AC 2007-1598: STUDENT/TEACHER ROLE SWAP IN HEAT TRANSFER

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Student/Teacher Role Swap in Heat Transfer

Abstract

Groups of mechanical engineering students taking the undergraduate heat transfer course were asked to play the role of a professor and design an experiment to teach future students the concept of thermal resistance and thermal resistance networks. The students had to construct and run the experiment to demonstrate its functionality. They also had to provide a technical report of the design and construction of it. In addition, they were required to create complete experimental procedure, data sheets, and analysis and to describe the requirements for a lab report based on the experiment that future students can complete and turn in for a grade in the heat transfer lab. The last part of the project that challenged the students to reflect on their own learning and the way future students may learn the concepts. The reflection component may not be present in typical projects, and/or may not be probed. The learning of the students was probed via a survey of a few questions. The questions asked the students if the project increased their understanding of the technical concept they had to design the experiment for, amount of work involved, ease of playing the role of a teacher, whether they became aware of the their own learning process, whether the new awareness would help in learning other materials, advantages/disadvantages and level of enjoyment and time spent on the project. The survey results were analyzed and have showed positive advantages of this learning experience in the areas mentioned above.

1. Introduction

Traditionally, engineering undergraduate students are provided with some design experiences in the capstone design course, and as part of some other engineering courses, which include design-type small projects or open-ended problems, throughout the curriculum. While very valuable in many ways, these design experiences do not include any reflection on, or awareness of, the learning process itself.

A project of this kind creates new educational opportunities and serves as an active and cooperative learning environment, similar to the one that Shuman et al.[1] have alluded to. It includes instructions that promote student understanding and development. In addition, it upgrades professor/student communication in a very interactive way. Such advantages may not be encountered in the typical undergraduate engineering curricula.

Active learning can be defined as any instructional method that engages students in their own learning process by encouraging them to think about what they learn and how well they learn it.[2] Active learning and cooperative learning methods show a significant increase in student learning.[3] The constructivist approach to learning is based on the notion that learners construct their own knowledge rather than knowledge being transferred to them. A constructive learning environment emphasizes knowledge construction instead of knowledge reproduction, and encourages thoughtful reflection on the learning experience.[4] Other researchers have pointed out that experiential learning environments prepare students to be self-directed and life-long learners. This is not usually encountered in the typical undergraduate engineering curricula, including the capstone design.[5] A good discussion of inductive teaching and learning methods and their advantages can be found in reference 6.

An undergraduate heat transfer lab experiment handout typically has a set of instructions as to how to run the experiment, how to collect certain data and then how to analyze and interpret the results. The analysis, interpretation and answers to some pertinent questions are usually included in a lab report that the students turn in to assess the students' understanding and to assign a grade. Designing or selecting an experiment, and then devising a procedure and a list of questions to enforce the learning of heat transfer concepts are all done by the instructor. Needless to say these tasks require a good level of understanding of the concepts themselves and the way students learn, as well as common mistakes and other intricacies that may be connected to the concept in question.

This paper briefly describes a heat transfer project conducted by several undergraduate mechanical engineering students during the past spring semester. The students had to design, build and demonstrate a working experiment illustrating the thermal resistance and the thermal resistance network concepts. The students had to play the role of an instructor, and device an analysis section for future heat transfer students to assess the learning of these students. The paper also assesses the design experience's effects on the students' awareness of their own learning, and it documents their comments and feedback.

2. Description of the Project

2.1 Topic and Tasks

The students were asked to design a heat transfer lab apparatus to determine the total thermal resistance of a typical wall made out of at least three layers combined in series-parallel arrangement. The design was intended to illustrate the thermal resistance concept that the students learned as one of the topics in their undergraduate-level heat transfer course. See for example references 7 and 8. The design was supposed be self-contained. Due to lack of funding, the students were asked to use simple and available materials and instruments that one can buy at local hardware stores. Some cautions were pointed out and included the typical pit-falls of heat transfer modes, and practical tips to insure the success of the design and to reduce the time needed to accomplish it. Some of constraints were:

1. The thermal resistance of each layer must be known. The students should be able to compare their results to those provided by manufactures.
2. The dimensions should be decided such that one-dimensional conduction can be assumed.
3. The system must reach steady state conditions with reasonable time (not more than one hour).
4. A way of calculating the heat losses in order to estimate the error and to improve the calculated results must be provided.
5. A safety factor must be included in the design.
6. The cost should be minimal.

