Conserving Energy in Existing Buildings: A Case Study of Purdue University's Residence Halls

Parag Rastogi, December 06, 2007.

Part I – INTRODUCTION

Humans are philosophers and philanthropists. We are loyal to family and to country. We believe in liberty, honesty and fraternity. And yet, we plunder the earth with a barbarity we would not imagine any human could be capable of. In order to stop this catastrophic destruction of the environment, balanced and concerted action from governments, people and organizations is urgently required. However, this cannot be accomplished at the cost of development, because the poor need clean water, food, shelter, electricity, clothes and employment. This is a paradox that might prove more difficult to solve than any posed by Xeno.

How can a college student find answers to such lofty issues – issues that have tormented humankind for decades and threaten, to paraphrase Wilfred Owen, 'clog our chariot-wheels' down in endless bogs of arguments and counter-arguments? I feel that these seemingly colossal issues can be tackled if we just start with ourselves and the community we live in. One such issue is humankind's almost insatiable thirst for energy. I feel we can bring about change in this area by educating consumers, administrators and technocrats of the virtues and feasibility of new technologies and novel education methods. To that end, I have chosen to do a project on **Reducing Residential Energy Consumption** by students living **in the Purdue campus**.

Environmental and natural resources are increasingly recognized as being limited and, in many cases, disappearing. The exhaustion of resources not only leaves the world economically barren, but also an unsuitable environment for humans to live. The opportunities to bring economics and environmental sensitivity together are boundless – even amongst students at Purdue. I investigated how wise decisions regarding energy consumption and efficiency can, and in many cases should, be implemented at Purdue. These decisions are often complex, requiring the examination of both the mechanical design flaws in the buildings as well as the sociological and economic factors that discourage students, faculty, and the administration from thinking about the consequences of their energy appetites. I have tried to come up with solutions for problems that plague residential buildings across the world and have found that there is no magic answer. Technologies that have obvious benefits in one kind of building have no effect whatsoever in another. Community initiatives that motivated the nation to take up recycling may not budge student's attitudes regarding wastage and propriety. Economics is a driving force behind many decisions and I will try to use economic tools to buttress my recommendations regarding both technological and social change.

My aim in this paper is to make recommendations for reducing the energy consumption of student residences on campus through technological and social methods. I will make recommendations based on facts, statistics and know-how gathered from various experts I interviewed and literature on the subject. The project's scope is limited to student residences on campus because I do not have the manpower to gather usage data and recommendations for rented houses, resident-owned houses and other different types of housing arrangement. I hope that by means of this paper and presentation I can convince the administration and students at Purdue to adopt methods of conserving energy without significantly impacting the quality of life we currently enjoy.

I will focus on and present a thorough quantitative analysis of potential electricity savings from lighting fixtures. I will also briefly discuss techniques and methods to save energy, both passively and actively, from other areas such as heating, cooling, appliance replacement, renovations etc. However, a rigorous analysis of the potential savings from the latter list is beyond the scope of this paper, so I will limit myself to a qualitative discussion of potential benefits or costs.

In this paper, when I talk about residence halls, I exclude dining facilities located inside residential buildings. I chose to do this because the energy consumption of dining facilities is of an entirely different nature from residential consumption and therefore necessitates different solutions. Thus, the term ‘residential’ applies to rooms/facilities used to house students and provide them with the non-food necessities of life in college. I include university-owned apartments, even though they are run and built differently from regular dorms, because they provide these same services and are run by Purdue’s Housing and Food Services (HFS) department.

The questions I am trying to address in this report are, broadly speaking, as follows:

1) What cost-effective technologies can be used in residential buildings on the Purdue campus to reduce energy consumption?
2) How do we make sure these technologies are actually adopted? That is, what incentives or mechanisms need to be in place to facilitate the adoption of these techniques?

While conducting my research I realized that there is virtually no research studying the impact of technological innovations in residence halls and other such institutional residential buildings. However, there is extensive research on reducing household energy consumption and I extrapolated their inferences to my subjects when relevant.

