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Developing a Customizable Renewable Energy System Laboratory Protocol for an Engineering & Technology Curriculum

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by

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ABSTRACT

In this paper the authors put forth an approach and give an example of how to produce a customizable Renewable Energy Laboratory Protocol, referred to here as a cRELP. Their intent is to assist applied engineering and technology programs with developing this type of laboratory protocol. The first half is concentrated on the author's hierarchal approach to cRELP development. This approach is similar to an upside-down pyramid, which starts with broad deliverables and progressively steps down to more focused outcomes. The second half of the paper focuses on a case study of the cRELP, intended to be incorporated into the *IET 352 Energy Systems and Sustainability* course offered at the Department of Applied Engineering and Technology, Morehead State University in Kentucky. This case study includes specific lab exercises, equipment needs and safety considerations in order to give the reader an example of how to formulate a cRELP's topics and content.

GENERAL AREA OF CONCERN

Renewable energy is currently an emerging technology both in America and the world as a whole. Specifically in the United States it has garnered increasing support by both government and private enterprises. As applied engineering and technology programs in various universities and colleges strive to keep their course offerings relevant to current industry and technology trends, more of these academic institutions are looking to implement renewable energy courses into their course offerings. This emerging line of renewable energy course offerings is vital, according to James Elder, Director of the Campaign for Environmental Literacy, adding that universities and colleges have a critical responsibility to equip the future leaders of society to “understand the complex connections and interdependencies between the environment, energy sources, and the economy” (Elder, 2009).

In partial response to this duty, educational institutions are increasingly implementing renewable energy utility systems across their campuses. Specifically, these institutions are among the largest purchasers of wind energy in America (Elder, 2009). Moreover, to date, 672 university and college presidents across the country have signed the *American College & University Presidents’ Climate Commitment*, which promotes the use of renewable and sustainable energy sources in conjunction with research and education (President's Climate Commitment, 2013). However, in order for educational institutions to effectively equip the future workforce for the multifaceted issues related to energy and sustainability, they need to move beyond campus utility issues and expose their students to renewable energy course topics (Yildiz & Coogler, 2012). Laboratory experimentation is an excellent tool to serve this purpose.

SIGNIFICANCE OF A cRELP

With the increased push by federal and state policy makers to advance America’s technological capabilities in renewable energy, coupled with increasing viability of this emerging technology, it is becoming more important for applied engineering and technology programs to offer courses infused with renewable energy topics (Yildiz & Coogler, 2012). As previously stated, these courses are needed to prepare future engineering and technology graduates for the energy workforce (Bari & Ferdousi, 2012). While most current course offerings have detailed curricula that emphasize renewable energy theory through lecture, many have yet to establish suitable complementing laboratory protocols. These laboratory protocols can significantly benefit students by offering them hands-on experience, which broadens and deepens their knowledge base. Integrating both theory and hands-on application into a classroom environment prepares students for the multifaceted demands of today's energy industry (Yildiz & Coogler, 2012).

At this point two questions may arise, "Why spend the time and exert the effort to generate a cRELP from scratch? Why not simply purchase an off-the-shelf trainer with pre-formulated lab experiments?" It would stand to reason that this approach would be easier and more cost effective. This assumption, though, according to Yildiz and Coogler can be incorrect. Laboratory equipment and manuals that are currently on the market today can be much more expensive than generating and building custom protocols and equipment (Yildiz & Coogler, 2012).

Upfront cost savings are not the only benefit of generating a cRELP. Other benefits include more effectively meeting stakeholder needs, more efficiently matching resources to laboratory protocols and more accurately marrying lab experiments to regionally applicable renewable energy technologies. When looking at an educational institution's stakeholder needs, being able to tailor a laboratory protocol to specific student and local industry needs can have a long-term benefit. Furthermore, resource matching (as it relates to instructor experience and financial budgets) is challenging to accomplish with off-the-shelf products, as they are either too simplistic or too complex to match specific or changing resources. Lastly, customizing a laboratory protocol allows course content to effectively marry with an institution's geographic location. This enables a successful dovetailing of course content and state-of-the-art technologies relevant in local industry. These benefits form a revolving cycle, as illustrated by Figure 1.