This project was worth 15% of the course grade.

The students encountered many unanticipated issues when they first tried to run the experiments after they had designed them. This is typical of some of the situations encountered in the work environment. Therefore the experience exposed the students to such situations, which is beneficial to the students' training.[9]

2.2 Participating Students

A total of six undergraduate mechanical engineering students participated in the project. Most of the students were seniors. The students worked in two teams of three. This pool of students was non-traditional: they were employees of Ford Motor Company. They had some technical background, but had decided to attend the university to obtain a BS degree in mechanical engineering. The company provided an incentive by paying for their tuition through an agreement with the university. After graduating, the students can climb the corporate ladder and increase their compensation. As such, the students had a maturity and age higher than typical students in undergraduate engineering programs. They also had good professional skills due to the nature of their work in the industry. However, it is the opinion of the authors that this project can work as well for, and provide the learning benefits to, traditional mechanical engineering students.

2.3 Heat Transfer Concept

The concept of thermal resistance is obtained by making an analogy between the steady-state heat transmission and the flow of electric current. The flow is due to a driving potential: in heat transfer the driving potential is a temperature difference between two locations, while in the case of electric current the voltage difference is the driving potential. The thermal resistance is obtained by employing this analogy and manipulating the heat transfer governing equations and casting them in the form of Ohm's law.

For a plane thin wall with its two surfaces at constant, yet different, temperatures (Fig. 1), the steady-state one-dimensional conduction heat transfer is given by Fourier's law:

$$\dot{Q} = k\,A\frac{T_1 - T_2}{L} \tag{1}$$

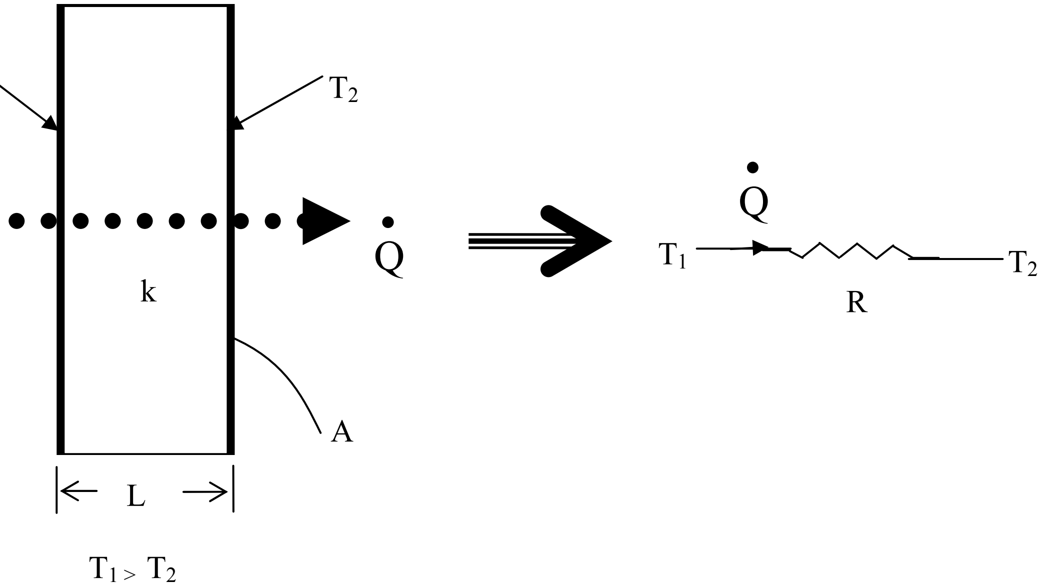

Fig. 1 Schematic to Illustrate the Concept of the Conduction Thermal Resistance

where A is the area of the wall perpendicular to the heat transfer direction,
k is the conductivity of the wall's material,
L is the thickness of the wall
T_1 and T_2 are the temperatures of at the surfaces
Equation (1) can be written in the form

$$\dot{Q} = \frac{T_1 - T_2}{R} \tag{2}$$

where R is the conduction thermal resistance of the wall. This is analogous to Ohm's law:

$$I = \frac{V_1 - V_2}{R_e} \tag{3}$$

where I is the electric current,
V_1 and V_2 are the voltages, and
R_e is the electric resistance.

