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Students as Sustainability Consultants: An Interdisciplinary Project for Sustainable Residential and Commercial Design

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Abstract

For the past several years at Illinois State University, undergraduate students in TEC 258: Renewable Energy Technology Applications have participated in a project to serve as design consultants for students in FCS 376: Interior Design IV, a capstone course. The project is interdisciplinary. Most students in the renewable energy class are from technology or engineering-related majors, and the students in the capstone course are from the Interior Design major. To scaffold the design project, students in both courses learn content relevant to design collaboration. For example, Interior Design students learn about how renewable energy technologies contribute to LEED certification from the U.S. Green Building Council, while students in the renewable energy course learn about energy conservation and passive solar design, in addition to more traditional renewable energy technologies like wind and solar. Midway through the semester, students from each class are grouped into teams of two to three students and paired with a group from the other class. Interior Design students create a written and oral report about their final design, integrating renewable energy advice. Students in the renewable energy course submit a written report about their recommendations and contributions to the design as well as how the design was appropriate for the constraints provided by their Interior Design client. Students were also asked to complete a survey describing their reactions to the project, how effective the project was in solidifying class content, and what they had learned by working with an allied professional from a different background.

Introduction

An undergraduate course on renewable energy systems has been offered at Illinois State University for the last seven years. The course is TEC 258: Renewable Energy Technology Applications. The course is offered once per academic year, with a typical enrollment of approximately eight to fifteen second- or third-year students. The course is required for students in the Sustainable & Renewable Energy undergraduate program, but also open to other students at the university. The Sustainable & Renewable Energy itself was established in 2007, with a mission to "prepare technically-oriented managerial professionals and leaders for business, industry, government, and education by articulating and integrating competencies in renewable energy." From its inception, the Renewable Energy Technology Applications course has been designed to be one of the most practical and hands-on courses in the Sustainable & Renewable Energy undergraduate major.

The course is focused primarily on solar and wind energy, beginning with the fundamental operating principles of the technologies, and leading to the application of these technologies to real-world projects at different scales, from residential to utility-scale projects. The course meets four hours per week, with approximately half of the class time devoted to lecture and half devoted to hands-on labs. Students are assessed in part on lab reports that they complete after each lab.

During the first half of the semester the course is focused on solar energy, primarily photovoltaics but also including solar thermal technologies and passive solar design principles. Labs in the course explore basic circuits, electric power and energy measurement, solar site assessment using a variety of tools, and several labs performed on custom-built "solar photovoltaic workstations" in the laboratory. The solar workstation labs allow measuring and plotting the I-V curve of individual photovoltaic cells and cells connected in series and parallel, measuring the maximum power point, measuring the performance of charge controllers and inverters, and measuring real, reactive, and apparent power provided by the inverter in AC circuits.

In the second half of the semester the course focuses on wind energy, beginning with elementary principles of fluid mechanics and airfoil design, and leading to the conversion of kinetic energy of fluids into electrical energy produced by rotating generators. Labs are focused on site assessment for wind turbines, energy production estimates, design and testing of 3d-printed airfoils in a wind tunnel, and design and testing of model wind turbines optimized for various performance metrics (first torque, then voltage output, then electrical power and energy production using a data acquisition system). A topical outline of the course is provided below.

Topical Outline

I. Solar PV System Applications
   A. Solar PV Electrical Characteristics
   B. Geographic Considerations for PV
   C. Solar Site Assessment
   D. Solar Energy Production Estimates
   E. Solar PV Workstation Labs
   F. Solar Passive Home Construction and Testing

II. Wind Power System Applications
   A. Wind Turbine Components and Operations
   B. Geographic Considerations for Wind Energy
   C. Wind Site Assessment
   D. Wind Energy Production Estimates
   E. Airfoil Design and Construction
   F. Wind Tunnel Testing of Model Wind Turbines

Project Description

A large body of literature suggests that self-directed projects enhance student learning. Students are often enthusiastic about the experiences that they gain through class projects [1], and students and faculty alike often feel that collaborative team experiences are essential to their development as engineering professionals [2, 3]. Student projects also aid in student identity development [4] and are particularly useful for student exploration of topics that are important but very recent and have not yet been integrated into standard curriculum [5, 6]. This is especially true when the projects relate to topics that the students perceive as culturally important, such as projects addressing climate change and renewable energy [7 -12]. The literature is abundantly clear that students benefit in multiple ways from self-guided projects. For these reasons, after teaching the

course several times and revising the basic course content, the course instructor recognized the need for an additional project to add depth to the course and allow students the opportunity to work in a deeper and more collaborative way.

