HUMBOLDT STATE UNIVERSITY
Environmental Science & Management

SUBJECT: Campus as a Living Lab Grant Report

DATE: June 5th, 2017

AUTHORS: Dr. Kevin Fingerman, Department of Environmental Science & Management
Morgan King, Sustainability and Waste Coordinator

Course overview:

Energy, Technology, and Society – ENVS 370 – is a junior/senior level required course for the Environmental Science – Energy & Climate major option at Humboldt State University (HSU). Students from the Environmental Engineering and Environmental Policy majors also frequently enroll in this course in order to further their exposure to energy analysis and policy. The course meets for two 50-minute lectures per week plus one 3-hour lab exercise.

ENVS 370 is designed to provide students with the methods, tools, and perspectives to understand society's many technical, economic, and policy choices concerning energy generation and use. It covers a broad spectrum of energy technologies, including the economic and policy drivers for their use, as well as their varied impacts on environmental sustainability, international development, and ethnic/gender/economic equity. These issues are inherently interdisciplinary, and our investigation of them draws on tools and narratives from engineering, sociology, economics, political science, public health, ecology, and other fields.

Project overview

ENVS 370 covers a lot of ground, but I have always felt that I was giving insufficient depth to the treatment of building energy analysis. Buildings consume approximately 70% of all electricity and the *vast* majority of the projected potential for negative-cost GHG emission mitigation comes from building energy efficiency. Given these facts, and the practical reality that building efficiency and auditing is a growth industry in which many of my students could find future employment, I deemed it important to further develop this segment of my course curriculum. In conversation with HSU Facilities Management, it became clear that there was a great deal of untapped potential to use the campus' building stock as a laboratory for this curriculum while at the same time enabling the collection of data and the conduct of analysis that could be very useful to building and energy managers here on campus.

I used CALL grant funding to purchase useful energy metering and auditing equipment as well as analytical software and to fund the development of a new curricular unit in ENVS 370. The 3-week module I developed on building performance – first implemented Spring, 2017 – uses buildings on HSU's campus for a case study. I developed a series of linked activities, introducing hands-on building efficiency auditing methods and threading data collected from campus buildings through several analytical exercises.

Curricular content description

The following is a description of the course module as it was implemented in this year's ENVS 370 course.

Week 1:

Lecture – Introduction to the role of buildings and energy efficiency as an element of climate mitigation.

Lab – Tour of highly-efficient Campus Center for Appropriate Technology (CCAT) facility. Conduct building energy audit exercise in the Multicultural Center house.

Week 2:

Lecture – California building energy efficiency code, energy retrofit options

Lab – Learn to use the State of California's CBECC-Res building energy use model. Parameterize a model of the multicultural center facility based on measurements from previous week. Comparing it to CCAT facility, and evaluating the energy impact of different interventions

Week 3:

Assignment – Problem Set calculating the levelized cost, emissions abatement, and marginal abatement cost of several of the evaluated interventions

Lab – Build a simulation model of each intervention to enable Monte Carlo simulation evaluating uncertainties surrounding cost effectiveness of possible interventions. *Final assignment* – develop a report for HSU facilities management evaluating the efficacy, cost-effectiveness, and abatement potential of several retrofit options. *See Annex 1.*

Equipment

A good deal of equipment was purchased to make this curriculum work well. These tools will be serving students in this course and others (as well as Facilities Management personnel) for years to come. Some of the equipment purchased for the course is listed below:

1. FlirONE thermal imaging cameras
2. Regin S220 Smoke pens – for evaluating air flow in enclosed spaces
3. Dr.Meter LX1330B Digital Light Meter
4. Full suite of "blower door" building envelope testing equipment – including frame, case, and pressure/flow gauge.
5. Student licenses for Crystal Ball simulation modeling software.
6. The Energy Detective (TED) real time electricity monitors – for evaluating electricity consumption over time

Conclusions

This course module was very well received by the students. I attribute its success to two related characteristics. First, the module drew on a series of different analytical approaches and learning modalities. Second, it was built around a single, visible case study – enabling the students to engage more deeply, approaching a single issue from multiple directions.