Comparing Eqs. (1) and (2), we obtain the following expression for the thermal resistance

$$R = \frac{L}{kA} \tag{4}$$

Similar expressions for the convection and the radiation heat transfer resistances can be obtained by casting Newton's law of cooling and the radiation exchange between two surfaces in the form of Ohm's law.

With this concept, thermal resistance networks- series, parallel and series-parallel- can describe heat transfer in complex structures made out of layers having different materials and orientations as well as simultaneous modes of heat transfer. For more details, see references 7 and 8.

The students used the above concepts and constraints and successfully designed two different experiments- one per group. A sample of one of the designs along with the data analysis section is given in the appendix.

3. Impact on Students' Awarness of Their Learning

3.1 Students Survey

The impact of the project on the students' partial awareness of their learning was assessed by a simple and short questionnaire administered to the students after completing the project. A survey of twelve questions was given to the students to complete. The survey was designed to get information and feedback on the following themes:

1. Whether the students enjoyed the project or if they thought it was too much work.
2. Whether the project increased their appreciation/understanding of the thermal resistance concept and their network.
3. Whether it was easy for the students to play the role of a teacher trying to teach other students the concept of thermal resistances and networks, and if role playing was tricky at some points.
4. Whether the students became aware of their own learning process and how they learn, while designing the experiment, and while coming up with a list of questions and data analysis of the results.

5. Which part of the above two (item 4) made them more aware of their learning and how they learn.
6. Whether they thought the little awareness of their learning process and how they learn would help their learning in other courses.
7. If time was not an issue, if the students would like to have such an experience in other courses.
8. The general advantages and the disadvantages of the project

3.2 Students' Responses

The responses of five students who completed the survey were collected and analyzed to obtain general trends and attitudes based on the project. The following general can be made.

Four of the students said they enjoyed the project, but said it was too much work, while only one student said the amount of work was reasonable. One student said that there should have been more feedback from the professor throughout the design process. Also, four students indicated that they would like to see such a project repeated in other courses, if there was ample time, while one said he/she was not sure.

All five respondents agreed that the project increased their understanding of the concept of thermal resistances and networks. A couple of students elaborated: one said that the project made them appreciate more the complexities of real-world thermal systems, while the other contrasted the project to typical assignments that were given in the course targeting the same concept.

Regarding playing the role of a teacher, three of the students said it was easy, but tricky sometimes, while one said it was easy and the other said it was not easy. One student said that he/she got to be 'good' at computing the different heat-transfer quantities in the design.

In terms of awareness of learning during the design of the experiment, three students said they became more aware, while two said they did not. One student commented by saying that the design project helped turning the equations into more tangible objects and processes, while another said that he/she learned form the mistakes. One student said that he/she did not put enough effort in the design and thus did not become aware of his/her learning.

In terms of awareness of learning while creating a list of questions and data analysis of the experiment, four students said they became aware, while one said he/she became a little aware, as he/she had been designing experiments for his/her work. Of the first four students, one said that he/she became more aware of the 'roadblocks' that might be encountered by new students trying to understand the concept of thermal resistances and networks.

The limited results of this small sample of students seem to indicate that more students found that coming up with questions to analyze the experimental data brought about more awareness than designing the experiment. Four students said the increased awareness would help them learn in other courses, while one said that he/she was not sure.

The advantages of the project perceived by the students included hands-on experience, seeing the theoretical concepts in action, seeing how different concepts relate, team work, increased level of understanding (so that one can teach), increased learning, project planning and paying attention to details. As for the disadvantages, students cited difficulty getting the team members together, lack of enough time (due date was during finals week), changing of scope, and not enough review and feedback from the instructor.

4. Conclusion

An undergraduate heat transfer design project, in which the students had to play the role of a teacher, was described. The nature of the assignment forced the students to reflect on their own learning, and the learning of other students. The impact of the project on students' awareness and learning was assessed using a survey. The reflection on and the awareness of the students of their own learning is scarce in other courses in the undergraduate engineering curriculum. The limited results seemed to show that there was an increased level of awareness of the students' learning, and that awareness will be used in other courses.