In fall 2023, a new semester project was introduced into the course. The new project involved a partnership between the Sustainable & Renewable Energy major and the Interior Design major wherein students from the renewable energy course worked in small groups to serve as consultants to students in the Interior Design capstone course. The Interior Design major is housed in a different department but is physically located in the same building. Because of their proximate location, informal conversations led instructors in both courses to notice the overlap in course topics and student projects on display in the hallways of the building. After several hallway conversations about collaboration possibilities, the instructors of the courses settled on an interdisciplinary consultation project. As part of their capstone project, Interior Design students are charged with designing a residential or commercial structure. Each group of students chooses a different project type, which may range from a multi-unit apartment complex to a single-family house to a mixed-use space. Although the name of the Interior Design program implies a focus on the design of materials and finishes for aesthetic purposes only, in fact, Interior Design students learn about principles of sustainable design and the LEED certification system overseen by the U.S. Green Building Council. They are assigned to consider sustainable design principles in their capstone design projects and complete a LEED checklist. This enables them to collaborate effectively with architects and engineers in their future careers. Meanwhile, students in the renewable energy course have by then been exposed to sustainable design principles and applications of renewable energy at various scales including residential and commercial scales. Therefore, the students in the renewable energy course are well equipped to serve as consultants to the Interior Design students. They assist the Interior Design students to make their designs more sustainable and make recommendations for integrating renewable energy systems.

The interdisciplinary project is assigned in approximately the sixth week of the fifteen-week semester. Students from both courses are grouped into teams of two to three students (typically two) and are assigned to work with a group from the other course. For the Interior Design students, the project assignment is to create a detailed design for a building that meets the needs of their client (a residential or commercial project developer) and simultaneously consider sustainability as an important attribute of the overall design. For the renewable energy students, the project assignment is to collaborate with the Interior Design students, understand the needs of *their* client (the project designer), and offer technical assistance to make the building as sustainable as possible. The project assignment provided to the renewable energy students is provided in Appendix A. To provide a starting point for the renewable energy students in these meetings, the instructor of the renewable energy course prepared a page of potentially useful reference information (e.g. typical energy use intensities, nominal local solar resources, etc.). This page is included for reference in Appendix B.

Although not required, the interdisciplinary groups were encouraged to meet several times during the semester, because the project should be iterative. At the first meeting between the groups, the Interior Design students should explain the purpose of the residential design, e.g. multi-unit, single unit, commercial or mixed-use space. At this meeting the students in the

renewable energy class learn about the nature of the project type and seek to understand the needs of their client. After this meeting, the renewable energy students work together to research the types of renewable energy systems that may best fit the needs of the specific project application. At the second meeting, the renewable energy students present their recommendations to the Interior Design students. The Interior Design students provide additional feedback, and together the groups of students iteratively tweak the design of the building and its associated sustainable and renewable energy features.

Soon after the assignment was given to the students and the students were paired with groups from the other class, one group from the Interior Design course came to visit the renewable energy class during a scheduled class time. The purpose of this visit was to provide an example of relevant topics and examples of recommendations that the renewable energy students may consider providing to the Interior Design groups. During this in-class session, the Interior Design students provided an informal presentation about the goals for their residential dwelling (a multi-unit complex with a common gathering area) and their preliminary design. The instructor of the renewable energy course then led the renewable energy class in a discussion about the pros and cons of several sustainable design attributes of the building, including building orientation and layout features, efficient building envelopes, and estimated sizing and placement of a photovoltaic system that could be integrated into the building design.