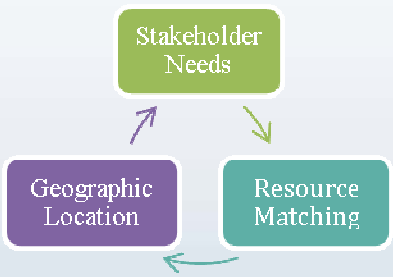

Figure 1: Cyclical benefits of a cRELP.

cRELP METHODOLOGY

As discussed above a “one size fits all” approach to laboratory protocol development will not yield the most benefit. In contrast, a cRELP is significantly more effective at meeting the multidimensional needs of an educational institution. In this section, a hierarchical approach to formulating a cRELP is presented. Figure 2 depicts this hierarchical approach as an upside-down pyramid of protocol deliverables. This upside-down pyramid starts with broad deliverables and progressively sharpens them at each successive level downward. In the following sections each of these steps will be presented and explained.

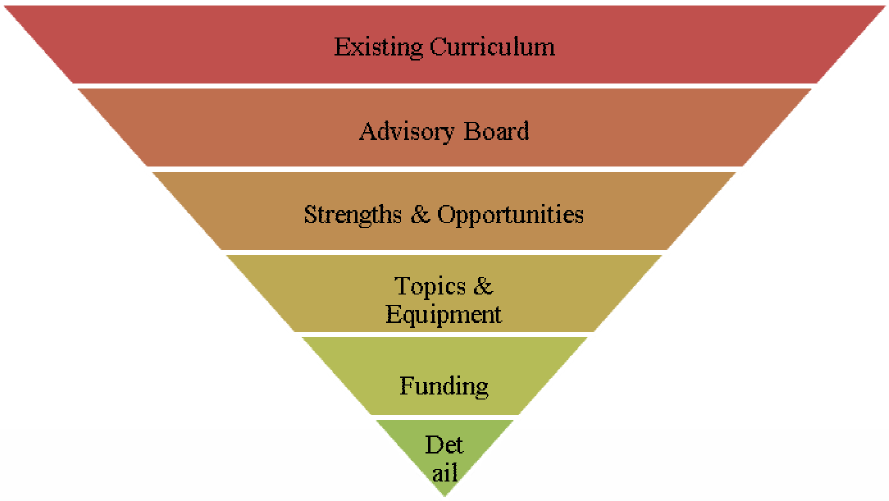

Figure 2: Upside-down pyramid hierarchical approach of deliverables of a cRELP.

Existing Curriculum

Looking at the hierarchy in Figure 2, the first level is to review the existing course offerings related to an institution’s proposed cRELP. This step produces a two-fold benefit: 1) it allows the instructor to understand the curricular landscape in which the proposed cRELP will be implemented in, and 2) it produces a good foundation from which to integrate the proposed protocol into the existing curriculum. This integration is important because renewable energy is an interdisciplinary topic. Integrating it across multiple degree tracks can lead to a deeper and broader experience for students, allowing them to see the multi-disciplinary connections of this technology (Elder, 2009).

Advisory Board

The next level down is the voice of an advisory board. This level is arguably the most important voice to listen to in the curriculum development process (Seybert, 2010). Advisory boards can be composed of industrial, academic, corporate or small business personnel and conversations with these individuals have significant value with a strong foundation of real-world application. Also, these advisory board members carry with them concrete job opportunities for graduates. These jobs, and the financial stability they bring, are an integral part of the education system. Listening to the voices of an advisory board is priceless, and thus should be key contributors to any curriculum content development (Seybert, 2010).

Advisory boards can give quality input into current and future renewable energy needs, which can be used to formulate laboratory protocol content. The first step in discerning these current and future needs is to communicate with board members through email, in person or with surveys/questionnaires. Whenever possible communicate with local industrial advisory board members and make it a goal to form a long-term relationship with them. Such cohesive relationships are invaluable assets that can benefit an educational institution far into the future. To this end, advisory boards are either strongly recommended or are a requirement by notable accrediting bodies such as the Accreditation Board of Engineering and Technology (ABET) and The Association of Technology, Management, and Applied Engineering (ATMAE), respectively (Seybert, 2010; ATMAE, 2013).