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APPENDIX: Sample Report

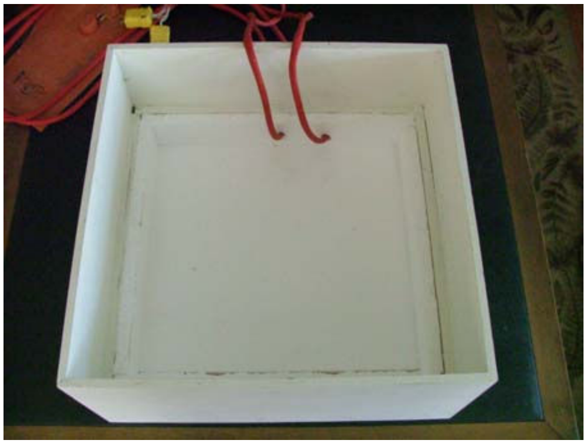
ME 340 Heat Transfer

Household Materials Resistance Box

Design of the Experiment: Household Materials Resistance Box (HMRB). The HMRB is constructed as follows:

A 16" square box was constructed out of 3/8 inch plywood. We chose to position the box and experiment materials horizontally for two reasons: first, since natural convection currents tend to move vertically, we felt that positioning the experiment horizontally would minimize the lateral variations in the outer surface temperature of the resistor materials, and help ensure that both conduction and convection occur in essentially the same direction; and second, positioning the box horizontally allows for the addition of subsequent resistor layers without having to use fasteners to hold them together.

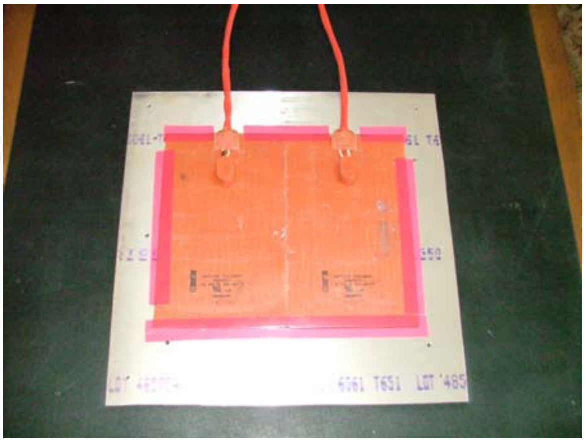
The inside of the box has narrow strips of plywood placed around the perimeter, used as a support for the heat source layer, and to allow space for the flexible heater connectors. Polystyrene insulation (¾ inch thick) lines this bottom area of the box, encasing the heat source on the sides and bottom and directing the heat in the upward direction.



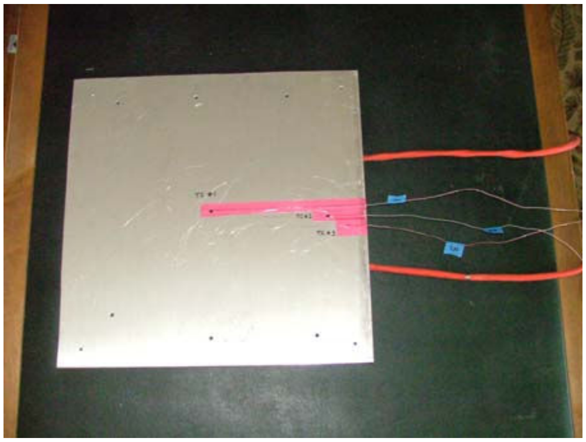
Inside of box, showing insulation &

Detail of inside of

Above the insulated space, the heat source (flexible resistance heaters) will be attached to an aluminum plate which will be used to distribute the heat evenly across the box's full horizontal dimensions. Thermocouples are placed on the top surface of the aluminum plate in 3 places: first, directly in the center; second, two inches from one outer edge and centered between adjacent sides, and third, positioned one inch from the outer edge.