Assessment

To assess the renewable energy students' work, students were required to submit a reflection paper. Expectations for the reflection paper were included in the project description given to the students at the beginning of the assignment, provided for reference in Appendix A. The reflection papers were expected to include the following minimum components:

1. Describe the project and the building that your ID colleague is proposing. Include relevant details like the layout and orientation of the building, intended use of the building, features that are incorporated, and anything else that could impact the implementation of renewable energy technologies (e.g. roof features or HVAC system).
2. Describe your suggestions and recommendations to the [ID] group. Be as specific as possible about what types of technologies you recommended (e.g. solar PV, wind, or other), the size of the system, the placement on/near the building, and any other important aspects related to the technologies.
3. If you work on renewable energy projects in your career after graduation, you will likely be working as a member of an interdisciplinary team. Describe your experience of working on an interdisciplinary team in this project. How difficult (or easy) was it for you to understand the project that was proposed by your ID colleague. How difficult (or easy) was it for you to tailor your suggestions and make them understandable to a group from a different educational background? Describe any challenges that came up during the consultation, and how you were able to overcome them.

Students generally met these expectations in their reflection papers. The buildings chosen by the Interior Design students were highly varied and included a multi-unit townhouse complex, single

family detached home, sorority, winery, yacht, high rise office building, hospital, and a stationary boat containing a restaurant and bar. Most of the renewable energy students recommended solar photovoltaic systems in various configurations to minimize shading from nearby trees and roof overhangs. Several suggested wind turbines and battery storage systems. Many recommended the clever use of roof overhangs, solar canopies or window blinds to shade windows in summer while allowing for solar gain in the winter. Other common strategies included well-insulated and sealed building envelopes, the use of skylights for natural light, triple-glazed windows with low-e coatings, and the placement of little-used rooms on the north side of the building.

Some students employed creative strategies to make the buildings more energy efficient or sustainable. Unique recommendations included the addition of rainwater collection systems, orienting the building on an east-west axis to maximize southern exposure, including a trombe wall and thermally massive flooring for thermal energy storage, geothermal heating and cooling, flexible amorphous silicon solar panels to conform to curved surfaces, minimizing vampire loads, and composting.

Students had generally positive views about working with their partners from the Interior Design capstone course, but many students explained that communication was difficult because of a lack of common "professional language." Some students noted that this project required a lot of listening and intentionally using less industry jargon. Several noted that the project took more time than expected. Another challenge that repeatedly emerged was that students found it more difficult than expected to make suggestions that fit within the envelope and structure of their client's building. The renewable energy students may have had good suggestions for "typical" applications, but many of them found that their suggestions simply did not fit or were not reasonable for the particular application needed by their Interior Design partners.

Most students wrote that in order to communicate effectively with their partners from a different discipline, they needed to be more clear and specific than anticipated. However, some of the students recognized that those same challenges existed for the Interior Design students as well. For example, one renewable energy student noted that their ID partner needed to explain the concept of "off-gassing" to them. This student described the collaboration process as "arduous but eye-opening." Many students wrote that they recognize that in their professional careers, they will need to be able to communicate effectively with people from other disciplines and backgrounds. Several students wrote that they now feel an improved sense of confidence in working with people from different backgrounds.

Students performed well on the project, with an average score of 92%. The most common reason for points deducted by the instructor was insufficient detail in the description. Other areas where points were deducted included misuse of power and energy terms and missing or insufficient calculations.

To assess the project assignment itself, students were asked to complete an anonymous online survey. The instructors were particularly interested in how much students perceived they had learned by completing the project, and how students perceived their learning resulting from this project as compared to a more traditional assessment method such as taking an exam on the same material. The survey consisted of the following five questions:

Renewable Energy Consultation Project Survey

Please answer the following questions about the Renewable Energy Consultation Project with the students from the Interior Design Capstone Course. Your responses will remain anonymous.