Strengths & Opportunities

The next level involves an analysis of an educational institution's strengths and opportunities related to specific topics of the cRELP. This analysis starts with an evaluation of the current instructor's background, experiences and research interests, alongside focusing the topics to include in the cRELP. The analysis also gives the faculty the ability to expand upon their research interest as well as involve students in innovative technology research.

In parallel, opportunities related to student needs should be analyzed in this step. This is accomplished with such tools as student surveys, student group decision-making and student questionnaires. These instruments are excellent at helping understand potential opportunities to service student stakeholder interests. At Sam Houston State University, professors Yildiz and Coogler employed these tools to help understand and serve their student's interests. This process helped them solidify specific topics to include in their alternative energy laboratory protocol (Yildiz & Coogler, 2012).

Finally, an educational institution's geographic location is a key aspect of its strengths and opportunities. Due to the fact that the abundance of renewable energy resources is different for different regions, this aspect should also be analyzed when considering what topics to include in a cRELP. Including renewable resource topics that are abundant to the region is a great starting point. Furthermore, these topics will most likely be prevalent in local industry and society. For example, when considering the applicability of Photovoltaic (PV) technology in a particular geographic area, there is a clear difference in degree from the Northeast United States to the Southwest United States, as illustrated by Figure 3. For educational institutions in the Southwest, it would make sense to focus on PV topics while those located in the Northeast may want to focus on wind, hydroelectric or other applicable renewable energy technologies.