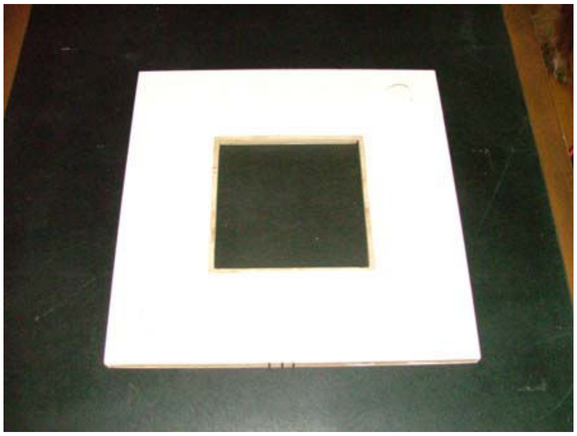


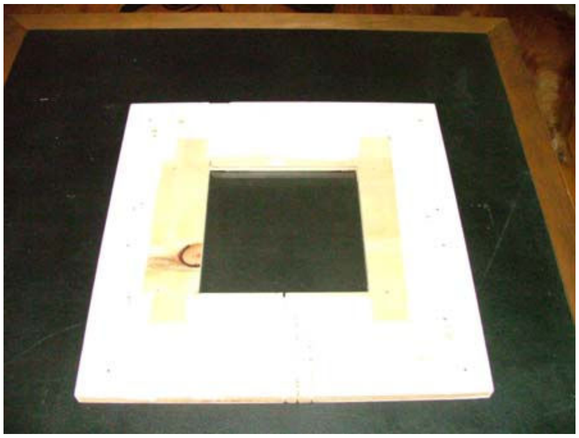
Bottom of aluminum plate showing flexible heaters



Top of aluminum plate showing

In direct contact with the aluminum plate is the first resistance layer, representing the thin wall and single-paned window.



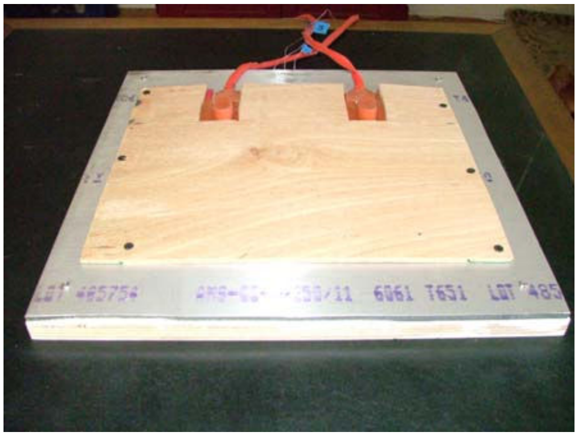


The wall layer is made of 3/4” plywood with an 8” square hole cut in the center. A single 1/8th inch thick pane of glass is caulked in place in the hole. (Note: When designing this wall layer, we decided that, in order to provide a secure method of fastening the glass in place in the panel, we would allow for a routed "ledge" to which the glass would be caulked. This "ledge" also slightly separates the glass from the aluminum plate: a measure we felt necessary, as initially we were unsure how hot our heat source would get and whether the glass might react adversely if it were in direct contact with the aluminum plate. Consequently this small air gap between the glass and the aluminum plate also acts as a resistor and will be factored into the calculations.)

Top of first wall Bottom of first wall

In order to ensure thorough and consistent contact between the heat source/aluminum plate (hereafter referred to simply as the **heat source**) and the first wall layer, we decided that these two components would be fastened together with screws after the first 3 thermocouples were installed, and would remain so unless any problems were encountered with the thermocouples (TC's). We also felt that fastening these together would help protect the TC's and hold them in place between the layers. Note: a slight recess was cut into the bottom of the wood of the first wall layer to allow room for the TC wire; otherwise the wire would interfere with direct contact between the heat source and the first wall layer, introducing the potential for error.


Detail of first wall layer recesses aligning with thermocouples.

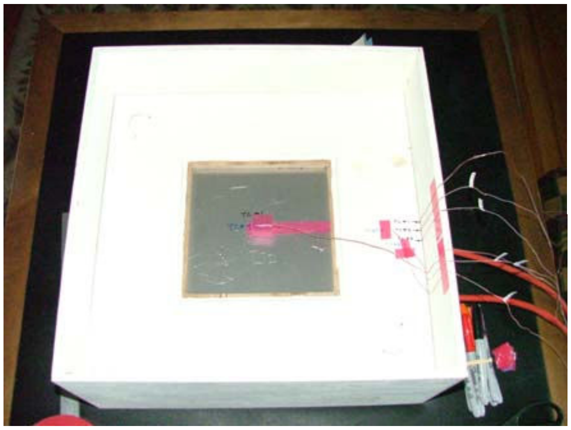

Aluminum plate, with heaters, mounted to bottom of first wall layer.

Two of these wall panels (3/4 plywood w/ center glass) are constructed in identical manner, the second to be used later in the experiment.

