Equinox House Project

Topic 1 House Energy Requirements

Ty Newell – January 27, 2010

The Equinox House is a “zero energy” house, or as I like to describe it, a “zero plus” house, meaning it provides both house operation energy and transportation energy. The solar electric system (often called a “PV” or “photovoltaic system) provides all house annual energy requirements plus enough energy for driving an electric vehicle 6000 to 8000 miles per year (about 20 miles per day, 7 days per week). Equinox House is “grid-tied”, meaning that it feeds energy back and forth with the electric grid. At night, Equinox borrows energy from the utility and during the day, Equinox feed excess electricity into the utility grid helping it with peak electrical demands.

This discussion is “tuned” to the Midwest where the weather is some of the most challenging in the country. But, the topics and trends discussed are relevant for most every location. Later discussions will look more directly at other regions of the country, but if you can’t wait for that, check out Luis Martinez’s recent PhD dissertation (Simplified Floor Area Based Energy-Moisture-Economic Model for Residential Buildings”, 2009, Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign). Luis is now a professor at the University of Central America J.S. Canas in El Salvador working in sustainable energy research. Luis was my last graduate student, and as he liked to say, I left the best to last, but I think some of my other grads might like to argue the point….

Figure 1 shows the predicted energy requirements and solar energy supply for the Equinox House for each month of the year. The Equinox House requires most of its energy during the winter. We can however, with design changes, alter the seasonal energy requirement distribution quite a bit. For the Equinox House, we have chosen to “balance” the house energy requirements in this manner, which minimizes the overall cost of the house. The energy consumption habits of its occupants will significantly alter the energy usage pattern, too. The energy requirements for a family with young children at home through the day is very different from the energy requirements of an empty nest couple like Deb and me, who are out most of the day. The blue line in Figure 1 shows the difference between the solar energy supply and the house electric energy requirements. During the summer, there is excess solar energy supplied (positive energy), which is designed to balance the energy deficit (negative energy balance) of the house in the winter. The green line in Figure 1 is a cumulative energy amount that adds the solar energy collected with the house energy used starting with the first month (January). The cumulative energy is negative until July when a positive energy balance occurs. The cumulative energy peaks in October as less solar energy and higher house energy demand reduce the cumulative back to zero by the end of the year. This energy load pattern for the year is favorable for our local utility, which has its peak electric energy requirements in the summer and excess in the winter.

The house energy requirement is made of many interacting energy flows, shown in Figure 2. Everything you do in your house impacts its energy requirements. If you exercise, the extra metabolism helps heat and humidify the house in winter, but adversely impacts the air conditioning and dehumidification load in the summer. If the TV or stereo is turned on, this energy heats the house. Windows are quite complicated because during the day they are letting solar radiant energy into the house, while heat may be transferred out of the window when the outside environment is colder than the inside air temperature. Figure 2 lists several "thermal energy loads" that impact the Equinox House electrical energy requirements. The thermal energy loads cannot simply be added together in order to find the house electrical energy demand. As seen in Figure 2, some of the thermal loads are "negative", indicating a cooling effect and others are positive showing a heating effect. During the summer, cooling loads are desired, while in the winter, heating loads such as lights and TV usage contribute to warming the house. Many of the succeeding discussions will pick these individual loads apart and take the mystery out of them. What windows are most appropriate for a house? How thick should the walls and roof be? How do the different choices for heating water affect the overall house performance? Should you add insulation under the floor? How do miscellaneous energy loads such as a stove, stereo, and TV affect house performance? What is the energy impact of the house occupants?