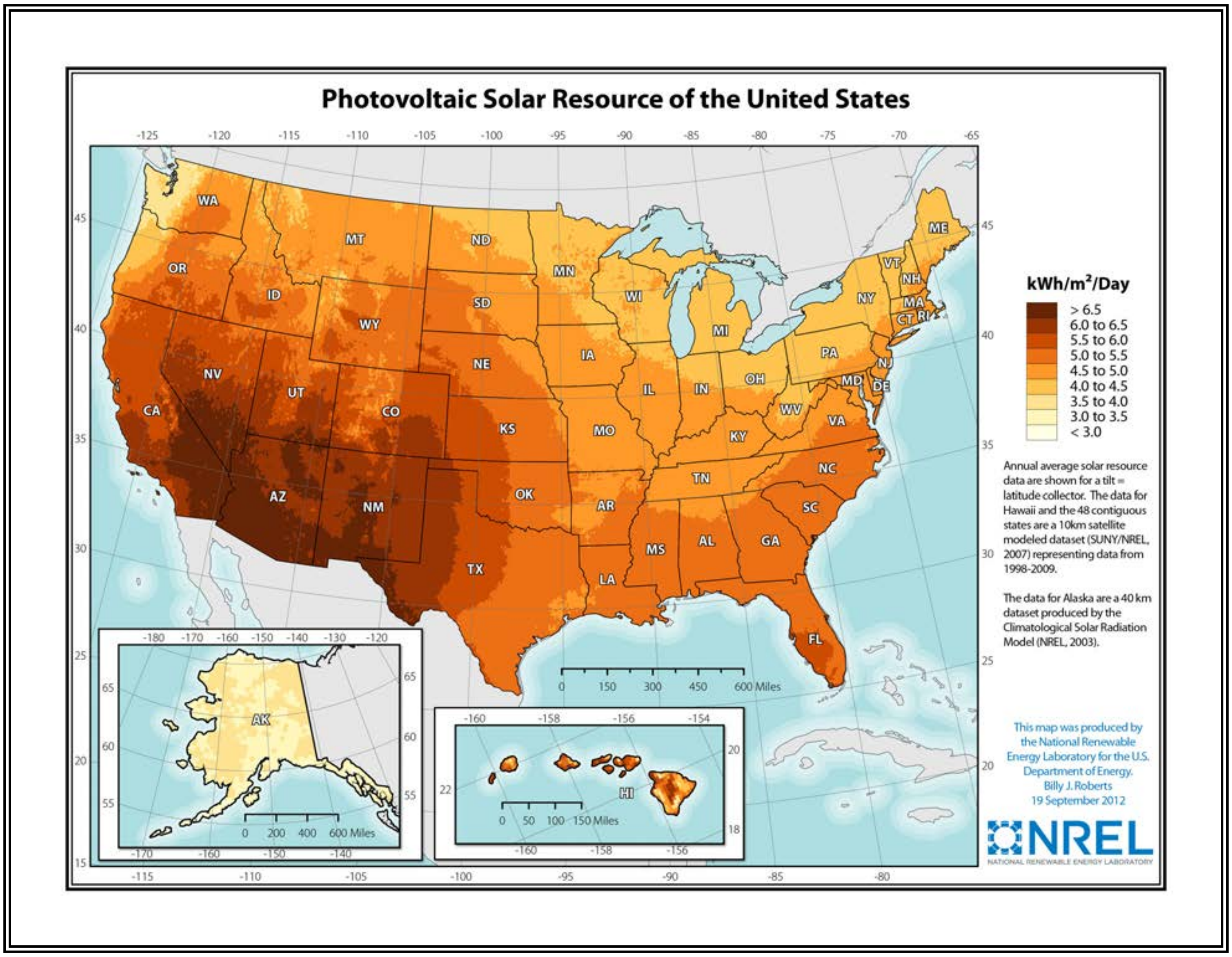

Figure 3: Photovoltaic resource across the United States (NREL, 2012).

Topics & Equipment

Once an educational institution has reviewed its existing course offerings, heard the voice of the advisory board and determined its strengths and opportunities, the next phase is to formulate a framework of the cRELP topics. (To aid in this process the layout of Appendix A can be referenced.) This phase can be broken into four distinct steps. These steps are presented below:

1. Breakout the cRELP into broad unit sections (i.e. solar, wind, geothermal, green building).
2. Populate each unit section with specific lab topics.
3. Select a reasonable number of achievable objectives for each lab (these help to further define each lab).

4. Generate a list of equipment needs necessary to achieve each lab objective.

It should be pointed out that the above four steps are iterative. Each must be reviewed and revised as needed until a clear and focused list is formulated. Also, reviewing other institution's laboratory protocols and equipment lists can be very helpful in working through these four steps. Additionally, renewable energy trainer product offerings are also helpful. These sources can serve as beneficial references in generating a cRELP.

Funding

The fifth step of the hierarchy in Figure 2 is to acquire funding for a cRELP. This step can be an intensive and broad-based research project on its own but determines the success or failure of the overall cRELP development. Efforts must be made whenever possible to broaden the possibilities of funding sources. To this end this section includes a handful of funding opportunities, as depicted in Table 1, some of which are for equipment only and some of which carry with them moneys to cover development time. It is worth noting that the main point to remember is this table is only a starting point. An educational institution looking to implement a cRELP should strive to apply for as much additional funding as possible.

As education budgets increasingly tighten, funding for curriculum and laboratory development becomes increasingly vital. Table 1 is a sample list of government and public funding opportunities related specifically to renewable energy education development and execution. The list in Table 1 is not exhaustive by any means, but should give the reader a springboard to start from (Constellation, 2013; US Department of Energy, 2013; US Government, 2013).

Table 1: A selection of possible funding opportunities for renewable energy education initiatives.

Fund Name	Fund Code	Funding Entity	Fund Amount	Website
E2 Energy to EducateSM	N/A	Constellation	$337,265 (2012)	www.constellation.com/community/pages/energy-to-educate-grants.aspx
State and local grants and funds	N/A	Various	Various	www.dsireusa.org
Energy Efficiency and Renewable Energy Information Dissemination, Outreach, Training and Technical Analysis/Assistance	81.117	DoE	~$25,000,000	www.grants.gov
Renewable Energy Research and Development	81.087	DoE	$76,699,391 (2012)	www.grants.gov
Used Energy-Related Laboratory Equipment Grants	81.022	DoE	Various	www.osti.gov/ledp/index.jsp

Detail

The final step of generating a cRELP is to design the detailed lab procedures and evaluation questions. It is important to note this step is most efficiently accomplished when the appropriate lab equipment has been acquired, installed and is available for hands-on operation by the instructor. The preliminary process of working through lab procedures should be performed on the physical equipment. This process allows for evaluation of the proposed procedures to see if they are appropriate. Then, once the procedures have been vetted, specific review questions can be formulated, which will more effectively assess students work.