Also used for the experiment is an additional thermocouple, placed several feet from the box, to monitor the surrounding room temperature.

The experiment will begin with these first components: the insulated box, the heat source, the first wall layer, and a measurement of the surrounding air temperature. The heat source and attached wall layer will be placed in the box. A second set of 3 TC's will be attached to the top surface of the first wall layer, positioned directly above the first 3. The heat source will be turned on and all the TC's will be monitored until steady state is achieved. The temperature differential between the 3 TC's on the heat source and the 3 on the first layer allow for the calculation of the resistance values of the wood, air and glass.

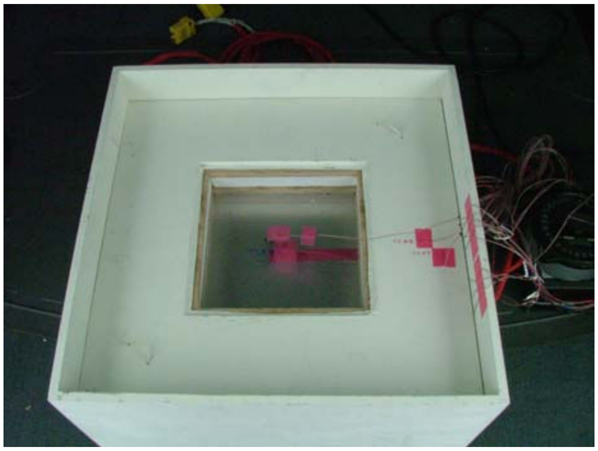
First wall layer, with heat source attached, placed in box. TC # 1 is visible through glass, 2 and 3 are not.



First wall layer with thermocouples 4, 5, and 6 added to top surface.

Once the data on the first layer has been obtained, we then place a layer of ¾" polystyrene insulation on top of the wood portion of the first wall layer, which represents adding insulation to an exterior wall. This particular insulation is commonly used in homes to insulate basement walls, and increasingly used to insulate between the studs of exterior framed walls. On top of this, we then place a second wall layer. Three more TC's are placed on this layer in the same manner as on the first layer.

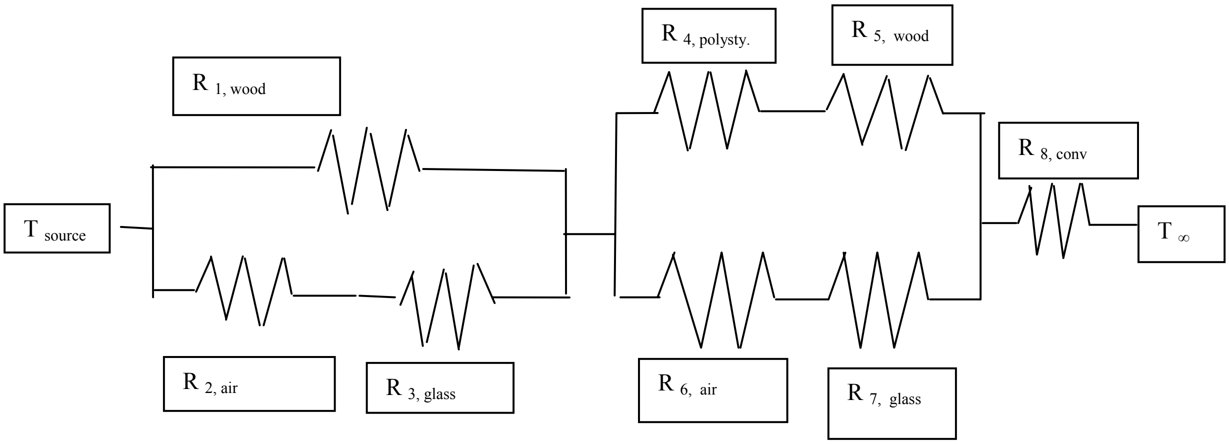
Layer of insulation added over first wall layer.



Second wall layer placed on top of insulation, and thermocouples 7, 8, and 9

The experiment continues by allowing the system to return to steady state. The data from the third set of TC's is then used to obtain the temperature differential between the heat source and the second, outer wall, and determine the increase in resistance, and thus the reduction in heat loss, through the addition of insulation, wood and double-paned glass.