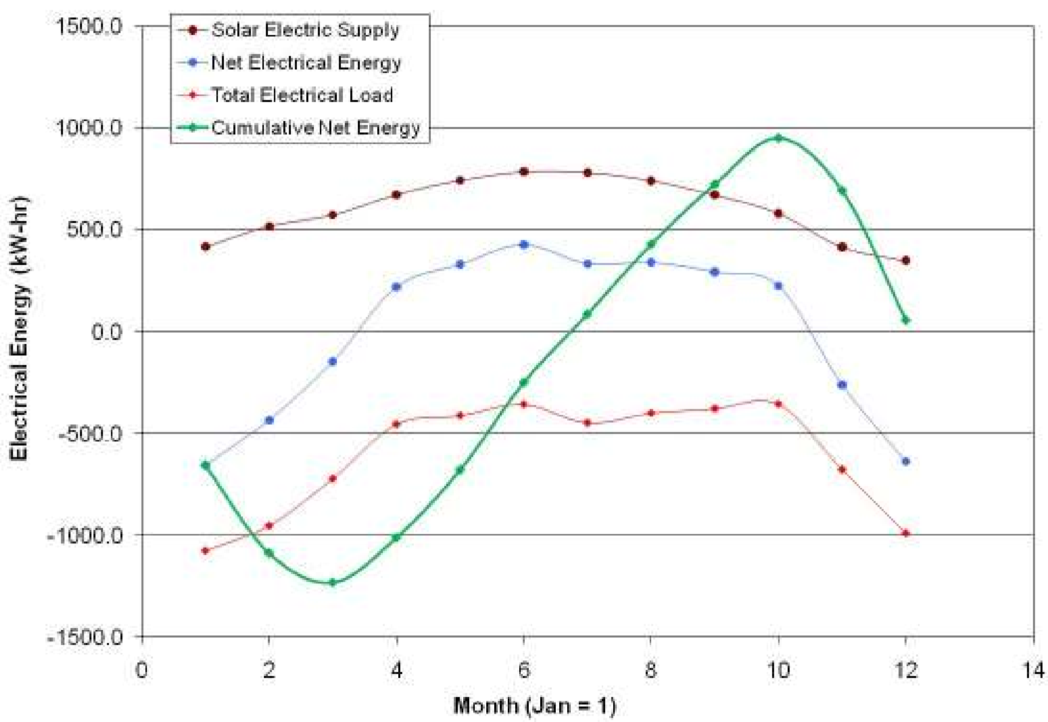

Figure 1 Predicted Equinox House energy requirement, solar energy supply, and net energy balance for each month of the year.

The energy units shown in Figures 1 and 2 are "kilowatt hours" (kW-hr), which are the energy units on your electric bill. What is a kW-hr? One way to look at it is that if you turn on a 100 watt light bulb for 10 hours, that would be 100 watts times 10 hours, resulting in 1000 watt-hours of energy usage, or 1 kilowatt-hour ("kilo" means 1000). Is that a lot? If you ride an exercise bike at a good pace, you might produce a couple hundred watts. If you do that for about 4 or 5 hours, which you probably don't, you would have produced one kilowatt hour. How much is that worth? In our area, you would have earned about 10 cents.

