill, upgrading in the energy performance, and also minimize the expense of the upgrades?

The lab groups will take measurements in the house that will enable them to model the thermal envelope- both as it is and with improvements. The reports that they write will have 3 parts. The first part will draw on their technical analysis to produce recommendations for the board of the housing organization. The audience for this report will be an educated but not technical audience so technical results must be clearly presented in a way that every member of the board can understand it. The second part will be their full technical analysis intended for a technical audience. The third part will be a reflection on how their proposed solution fits the context of the problem.

Back to ABET Criteria

The ABET 2000 Criteria pushed curriculum design to include the context of practice. The new 2019-2020 Criteria sharpen the focus on teaching within the context of engineering practice. As faculty we must design curricula that meet the ABET Criteria. As part of those newly stated criteria, Criterion 3, Student Outcomes[1] is shown in the table below.

Table 1

ABET Criterion 3: Student Outcomes

The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. Student outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program.
1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The projects described in this paper meet almost all, if not all, of the stated criteria. The current project meets the student outcomes in the following way: In creating both steady state and transient models for the thermal performance of the house, students demonstrate student outcome 1. By considering the context of the stated problem with all the constraints of context, students will demonstrate student outcome 2. By preparing sections of the report for a non-technical audience and other sections for a technical audience, students demonstrate student outcome 3. Each of these projects came out of a faculty member's professional experience and involved the faculty member recognizing and acting on a problem in which they had the expertise required. Student outcome 4 will be met by sharing with the students how relationships with the people and organizations involved allowed for the problem to be addressed. Student outcome 5 can be met by making some aspects of the work group work and by holding a formal reflection session in the lab after the project is completed. Student outcome 6 will be demonstrated through the solutions proposed that will be based on multiple inputs. Student outcome 7 will be met as students will not only apply heat transfer knowledge but will also research types of insulation, heating plants, code requirements that must be met, and the social environment in which the proposed solution must function.

Concluding Thoughts

My own reflection on a number of projects such as the three described here highlights the importance of my own involvement first. For the elementary school I had no involvement until I read the article and went to the school to see the problem for myself. Establishing a good working relationship with the principal before outlining a possible project was a key step. The project went forward only with full "buy-in" from the principal and students were able to step into an established relationship. I shared with the students how this relationship evolved. In the case of community development organization and their sister housing organization, I have a long-standing relationship as a board member and volunteer for both organizations. The rules of engagement for community service - rules that value and protect the dignity of those we hope to help - are not immediately apparent to many students who see things through the lens of their own life experience. The help offered must be authentic in purpose and offered with the realization that the benefits are reciprocal. The importance of building relationships cannot be understated yet skill in building relationships with people unlike ourselves is not typically addressed in engineering curriculums. Relationship building, building trust and friendship, spending time with people and learning to listen, these are all citizenship skills that many of our students (and many of us) have not been required to develop. These projects are important me, and the people involved are important to me. I am inviting students to join me in this work and also showing them how to enter into it. I am also physically present with them on site so that I will be able to help students make sense of reactions and events that they may not understand. For students who are uncomfortable in interacting with people of quite different circumstances in life, the structure of the project allows for pulling back from too high of a personal level of involvement while certainly learning to understand a different point of view and a different life experience.

All mechanical engineering students are required to take this course. In the curriculum it is placed in the senior year at the same time as the senior project experience which has much more of an industry focus. The material in the course is a culmination of the thermo-fluids string of courses and requires mastery of many concepts. While the project is not as demanding as the senior project, it does fully support the senior project experience by providing aspects of every one of the student outcomes of Criterion 3 of the 2019-2020 ABET Criteria. Most importantly, because the projects are drawn from the context of culture they provide space for including the social, economic, and environmental contexts for heat transfer applications. In closing I think again about my students' request for "practical" knowledge in the heat transfer course. Might it be a request to model how this new information can fit into their everyday lives – not just as engineers, but also as citizens? Is this not also the thrust of the newly stated ABET Criteria?

References

1. www.abet.org/accreditation/accreditation-criteria/