The construction of the HMRB consists of several layers of resistance, both in series and in parallel. The diagram below illustrates this:



Data Acquisition

Experiment will require a digital thermocouple readout and ten thermocouples. If readout cannot accept ten, then a switching mechanism is required. This experiment required a switch, as the available readout only had 5 slots.

1. Attach a length of TC wire to channel one on the readout. Attach the other end to the switch input connector, ensuring correct polarity.
2. Attach the ten thermocouples to the first ten TC positions on the switch.
3. Check functionality of each thermocouple by selecting it on the switch and applying a known heat source to the thermocouple tip.
4. Ensure that each wire is adequately marked with a tag, such as T.C. #1, T.C. #2, etc.
5. Attach thermocouples 1, 2, and 3 to the aluminum plate according to the photos and drawings.
6. Attach thermocouples 4, 5, and 6 to the top (outer surface) of wall layer number one.
7. Attach thermocouples 7, 8, and 9 to the top (outer surface) of wall layer number two.

8. Use TC number 10 for ambient air temperature, placed about 4-6 feet from the HMRB. TC should not touch any surfaces, but should be suspended in the air.

Analysis and Results

After our initial assembly, we collected the experimental data and performed all the calculations to compare theoretical versus actual values. Our first attempt yielded a 100% error between the two, with our actual heat transfer being twice as high as the theoretical heat transfer.

We re-examined our experiment to try and find possible sources of error that we'd previously overlooked.

- ✓ We filled the space below the heat source with additional insulation.
- ✓ We sealed the hole through the side of the box through which the cord passed.
- ✓ We stuffed insulation into the tiny air gap around the perimeter of the first wall layer and taped it to seal it from air flow.
- ✓ We re-measured all of our dimensions and corrected our formulas for a higher degree of measurement accuracy.

While we made these changes, we continued to monitor the steady state conditions for the first wall layer. We were able to reduce the error by about 40-50%.

While we had initially designed the box to be a one-dimensional heat transfer project, we realized that there likely was some heat loss to the sides and bottom of the box. But when we calculated the heat loss from the sides to be about 1.68 Btu's, we determined that this was not a significant source of error. Given that the bottom of the box had nearly 3 times the amount of insulation as the sides, we dismissed heat loss through it as a source of error.

We examined the emmissivity of the aluminum plate and the glass. We observed that moisture was collecting on the surface of the glass and examined that. We examine conduction interference between the aluminum and the wood. Through numerous calculations, we determined that none of these were individually significant sources of error.

Then we re-examined our initial k values for wood, glass and the air gap. Through a number of iterations, and through comparing the k values from various sources, (tables in the text, and various websites) we were able to make corrections for the wood and the glass.

- ✓ The corrected k value of wood is .067 Btu/h ft^2 °F.
- ✓ The corrected k value for glass is .137 Btu/h ft^2 °F.

We determined that the most significant source of error was the air gap under the glass, and decided that its k value involved a number of factors that we weren't able to isolate. We finally settled on making this value a variable and solving the heat transfer equation by adjusting this value.

- ✓ The corrected k value of air is calculated to be .211 Btu/h ft^{2} °F.

This value yielded a theoretical heat transfer value of 204.7 Btu. The experimental heat transfer was 204.728.

Area wood	1.472	R wood	0.591472	L wood	0.058333	k wood	0.067
Area glass	0.35	R glass	0.21724	L glass	0.010417	k glass	0.137
Area air	0.35	R air	0.466035	L air	0.034417	k air	0.211
		R air glass	0.683275				
		R total	0.317034				
		Q theor	204.71				

HEAT TRANSFER RESISTANCE LAB

Objective : To demonstrate how resistance materials can be used to reduce energy loss and familiarize the student with methods for calculating heat transfer through the use of thermal resistance concepts that are analogous to those used in electrical resistance calculations.

1. When you arrive in the lab, the heat source in the Household Materials Resistance Box (HMRB) will have been turned on and have reached steady state. Three thermocouples are attached to the heat source as indicated by the diagram. Four additional thermocouples are attached to the first wall layer, according to the thermocouple diagram.

2. Verify that the system is at steady state by recording the temperatures for TC's 1 through 6 and 10. Wait ten minutes and take a second reading of the TC's.

3. Record the ambient air temperature.

The following steps can be optional, either with or without the addition of insulation. Note that adding these will significantly increase the amount of time required to conduct this experiment.