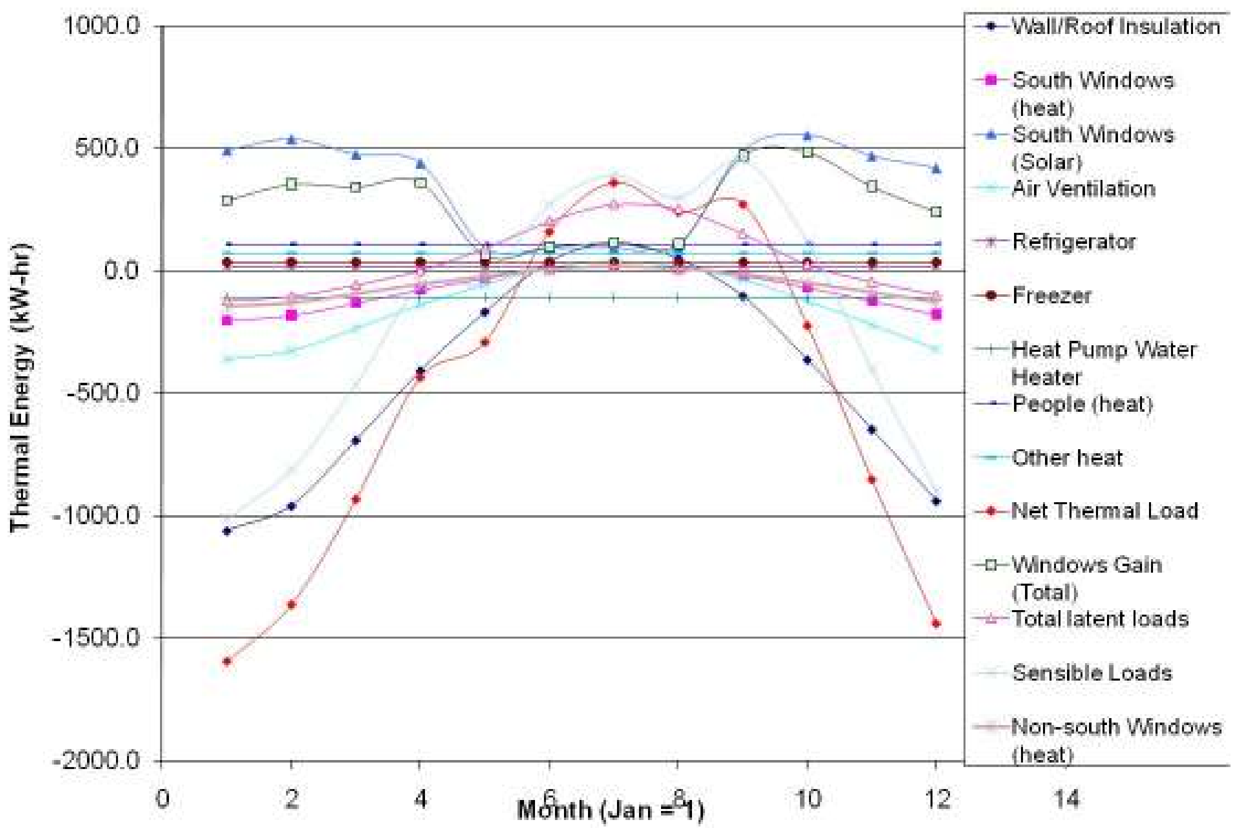

Figure 2 Predicted thermal energy loads for the Equinox House.

Equinox House Energy Secrets

There really are no secrets to Equinox House performance. Although there are many interacting factors that result in the Equinox House's high energy performance level, there are three primary factors that determine a house's ability to reach a superior level of performance.

1) Highly insulated shell
2) Sealing of all cracks and elimination of exterior wall penetrations
3) A high performance heating/cooling system

Figure 3 shows how these factors affect the performance of the Equinox House. The figure shows the average energy per day usage (kW-hr per day) of Equinox under four different scenarios plotted against the average outside temperature for each month of the year. Remember, if you had to produce a kW-hr in a day, you would be pedaling an exercise bike at a high level of human power for 4 to 5 hours. The left side of the plot with the coldest temperatures, are the coldest months of the year (December, January, February). The right side of the plot with the warmest outside temperatures are the warmest months of the year (June, July and August). The data labeled “Equinox”, represents the Equinox House design. The data labeled “Equinox R22” is a house with half of the insulation value in its walls and roof as used for the Equinox House, which is typical of a modern, well-insulated house. The Equinox House has an average insulation value of R44. The third data set labeled “Equinox Infiltration” represents a house with three times the infiltration (air leakage) as the Equinox House with the R22 insulation levels. The Equinox House infiltration is a controlled ventilation and exhaust of house air, in which energy is exchanged between the fresh air and the exhausted air when it is desirable to do so, whereas conventional house design has uncontrolled infiltration which results in poor movement of fresh air through the house as well as adverse energy conditioning effects. The last data set labeled “Equinox Elec Heating” is a house with typical infiltration and R22 insulation, and winter heating from an electric resistance heating system rather than a high performance heat pump system. A heat pump system will be two to three times more efficient than an electric resistance heating system or a gas furnace system. An interesting item to note in Figure 3 is that the lowest house energy requirement for the Equinox House occurs when the outside temperature is 55F, whereas the other variations to Equinox House have their lowest energy data point around 65F. This indicates that Equinox House will maintain comfortable inside conditions (70F) without requiring heating when outdoor temperatures are 55F, while houses of more conventional construction will activate their heating systems when it is below 65F outside.