1. After completing the Renewable Energy Consultation Project, I am better able to describe how to integrate renewable energy and/or sustainable practices into building/construction projects. (Likert scale Strongly disagree 1 - 5 Strongly agree)
2. I learned more about the integration of renewable energy and sustainable building practices by completing the Renewable Energy Consultation Project than I would have learned by taking an exam on the same material. (Likert scale Strongly disagree 1 - 5 Strongly agree)
3. The Renewable Energy Consultation Project was enjoyable. (Likert scale Strongly disagree 1 - 5 Strongly agree)
4. I recommend keeping the Renewable Energy Consultation Project as part of the curriculum in [course name]. (Likert scale Strongly disagree 1 - 5 Strongly agree)
5. Do you have any suggestions for how to improve the Renewable Energy Consultation Project? (open text / answer field)

In the fall 2023 semester there were eight students enrolled in the renewable energy course. After several requests to complete the survey, four students completed it. The results of the survey are shown in Figure 1 through Figure 5.

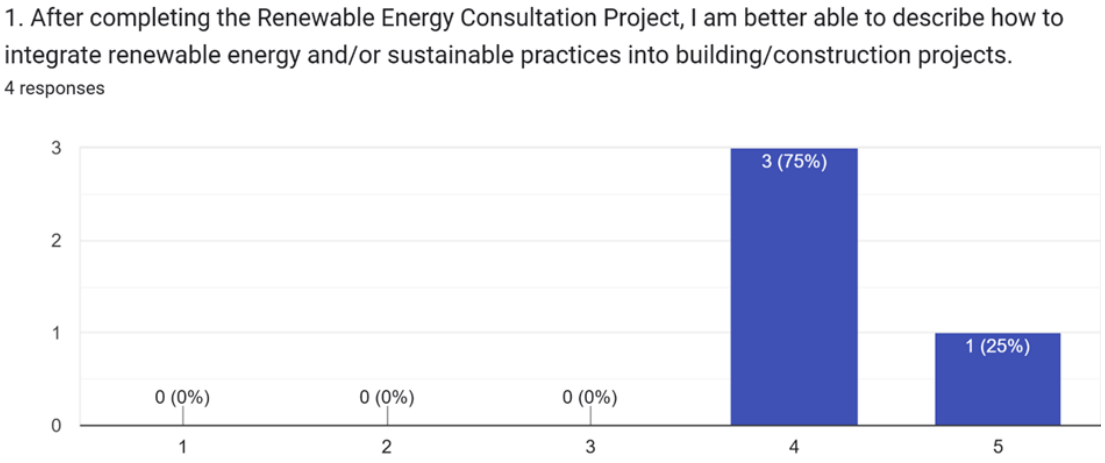

Figure 1. Student responses to survey question 1.

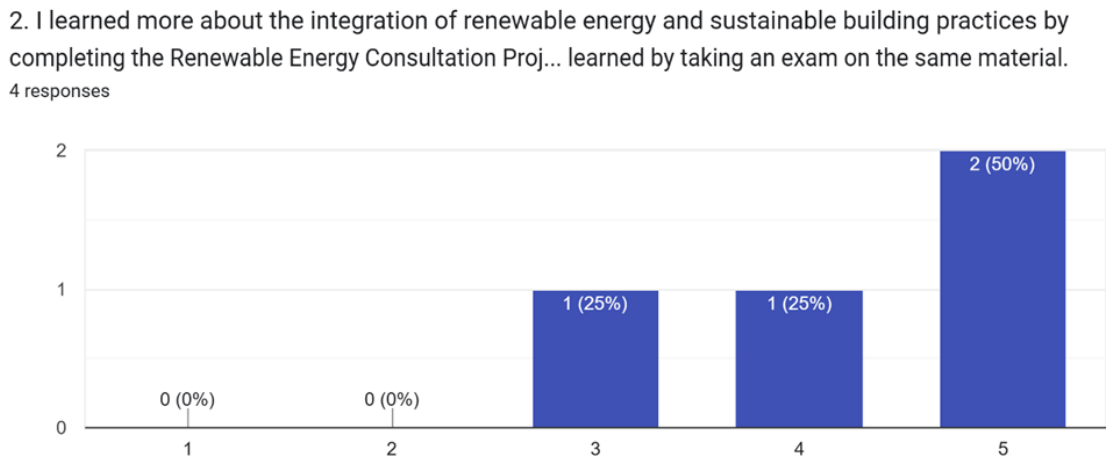

Figure 2. Student responses to survey question 2.