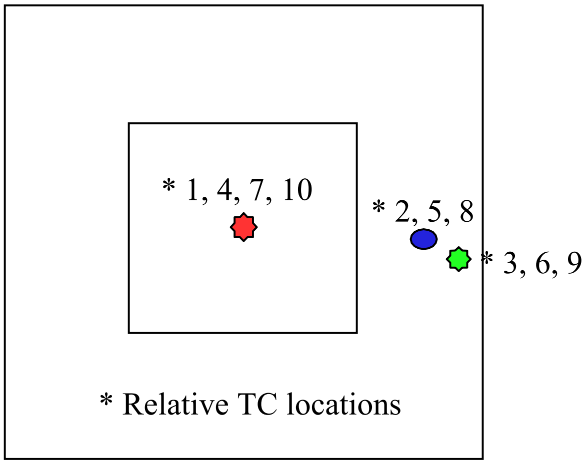
4. Optional: Add the polystyrene insulation layer over the first wall layer.

5. Add the second wall layer. The final three thermocouples are attached to the outer surface of this layer, according to the thermocouple diagram

6. Allow the HMRB to return to steady state. This will take some time *(2-4 hours)* Record the outer surface temperatures of the second wall layer, noting the TC locations.

7. Record the ambient air temperature to verify that the environmental conditions have not changed

HEAT TRANSFER RESISTANCE – DATA SHEET (Thermocouple location diagram)



T.C. #'s 1, 4, 7, and 10 are located in the center of each layer, one on the top of the heat source, two on the first wall layer (top and bottom of the glass), and one on the second wall layer, respectively.

Note: Thermocouples 2 and 3 are not visible, as they are between the wood and aluminum.

T.C. #'s 2, 5, and 8 are located 2 inches from edge of the each layer, one each on the heat source, the first wall layer and the second wall layer respectively.

T.C. #'s 3, 6, and 9 are located 2 inches from edge of the each layer, one each on the heat source, the first wall layer and the second wall layer respectively.

Assumptions:
Heat transfer is one-dimensional, with no heat generation.
The k value of wood is .067 Btu/h ft^2 °F. (Optionally given to the student)
The k value for glass is .137 Btu/h ft^2 °F. (Optionally given to the student)
The k value of air is .211 Btu/h ft^2 °F.

HEAT TRANSFER RESISTANCE – DATA SHEET (temperatures)

Record Temperatures for steady state with first wall layer only:

Thermocouple #	Location	Temp at Steady State Time: ___________	Temp at Steady State Time: ___________
T.C. # 1	Aluminum plate, center		
T.C. # 2	Aluminum plate, 2" from edge		
T.C. # 3	Aluminum plate, 1" from edge		
T.C. # 4	1st wall layer, top center (on glass)		
T.C. # 5	1st wall layer, top, 2" from edge (on wood)		
T.C. # 6	1st wall layer, top, 1" from edge (on wood)		
T.C. #10	1st wall layer, bottom, center (on glass)		
	Ambient Temperature (T∞)		

Record Temperatures for steady state with both wall layers and insulation:

Thermocouple #	Location	Temp at Steady State Time: ___________	Temp at Steady State Time: ___________
T.C. # 1	Aluminum plate, top center		
T.C. # 2	Aluminum plate, top, 2" from edge		
T.C. # 3	Aluminum plate, top, 1" from edge		
T.C. # 4	1st wall layer, top, center (on glass)		
T.C. # 5	1st wall layer, top, 2" from edge (on wood)		
T.C. # 6	1st wall layer, top, 1" from edge (on wood)		
T.C. # 7	2nd wall layer, top, center (on glass)		
T.C. # 8	2nd wall layer, top, 2" from edge (on wood)		
T.C. # 9	2nd wall layer, top, 1" from edge (on wood)		
T.C. # 10	1st wall layer, bottom, center (on glass)		
	Ambient Temperature (T∞)		

Student Data Analysis

1. Draw the resistance diagram for the HMRB.

2. Calculate the theoretical R_{total} for the first wall layer. Calculate the theoretical R_{total} for the combination of the first wall, (insulation, optional), and second wall layers.

3. Calculate the actual R_{total} for the first wall layer. Calculate the actual R_{total} for the combination of the first wall, (insulation, optional), and second wall layers.

4. Calculate actual and theoretical heat transfer $\dot{Q}$ and list possible reasons for the discrepancy.