I discussed the unit informally with the class in hopes of continuing to improve it, and they were uniformly enthusiastic about the content. Particularly encouraging was the positive response to the computer modeling exercises, which can be more difficult to make engaging. It is clear that tying the modeling work to the hands-on building audit exercises made the modeling feel more 'real' and enabled them to see its real-world utility and practical application. Having the same real-world case study run through several weeks of content allowed us to dig deeper into that case and gave them a better sense of the type of work they may go on to do as professionals than I can create with stand-alone exercises which are necessarily more superficial.

In particular, I feel that the CALL-funded course module strengthened two Learning Outcomes in my ENVS 370 course:

1. *Exhibit knowledge and understanding of the technical issues that shape modern energy systems.* Building energy efficiency is a major topic in contemporary energy systems. The students were exposed to an array of analytical approaches and technical tools. They learned about energy audit techniques as well as the energy use modeling tool that is used by building auditors and designers here in California.
2. *Work confidently with an array of quantitative concepts and tools that are necessary to engage deeply with energy issues.* There was a good deal of quantitative content threaded throughout this curricular unit. Students learned to conduct quantitative financial cost-benefit analyses as well as to build sophisticated spreadsheet models evaluating the uncertainty associated with these projections. Tying this content to a real, hands-on case study and using it to make real recommendations to the university was very helpful in communicating the practical/professional value of these skills.

ANNEX 1 – FINAL BUILDING RETROFIT SIMULATION MODELING EXERCISE

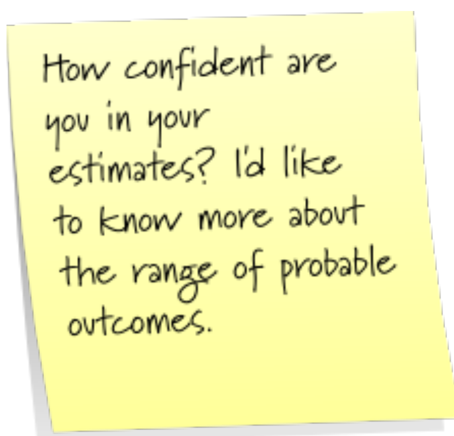
Simulation modeling of life cycle cost using Crystal Ball
ENGR 370: Energy, Environment, and Society
Spring, 2017

Final Submission: Turn in a brief (1-3 pages) report along with an electronic copy of your spreadsheet by Tuesday, May 2nd at 1pm.

You have been hired as the energy and sustainability analyst in the Facilities Management department at HSU. Facilities is considering options to reduce the energy and climate footprint of some of the older buildings on campus – including the MCC – pursuant to its goals set out under the recently-published climate action plan. As described in your earlier work on the subject, Facilities Management has developed the following short-list of potential interventions based on your earlier auditing and building energy modeling work:

a) Tighten the building envelope
b) Replace antiquated HVAC system with Lennox heat pump
c) Install wall insulation
d) Upgrade electronics (and implement behavior change program) to reduce plug loads by 30%

Given the budgetary constraints for HSU, your bosses insist on careful life cycle cost estimates for all proposed projects. Recognizing this, you set out earlier to generate net annualized cost and marginal abatement cost estimates for all of the above actions. Your work on this was sent back to you by facilities VP Traci Ferdolage with the following note attached:



It occurs to you that Traci is right, and that this is a good chance to flex some of your simulation modeling skills to give management more complete information (and to impress your boss's boss's boss while you're at it). You do some brainstorming with colleagues as well as some due diligence talking to vendors and looking at comparable case studies to develop the following estimates of the probability distributions surrounding each of the key inputs you used in your initial modeling.