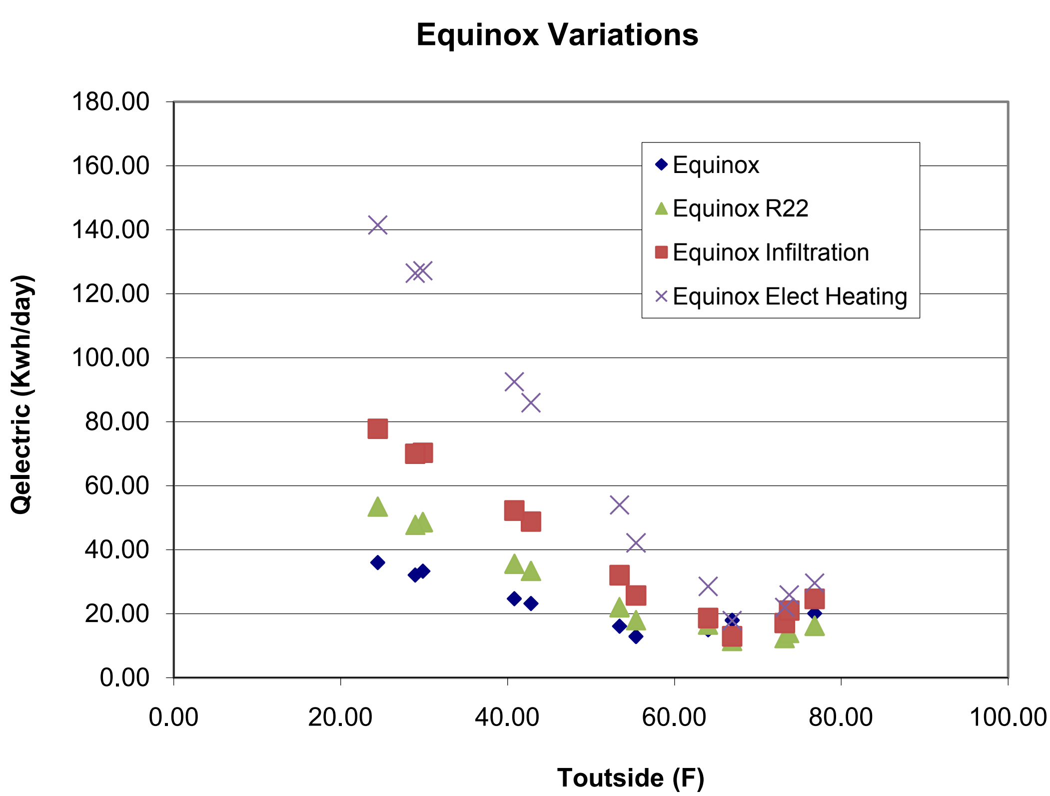

Figure 3 Variations of Equinox House design characteristics.

A house with "modern" construction in central Illinois requires 24,000 kW-hr of energy consumption per year. The Equinox House is predicted to require 7200 kW-hr per year, or less than 1/3 of the energy requirement of a modern house. How much is this difference worth? On a simple economic basis, assuming 10 cents per kW-hr, a home with typical "modern" construction methods will cost $2400 per year, or about $48,000 over 20 years. The Equinox House would cost $720 per year, or $14,400 over 20 years. The $33,600 difference between the two is enough to purchase the solar energy system for the house and for the majority of your electric vehicle transportation energy. That is, the Equinox House with a solar system will cost no more than a conventional house that uses cheap, polluting energy from conventional power plants as well as displacing 75% of your car's energy requirement. Why not just build a house with the energy efficiency of the Equinox House, use conventional energy, and then pocket the difference? Well, that's something you need to ask your conscience about. Do the extra levels of insulation, extra sealing of the house exterior shell and high performance heating/cooling system cost a lot more than a conventional house? We will cover that in future discussions as we break the house energy systems down. However, the brief answer is "no", on a cost per square foot basis for building and operating the house, the extra cost for these items will not increase the overall cost of the house if other factors are properly implemented into the design of the house.

Comparison of Equinox House to Modern Conventional House Energy

Before ending this discussion, let's compare the predicted performance of the Equinox House with the performance of some real houses. The previous section presented some computer modeling results for predicted performance of some house designs. Figures 4, 5, and 6 are plots that show the average daily energy used relative to the outside ambient temperature for three real houses located in Urbana, Illinois. Each plot shows the predicted Equinox House energy in relation to energy data for the three real houses. All three homes are similar in size to the Equinox House (~2000 to 2500 sq ft floor area), and were built within the last five years using "modern" construction methods. Notice that all three homes have energy performance levels that are quite similar to those predicted for a conventional, modern construction house shown in Figure 3.