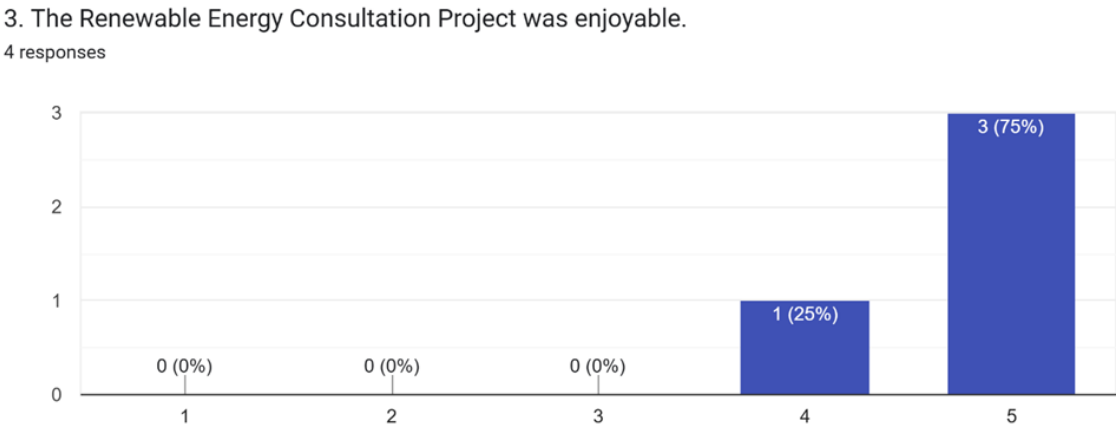

Figure 3. Student responses to survey question 3.

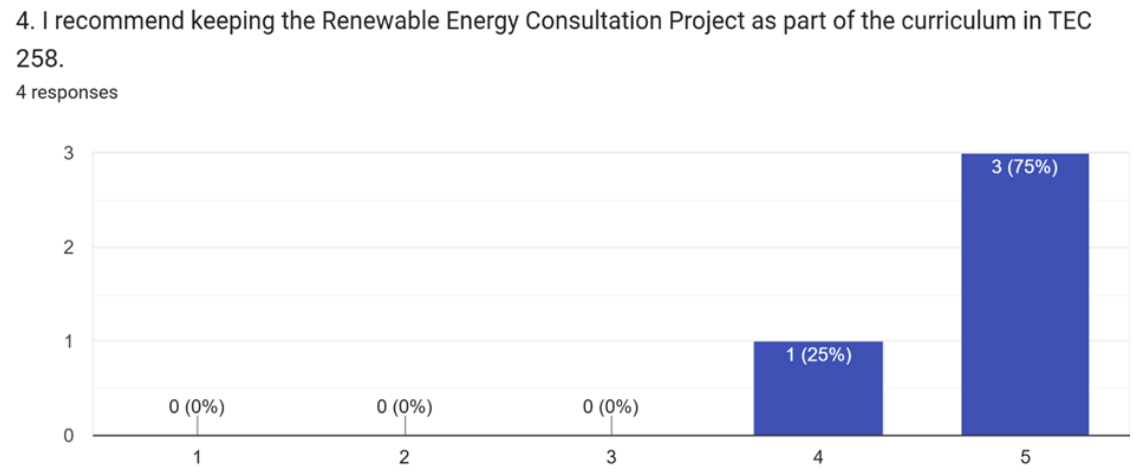

Figure 4. Student responses to survey question 4.

Figure 5. Student responses to survey question 5.

The students' responses to the survey questions indicate an overall positive view of the project assignment. All students either agreed or strongly agreed that they were now better able to describe how to integrate sustainable practices and renewable energy systems into buildings. Most students responded that they had learned more from this project than they would have learned from taking a test on the same material, but one of the four students was neutral on this question. Most students strongly agreed that the project was enjoyable, and most students recommended keeping the project as part of the course. In the last question, students did not have any recommendations for improving the project.

Conclusions

The instructors believe this project has been an effective and beneficial assignment and intend to continue the project in future iterations of their courses. However, since the first time this project was assigned to students in fall 2023, the instructors have revised several aspects of the project.