MSU'S cRELP

Currently, the faculty and staff of the Department of Applied Engineering and Technology (AET), at Morehead State University (MSU) are in the process of implementing renewable energy and sustainability course offerings. The first of these courses is its *IET 352 Energy Systems and Sustainability* course. The course is currently offered as lecture-only sections but the AET Department is working to incorporate a cRELP into this course. A case study example of the *IET 352 Energy Systems and Sustainability* cRELP is hereby presented to support the proposed cRELP approach in Figure 2 and as a reference for the reader.

Laboratory Topics

The AET Department's cRELP included five unit sections: *Introductory*, *Solar, Wind, Fuel Cells and Green Buildings*. The *Introductory* unit includes labs focusing on safety, proper data collection and tool use. The *Solar* unit incorporates PV technologies, tracking vs. stationary installations and concentrated collectors. The *Wind* section looks at wind turbine design factors and efficiency and hybrid solar/wind systems. The *Fuel Cells* section includes a lab related to hydrogen fuel cell operation and efficiency. The final section, *Green Buildings*, looks at passive solar architecture and the effects of insulation and building materials on energy efficiency.

Each lab experiment in the five-unit sections included corresponding objectives related to each topic. These objectives were chosen to integrate with 1) topics included in the course's lecture section, 2) local industrial advisory board input and 3) faculty and student strengths and opportunities. An outline of these topics and objectives is presented in Appendix A for the reader's reference. It is important to note the objectives serve the purpose of focusing each lab exercise and to aid the faculty and staff in formulating appropriate assessment criteria.

Laboratory Equipment

In conjunction with the lab topics and objectives discussed above, the AET department's faculty and staff also generated a list of specific equipment needs related to each lab experiment. This list was crucial for the cRELP development because it was necessary to quantify these needs in order to formalize proposals for equipment grant funding. Table 2 below is the proposed list of equipment needs produced by the MSU AET faculty and staff.

Table 2: Proposed laboratory protocol equipment needs for the AET Department, Morehead State University.

Laboratory Equipment List		
Inverter	Solar Data Logger	Anemometer (Hand Held)
Deep cycle 12V battery	Impulse Steam Turbine	Wind turbine
Pyranometer	Parabolic Reflector	Heat box/enclosure
Solar cell modules	Receiver System	Multimeter

Solar Pathfinder	Hydrogen Cell Fuel Cell	Laser Thermometer
Solar Tracking System	Compressed Air	Kill-a-Watt Meter
Solar Simulator	Compressed hydrogen	RTD Thermometer
Spectrophotometer	Tachometer	

Laboratory Safety

Another element of the AET Department's cRELP was lab safety. This topic should be central to any laboratory protocol and experiment. To this end it is a great practice to include an introductory lab exercise dealing specifically with laboratory safety and equipment usage. This exercise can include a review of all general safety issues (i.e. first aid, eye wash stations, personal protective equipment, exits, etc.) but also specific safety issues related to the equipment and tools used in each lab experiment. For these reasons, a safety lab at the beginning of the protocol and a short safety review must be included in each subsequent lab experiment.

When deciding what specific safety issues to include in a cRELP, a good starting point is the educational institution's laboratory safety regulations and emergency procedures. Extending beyond this, equipment manufacture's recommendations and local or national regulatory body's policies can be reviewed and incorporated into the laboratory protocol literature to further strengthen the foundation of safety.

Similar to how an employee's perception of safety is affected by management's safety culture (O'Toole, 2002), a student's perception of safety is shaped to a large extent by how this topic is addressed by the instructor during laboratory experiments. Therefore, incorporating safety as a keystone of each and every lab experiment will help prepare students for careers that champion safety and safe work practices.

CONCLUSION

The cRELP, if effectively implemented, can be a viable tool for preparing students in Energy Systems and Sustainability for the needs of the emerging renewable energy workforce. As shown in the pyramid hierarchical approach of deliverables for a cRELP (Figure 2) and supported with the case study, a clear step-by-step approach to generating a cRELP is possible, which can be tailored to the specific faculty, students, region and local market. Also, the authors showed how their proposed approach starts with broad topics, which are systematically refined through cyclical iterations until a distilled cRELP is generated.

Furthermore, some of the most important voices of input in this process are local advisory boards, faculty and students. Funding a cRELP is also important. This step can be a research project on its own, which requires time and effort to accomplish. To help the reader in this process the authors gave examples of a few funding opportunities currently available, which can be found in Table 1.