House #3 in Figure 6 is interesting because the house has a ground source heat pump. Ground source heat pumps can be efficient if the ground coupling has sufficient energy capacitance. The problem one encounters with ground source heat pumps is knowing how much ground coupling is needed. That is, information on the ground properties and the movement of water through the soil are very important. Unfortunately, that information is not available and can be very site specific. For the house shown in Figure 6, the two data points circled in black are for October and November when the ground is relatively warm. As the house progresses through the winter, the heat removed from the ground for heating the house cools the ground, which reduces the efficiency and heating capacity of the ground source heat pump. By December, the system adds electric resistance heating in order to meet the required house heating load. As the house reaches springtime, the red circled data points show February and March conditions. Even though the average outside temperature for February and March are similar to that experienced in October and November, the house energy requirement is double that of the fall months because of the loss of ground energy availability.

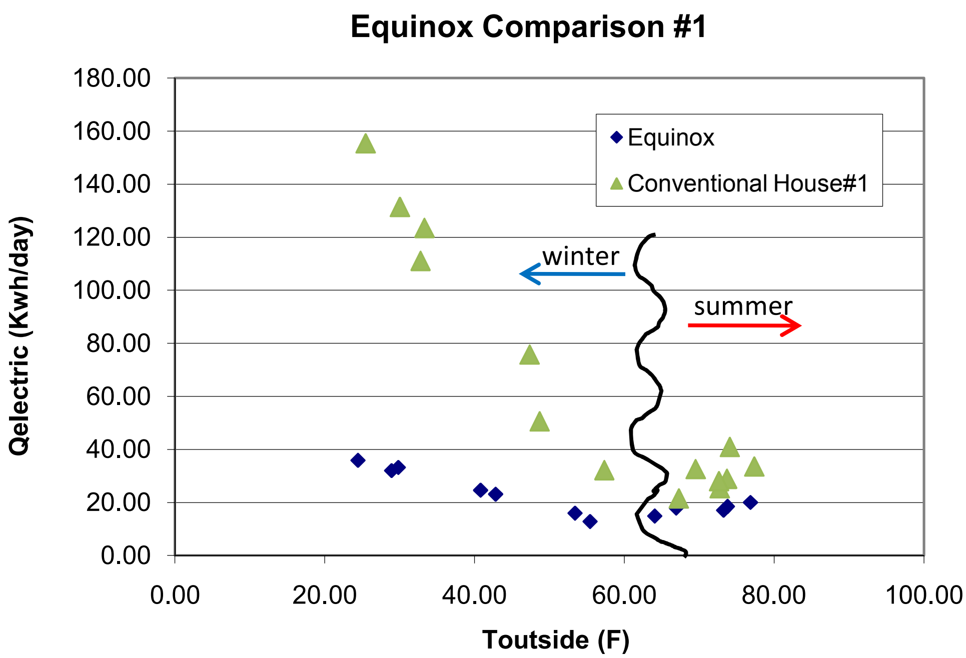

Figure 4 Comparison #1 of Equinox House with a recently constructed house.