First, the project was initially envisioned as a one-on-one discussion between one Interior Design student and one student in the renewable energy course. Instructors initially felt this would ensure active participation by all students. However, it quickly became apparent that students felt more comfortable working with a partner from their class. The instructors agreed to this change because working in teams is a valuable and necessary skill in the students' future careers. In

addition, the Interior Design students were already working in pairs on their capstone projects, so assigning pairs of renewable energy students to consult with pairs of Interior Design students simplified the logistics of the assignment.

Second, in part because of the project was conceived while emerging from the COVID-19 pandemic, instructors initially required only one in-person meeting between the groups of Interior Design and renewable energy students. This simplified the project for students. However, instructors feel that requiring additional in-person meetings strengthens the interdisciplinary experience by requiring more interdisciplinary interactions. Beginning in the fall 2024 semester, the groups of students were required to meet a minimum of twice, with specific tasks to be accomplished at each meeting.

Finally, multiple meetings between groups also allows for the assignment of intermediate project milestones and design iterations. For example, renewable energy students now submit an intermediate report after their first meeting. In this report, the students describe the goals and constraints of their clients (the Interior Design students), the potential building sites that are under consideration, make two recommendations per potential building site, and make additional recommendations related to energy conservation or high-efficiency equipment. After the second meeting, students submit a second report that describes their client's revised goals and constraints, the final building site that was selected, recommendations related to renewable energy integration and energy efficiency, and provides an economic analysis of the renewable energy system. The inclusion of milestones and design iterations provides a more realistic and meaningful project design experience.

Based on the written reflections submitted by the students, this assignment accomplished the instructors' goal of pushing the students to collaborate in interdisciplinary groups, sometimes making the students uncomfortable. The initial discomfort is natural, but the instructors are encouraged by the students' reports of increased confidence in working with diverse groups, as well as the fact that most of them ultimately enjoyed working on the project. For many of them, this experience may be helpful in their future careers when they need to work effectively on teams with people from a variety of educational, professional, and cultural backgrounds.

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Appendix A: Project Assignment

TEC 258 Renewable Energy Consultation Project

In this project, you will serve as consultants to fellow ISU students from the FCS Interior Design (ID) Program. The ID students are working on capstone projects to design sustainable homes. Now that you have some experience with renewable energy systems through this class and other classes in the Sustainable & Renewable Energy major, you should offer your suggestions and recommendations to the ID students in order to help them incorporate renewable energy and/or sustainable design principles into their home designs.

Each student from TEC 258 will be paired up with one student from FCS 376. Drs. Aldeman & Dyar will provide contact information. You may work in groups, as long as both group members meet with both of the Interior Design students that you are assigned.

The consultation project consists of the following parts:

1. Meet with your assigned colleague from the Interior Design program and discuss their home design (estimated meeting time ~30 minutes).
2. During the meeting, offer suggestions about how to incorporate renewable energy and other sustainable features into their home design. Hint: think about your passive solar home design, but remember that the ID students may have a variety of different goals for their project.
3. Write and submit a typed 1-2 page single-spaced Consultation Reflection Paper about the home design, what you discussed during your meeting with your ID colleague, and the suggestions and recommendations that you made to make the home more sustainable. If you have hand-written calculations or sketches, staple them to the end of the report.

Dr. Dyar and I recommend that you meet as soon as reasonably possible, so that the ID students have time to revise their design before the end of the semester, and so you have time to complete the Reflection Paper about the consultation.

The Consultation Reflection Paper will be a summary of your consultation, not a lab report. You do not need to follow the standard lab report template as you did with many of the other labs in this course. The reflection paper should be 1-2 pages single-spaced, and it should have (at least) 3 paragraphs that address the following:

Paragraph 1 - Describe the project and the building that your ID colleague is proposing. Include relevant details like the layout and orientation of the building, intended use of the building, features that are incorporated, and anything else that could impact the implementation of renewable energy technologies (e.g. roof features or HVAC system).
Paragraph 2 - Describe your suggestions and recommendations to the ID group. Be as specific as possible about what types of technologies you recommended (e.g. solar PV, wind, or other), the size of the system, the placement on/near the building, and any other important aspects related to the technologies.
Paragraph 3 - If you work on renewable energy projects in your career after graduation, you will likely be working as a member of an interdisciplinary team. Describe your experience of working on an interdisciplinary team in this project. How difficult (or easy)

was it for you to understand the project that was proposed by your ID colleague. How difficult (or easy) was it for you to tailor your suggestions and make them understandable to a group from a different educational background? Describe any challenges that came up during the consultation, and how you were able to overcome them.

