In order to give you an idea of how your Wind Power Case Study grade came about, here I present my own results of the wind power case study. I aimed for rather over-the-top detail, but it should give you a very good idea of the most I could have hoped for, and thus where you might have done a bit better. By and large you all did a fantastic job with this!

As I mentioned in my email, I have been sick this past week and thus haven't had nearly as much time to put into this write-up as I would like. I've tried to clarify my notes a little bit, but it is hardly complete.

The WindCaseStudySpreadsheet contains all the financial data. The wind power data comes from, appropriately enough, the WindPowerCalculations spreadsheet. I've used named cells and cell ranges to make it easier to understand what the spreadsheets are doing.

The financials spreadsheet is reasonably straightforward. Two things I included that many of you did not:
1) I calculated the costs on the assumption that the Northfield School District and Carleton went in on a joint project, because Rich told us that Carleton only planned to proceed on that condition
2) I included an "availability factor," to account for the fact that even the best turbine is not up and running 100% of the time. I used 98% (as did Nancy), though that's probably a bit pessimistic. You can see that this is a moderately important factor by fiddling with it and looking at the resulting change in the financials chart.

The wind power spreadsheet is appreciably more involved. I worked hard to make it use all of the available data, but to also take into careful account the fact that not all of the data was reliable. This included throwing out unreliable data, but also being careful to account for the thrown-out time (as Andy W. emphasized in his write-up!). (Just because the anemometer or thermometer was on the fritz doesn't mean the turbine would be down during that time…at least, not with an availability factor operating on the financials spreadsheet.) I used a lookup function to determine the actual power expected, hour by hour, from the turbine. Since the air was often denser than the maximum density in the power curve, I extrapolated it (approximately) out to higher densities. Neglecting the influence of density on the power curve has a small (but not negligible, a few %) impact on the power produced.

Note that some of the wind speed data points flagged as -2's were probably actually good data from a very still day. These do occur, and throwing them out tends to boost the average wind speed a bit above the real value.

The data in the "Dry Air Density" column is calculated using the ideal gas law and the average molar mass of dry air, which is 28.9$_4$ g/mol, as follows:

$$\mathrm{PV} = n\mathrm{RT} \;\Rightarrow\; \frac{\mathrm{P}}{\mathrm{RT}} = \frac{n}{\mathrm{V}} \;\Rightarrow\; \rho = \frac{\text{mass}}{\text{volume}} = \frac{\text{mass of air}}{\text{volume of air}} = \frac{(\text{moles of air})(\mathrm{MW_{air}})}{\text{volume of air}} = \frac{n}{\mathrm{V}}\mathrm{MW_{air}} = \frac{\mathrm{P}}{\mathrm{RT}}\mathrm{MW_{air}}$$

Given the local elevation is 280 m above sea level, the Windpower.org Power Calculator tells us the pressure will be about 3.$_{32}$ kPa lower than at sea level, or about 98 kPa. I decided against correcting for weather-induced pressure changes (since they amount to at most 0.27% of this) or for humidity in the air (which slightly lowers the average molar mass of air, but even less than 0.27% on the muggiest of days). Thus,

$$\rho_{\text{dry air}} = \frac{\mathrm{P}}{\mathrm{RT}}\mathrm{MW_{air}} = \frac{98\ \mathrm{kPa}}{\left(8.31_{45}\ \frac{\mathrm{J}}{\mathrm{mol\cdot K}}\right)\left(\mathrm{T_{measured,\ in\ K}}\right)}\left(28.9_4\ \mathrm{g/mol}\right)\left(\frac{\mathrm{kg/(m\cdot s^2)}}{\mathrm{Pa}}\right)\left(\frac{\mathrm{J}}{\mathrm{kg\cdot m^2/s^2}}\right) = \frac{34_1}{\mathrm{T_{meas}}}\,\frac{\mathrm{kg\cdot K}}{\mathrm{m^3}}$$

In actuality, Carleton will go with a maintenance contract and extended warranty that will run \$11,000 per month, but if we did in fact do our own maintenance the cost would be lower at the outset and higher later in the life of the turbine. I did as you all did and just paid out 1.5% of the turbine cost in equal payments over the course of a year. Actually, this was one of the most common boo-boos made in this project: several of you paid a year's worth of maintenance costs each month, and that made a substantial difference!

While it is not completely clear how long a turbine like this will operate, I didn't think it wise to make any assumptions about it lasting longer than twenty years. The 20-year mark is probably the best place to compare the different scenarios and see how they stack up:

Scenario	Funds remaining after 20 years	Relative annual return on status-quo
Business as Usual	$ 5,485,500	0.0%
WindSource	$ 4,663,200	-0.75%
Turbine	$12,934,100	+6.8%
Hosed	$ 7,578,400	+1.9%

Based on my results, this project makes a lot of sense even on purely financial grounds. I would anticipate being in a better financial position after 20 years relative to the status quo, even with the "hosed" scenario.

In order to answer a question that several people brought up, I calculated temperatures weighted by available wind potential, to see if there was a correlation between temperature and windspeed within a given month. I found that where there was any correlation at all, there was a slight tendency for the wind to blow harder when is was warm than when it was cold, but only in the winter. This fits in with our observation that the wind seemed to blow hardest around mid-day, though it didn't show up in the summer.

Something that I didn't account for that some of you tried to was the energy required by the turbine in order for it to operate. Approximating that to be 30,000 kWh per month, this drain has a notable (but not staggering) impact on the financial results.

One last thing: I really don't have time for this, but I'm going to do it since Micah did a great job of it and I think it is really insightful, so I'll try to provide you all with a taste. Using the Financial Tables tab, and tweaking one parameter elsewhere, I could determine the impact of each change on the final results in each scenario. I've summarized a few of these in the table below. This is called a sensitivity analysis, and is a really great way of getting error estimates for super-complex problems like this one. It shows you what assumptions are most important, and what impact an error in those assumptions will have.

Sensitivity Analysis for Wind Power Case Study

% Change in Financial Change Result Induced by Indicated Change in Assumptions

Change Made	Business as Usual	WindSource	Turbine	Hosed
Increased availability factor to 99%	0%	0%	+4%	+3%
Ignored power curve density dependence (assumed 1.27 kg/m^3)	0%	0%	+18%	+13%
Did not correct for 80 m rotor hub height (assumed 70 m)	0%	0%	-14%	-9%
Assumed a roughness class of 2 instead of 1.5	0%	0%	+2%	+1%
Did not extrapolate power curve to higher densities	0%	0%	-0.8%	-0.5%
Changed initial investment to $15 million (from $10 million)	+190%	+160%	+290%	+350%
Changed real interest rate to 6% (from 5%)	+70%	+60%	+130%	+130%
Shortened forecasting period to 10 years (from 20 years)	+60%	+60%	-100%	+30%
Did not share costs with school district (only one turbine)	0%	0%	-8%	-9%
Increased land lease to 3% of Xcel energy payments (from 2%)	0%	0%	-2%	-3%
Eliminated federal production credits entirely, immediately	0%	0%	-120%	-20%
Eliminated state production credits entirely, immediately	0%	0%	-100%	-17%
Increased maintenance costs to $11000 per month (warranty)	0%	0%	-130%	-160%
Adding 30000 kWh of energy to consumption, for turbine	0%	0%	-16%	-20%
Increasing WindSource percentage to 20% (from 10%)	0%	-15%	0%	0%