Lastly, the work of developing a cRELP carries with it multifaceted benefits. In the short term, the students are the ones to benefit from the integration of renewable energy topics into course offerings. In the long term, industry, society and our environment are the beneficiaries, which in turn affect us all.

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Appendix A

MSU's cRELP Topics and Objectives

Lab #1: Lab Safety Standards
Objectives

1. Acquire a general understanding of all lab equipment and the safety hazards associated with each.
2. Familiarize oneself with the location of lab First Aid station.
3. Locate all fire extinguishers and exit routs.
4. Understand and be able to summarize the MSU emergency procedures.

Lab #2: Data Collection Tools and Techniques
Objectives

5. Familiarize oneself with each data collection tool of the lab.
6. Demonstrate the ability to measure and record data observations for each tool.
7. Distinguish and convert appropriate engineering and scientific units related to each tool.
8. Compare the contrast the different data each tool is used to measure.

Lab #3: Solar Cells
Objectives

1. Analyze the difference between series and parallel load resistor wiring configurations.
2. Determine the factors that affect a Solar Cell's I_{SC} and V_{OC} and how temperature impacts power output.
3. Plot voltage and current observations to build a VI curve to determine Maximum Power Point.
4. Calculate the fill effect and efficiency of a Solar Cell.

Lab #4: Photovoltaic Panels: Tracking vs. Stationary
Objectives

1. Determine how the angle of a photovoltaic panel affects its power and efficiency levels.
2. Understand the difference between manufacture's efficiency rating and "real-world" efficiency observations.
3. Determine whether photovoltaic power output is directly or inversely proportional to cell temperature.
4. Analyze the difference between series and parallel load resistor wiring configurations.

Lab #5: Solar Thermal Hot Water Systems
Objectives

1. Distinguish the difference between and understand the uses of both solar-to-electric and solar-to-thermal energy conversion.
2. Calculate the difference and net efficiency of adding solar thermal heating to a hot water system.
3. Be able to identify appropriate site locations for a solar thermal hot water system.

Lab #6: Concentrated Solar Power (Electric Gen.)
Objectives

1. Calculate the geometric concentration ratio between the reflector and receiver.
2. Calculate the steady state heat transferred to water at different flow rates.
3. Determine the correlation between steam temperature and turbine speed.
4. Calculate the maximum efficiency of the system, including maximum system temperatures.

Lab #7: Analysis of Wind Turbines
Objectives

1. Analyze the effect of wind speed on turbine efficiency and power output.
2. Understand and comment on how wind direction affects a turbine's efficiency and power output and how a turbine's pitch and yaw can be adjusted to compensate.
3. Determine how turbine blade diameter effects power output and why.
4. Plot the turbine voltage output based on wind speed.

Lab #8: Hybrid Systems (Solar & Wind)
Objectives

1. Realize the benefits of multiple sources of renewable energy to maintain consistent power generation.
2. Understand how to integrate different sources of variable renewable energy into one power generation system.
3. Be able to compare the contrast the advantages and disadvantages of wind and solar energy sources and how to utilize both in a hybrid application.

Lab #9: Hydrogen Fuel Cell
Objectives

1. Understand a fuel cell's efficiency with the use of voltage, current and power curves.
2. Determine the effects of system loading on the efficiency and power output of a fuel cell.
3. Gain hands-on experience of how hydrogen gas flow and air flow affects a fuel cell's performance.
4. Be able to describe and diagram the common components of a hydrogen fuel cell.

Lab #10: Passive Solar Architecture
Objectives

1. Distinguish the difference between active and passive solar energy.
2. Evaluate the effects of thermal convection and describe it in terms of temperature and pressure differentials.
3. Examine how window eave design effects winter and summer solar heat absorption and reflection.
4. Describe the design constrains of both winter and summer solar heating/cooling and how each can be overcome in a single buildings design.

Lab #11: Efficient Insulation Materials/Techniques
Objectives

1. Analyze the effects of insolation types and techniques and how they affect a building's thermal efficiency.
2. Calculate the percentage of energy efficiency/savings of a well-insulated building vs. an un-insulated building.
3. Plot the thermal heat loss over time for each insulation type/technique to generate heat loss profiles.