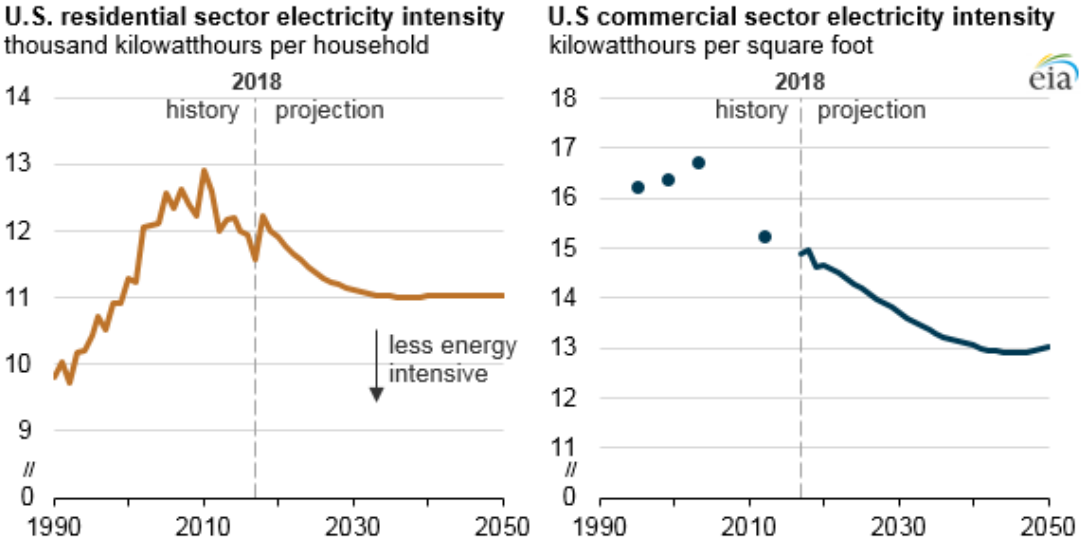
The Consultation Reflection Paper should be printed and submitted in-person by the last class of the semester: Thursday, Dec. 7 at 10 AM. You may submit it any time before then.

Appendix B: Useful information provided as starting point for renewable energy students

Average electricity consumption

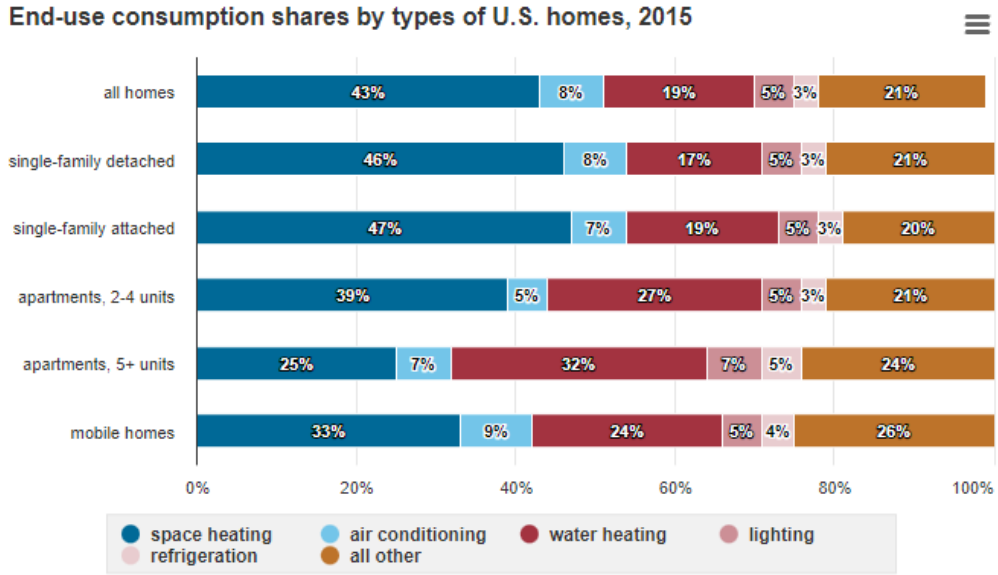
Energy use per square foot is called “energy use intensity”