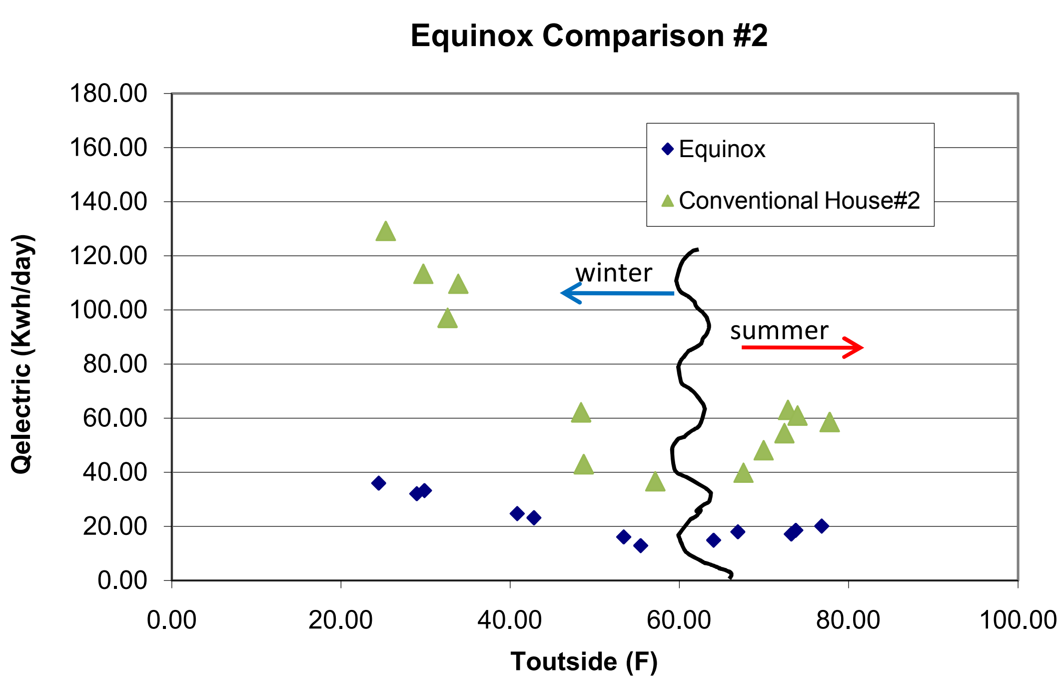

Figure 5 Comparison #2 of Equinox House with a recently constructed house.

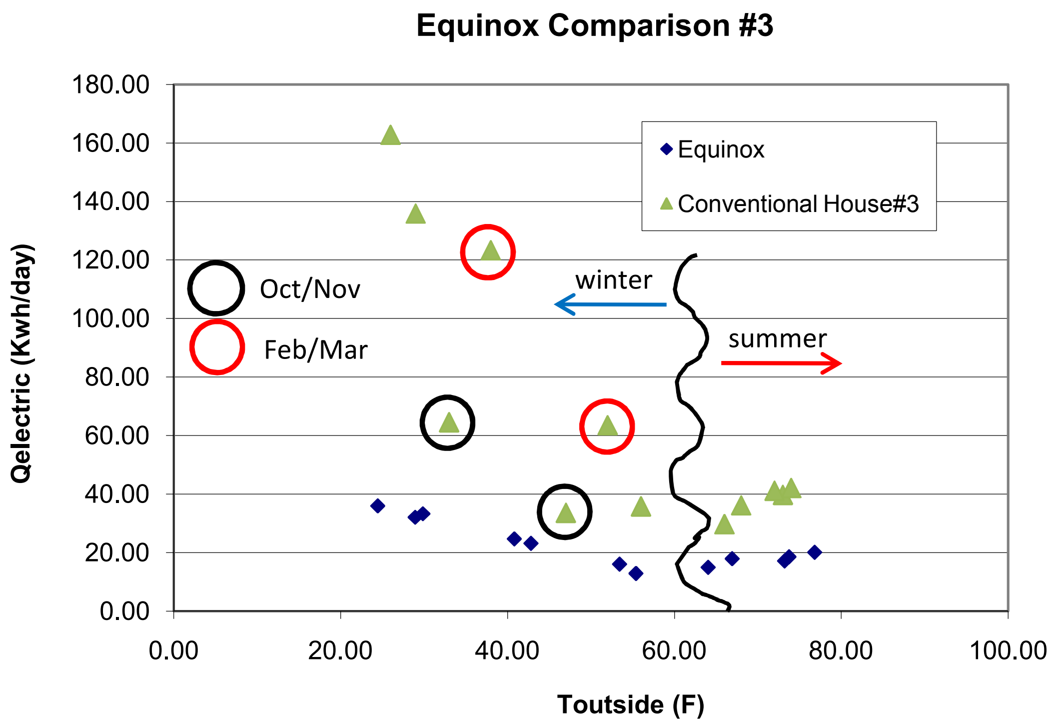

Figure 6 Comparison #3 of Equinox House with a recently constructed house.

Conclusion

Ok, so now you have a taste of my dull style of writing. Isn't it odd that someone (me) can be excited by stuff like this, while most people will need a box of Nodose and a sixpack of Red Bull to read through it? I once gave a three day series of lectures (more than 8 hours per day of me blabbing) in Beijing to a group of 40 Chinese engineers on refrigerator design. Forty hours of me droning on about condenser hot loops, door flange design, mullions, and suction line heater exchangers! As the honored guest at dinners, I was given various "special" animal parts (eg, duck brain) to eat that I would not normally think of as food (and still don't). I think they were getting back at me for each day of excruciating lectures.