a) Tighten the building envelope

i. Capital cost: Triangular distribution of $2,000 min, $2,500 most likely, $2,800 max
ii. Time horizon: Uniform distribution 12-18 years

b) Replace HVAC system with heat pump

i. Capital cost: The device is definitely $7,800. The install should present a triangular distribution of $1,500 min, $2,200 most likely, and $3,200 max

ii. Time horizon: The remaining life span of the building - normal distribution with a mean of 25 years and standard deviation (σ) of 3 years.

c) Wall insulation

i. Capital cost: Normal distribution $12,000 s.d. $900

ii. Time horizon: The remaining life span of the building - normal distribution with a mean of 25 years and σ of 3 years.

d) Reduce plug loads by 30%

i. Capital cost: Anywhere from $600-$875 with approximately equal likelihood anywhere along that range.

ii. Time horizon: These changes would apply to current technologies only; you estimate a triangular distribution with 6 years min, 7 years most likely, and 9 years max.

e) Solar PV installation

i. Capital cost: Triangular $3.30/W min, $3.50/W most likely, and $3.60/W max

ii. Capacity factor: Triangular .165 min, .17 most likely, .22 max.

iii. Time horizon: Normal distribution with a mean of 25 years and σ of 2.5 years.

Discount rate: 4% ± 0.7% - uniform distribution

Energy price: You pulled the last 15 years of gas and electricity prices and normalized them to 2016$ to generate price averages since you (reasonably) expect future prices to follow past trends. You expect the following distribution of prices for energy carriers:

Electricity: $0.151/kWh, σ = $0.0121
Natural Gas: $0.966/therm, σ = $0.081

Energy use: Your literature review has led you to expect the actual performance of the different interventions to follow normal distributions. The ranges on your distributions will vary – with building envelope performance varying more than technological interventions.

	Seal house to 5 AC/hour @50Pa	Switch out HVAC to heat pump	Insulate walls	Reduce plug loads by 30%
Δ Electricity (kWh/yr)	-281	12,464	-639	-1022
Δ Gas (therms/yr)	-323	-1347	-733	0
σ Electricity (kWh/yr)	10	300	21	25
σ Gas (therms/yr)	25	13	40	0

ANNEX 1 – FINAL BUILDING RETROFIT SIMULATION MODELING EXERCISE

You realize that you can use the outputs of your simulation to refine the model. Examine the sensitivity reports under the "view charts" heading in your model. You spend some more time investigating any one parameter of your choice to refine your prediction – thereby reducing its uncertainty by 50% (i.e. reducing σ on a normal distribution or the range above/below the mean on a triangular or uniform distribution by half). Redefine the relevant assumption to reflect this refinement.

Based on the above information, reassess the options and report your expectations and recommendations to the Facilities Management leadership. I'm not going to tell you specifically what analysis to do here, just that you should give V.P. Ferdolage and her team as much useful information as you can given what you have at hand. Think about the following:

- Which interventions would you recommend and why? Is each intervention expected to pay for itself and by how much (i.e. is the expected net cost per year positive or negative and/or what is the NPV of the net savings or cost over time)? What is the % confidence in your assertion for each?
- If you recommend building the PV system – how large in capacity would you suggest building it? What if you wanted to zero out the electricity use of the house after making other interventions you're recommending?
- You may not want to report the full range of a given output (cost, emissions savings, etc). What is the 80% or 90% confidence interval?
- How would implementation of a carbon price (at say $20/tonne) affect the outcome? Assume that this pricing is integrated into energy prices.
- Marginal abatement cost (MAC) curves are a useful way to present the options available for GHG mitigation. I would suggest including one in your report. It can be either a series of variable-width columns or a single stair-step line. Both are possible (thought difficult) to create in Excel, so give yourself some time to figure it out.

Build your spreadsheet – and write your report – with the thought in mind that you will be handing them to your boss as a work product. This means formatting matters in that it can help make your case clearly and someone else can follow what you've done.

Note: Crystal Ball software is available on campus only in the FOR 203 computer lab. There are open lab times Monday/Weds 8-1; Friday 2-5. Otherwise, check the schedule on the door for availability. If you have a Windows machine, you can also download and install a free trial license for the software here.