Average electricity consumption per household:



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2019* Reference case, *Monthly Energy Review*, Commercial Buildings Consumption Surveys (1995–2012), and U.S. Census Bureau Household Estimates

Commercial electricity intensity can be significantly higher than residential electricity intensity
Typical residential electricity intensity or a single family detached: ~ 3 - 6 kWh/ft^2



Note: Shares are a percentage of annual site energy consumption. Site energy consumption excludes the losses in electricity generation and delivery.
Source: U.S. Energy Information Administration, *2015 Residential Energy Consumption Survey*

Average peak sun hours in Normal, IL

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.0	2.8	3.6	4.8	5.8	6.4	6.3	5.5	4.4	3.2	2.0	1.6	4.0
	Min/Max	1.6/2.2	2.5/3.2	3.0/4.2	4.1/5.6	4.4/6.8	5.8/7.2	5.8/6.9	4.8/6.1	3.8/5.3	2.7/3.7	1.6/2.5	1.3/1.9	3.8/4.4
Latitude -15	Average	2.9	3.7	4.2	5.2	5.8	6.3	6.2	5.9	5.2	4.3	2.9	2.4	4.6
	Min/Max	2.2/3.4	3.1/4.5	3.4/5.2	4.3/6.1	4.4/6.9	5.6/7.0	5.7/6.9	5.1/6.5	4.3/6.4	3.3/5.0	2.0/3.8	1.8/3.2	4.3/5.0
Latitude	Average	3.3	4.1	4.4	5.1	5.5	5.8	5.8	5.7	5.2	4.6	3.2	2.7	4.6
	Min/Max	2.4/3.9	3.3/5.0	3.5/5.4	4.2/5.9	4.1/6.5	5.1/6.4	5.3/6.5	4.9/6.3	4.3/6.5	3.5/5.4	2.2/4.3	2.0/3.7	4.3/5.0
Latitude +15	Average	3.5	4.2	4.2	4.7	4.8	5.0	5.1	5.1	5.0	4.6	3.3	2.9	4.4
	Min/Max	2.5/4.1	3.4/5.1	3.3/5.3	3.9/5.5	3.7/5.7	4.4/5.5	4.6/5.6	4.4/5.7	4.0/6.3	3.4/5.5	2.2/4.6	2.0/4.0	4.0/4.8
90	Average	3.3	3.7	3.2	3.0	2.7	2.6	2.7	3.1	3.5	3.7	2.9	2.7	3.1
	Min/Max	2.2/4.0	3.0/4.4	2.6/4.0	2.5/3.5	2.2/3.1	2.3/2.8	2.5/3.0	2.7/3.4	2.8/4.4	2.7/4.5	1.9/4.1	1.8/3.9	2.8/3.4

<u>Back-of-the-envelope calculations...</u>
On average, each solar panel is about 40” x 70”
On average, each solar panel is rated to produce about 360 Watts = 0.36 kW
(you can look up actual product specs at websites for REC, SunPower, LG, Jinko, Hanwha, etc.)
Typical solar system losses are around 15-20% (for wiring, inverter losses, soiling, etc.)

Example: one solar panel installed near [location redacted] at a tilt angle equal to [latitude]

Annual energy production = 0.36 kW * 4.6 hours/day * 365 days/yr * 85% = **514 kWh/yr**

For angled roof, panels are typically installed at the same angle as the roof, with no space between panels

For flat roofs – panels are typically installed at low tilt angles (15°-20°) with inter-row spacing 2-3 ft.

Example 2: If a home uses 12,000 kWh per year, then to offset all electricity...
(12,000 kWh/yr) / (514 kWh/yr/panel) = 23.3 panels
This would require (23 panels)*(40 in.)*(70 in.)*(1 ft^2 / 144 in^2) = 447 ft^2 on angled roof