Executive Summary

The purpose of this project is to provide a quantitative and qualitative analysis of select technologies supplemented by behaviour change programs for reducing residential energy consumption in the campus residence halls.

Quantitatively analysing the application of sensors and conservation education programs for lighting in student rooms yields scenarios with varying potential. The best possible situation in my opinion, Scenario C – III, yields savings of 204.258 GWh or $ 13,476,180.00 over the decade 2007-2016. A more conservative estimate (Scenario C – I) yields savings of 142.702 GWh or $ 9,457,311.00. These estimates account for small increases in energy prices every year. It is beyond the scope of this paper to estimate the effect of energy shocks or price spikes on potential savings, but it suffices to say these will not be insignificant. Other recommendations, analysed largely qualitatively, include:

Indoor climate control systems (including air delivery, fresh air provision, delivery of heat, etc.). This is related to recalibrating and regularly checking heating and cooling, although the latter is discussed separately (under Retrofitting and Renovation).

Better design of new buildings (materials, alignment, etc.)

Replacing appliances (such as those in laundry facilities)

Weatherising measures

Fixing age-related problems

Together, these measures will save Purdue much more money and energy than I estimate from simply changing lighting systems.

Research

I interviewed two resource persons on campus to get a feel for viable technological solutions specific to our location and needs. These persons were Prof Loring Nies, professor of Environmental Engineering in the School of Civil Engineering at Purdue, and Dan Schuster, Project Engineering Group Manager in the Engineering Utilities and Construction Department at Purdue University. I also conducted a survey of fifteen students to determine usage patterns. The students I chose came from a variety of backgrounds.

To supplement these interviews, I looked for relevant resources on the internet, especially scholarly papers on this and other subjects. Particularly helpful to my project was the report titled *Carbon Neutrality at Purdue*, produced by a class taught on campus in the spring semester of 2007.

Overview of Approach

Since the aim of this paper is to arrive at a conclusion wherein maximum savings can be achieved from reasonably cost effective conservations programs involving technological as well as social changes, my paper will be organised around four scenarios as follows:

	Purdue implements technological solutions		
Residents change behaviour		**Yes**	**No**
	Yes	Scenario C (I)	Scenario B (II)
	No	Scenario A (II)	Scenario D (O)

Table 1.1

These scenarios are ranked according to desirability and ease of implementation, with O being the current scenario (base). I will do a detailed quantitative analysis of the lighting and indoor climate control system of a room in Hillenbrand residence hall[i], recommending possible technological additions or changes. I will then extrapolate this analysis to all dorms, accounting for the differences in room types across the campus. I will also look at other feasible design and retrofit changes in the halls, though not in as much detail. I will follow up technological recommendations with possible or desirable behaviour changes to supplement and multiply savings. Thus, my approach will create the abovementioned three scenarios compared with the base scenario.

These recommendations are divided into four broad categories as follows:

1) Programmable lighting
2) Programmable indoor climate control systems
3) Design innovations
4) Retrofitting and renovation

Subsequently I will briefly discuss the implementation of my recommendations, including monitoring and revision of policies. I will conclude by presenting the results of the quantitative analysis and the implications it would have for Purdue University, its finances and its students.

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[i] Hillenbrand residence hall is a residential facility for Purdue students located at 1301 3rd Street, West Lafayette, IN – 47906. For a complete list of residential facilities owned and operated by Purdue University's Housing and Food Services Department (HFS) in the West Lafayette campus, please see www.housing.purdue.edu

Part II – ALTERNATIVES and RECOMMENDATIONS

In all the categories discussed below, there are simple fixes and complex ones. The simple ones are often not the ones with the most benefit, because of the nature of usage of residential halls facilities. Most common areas are frequented by a varying number of people throughout the night and day. Room usage and types vary widely. Thus, getting the most savings from conservation programs in residential halls requires a mixture of technological improvements and efforts to modify behaviour. Programs have to be tailored for different kinds of halls because of their varying age and design. Another problem with residence halls is that residents typically do not live in the same residence hall for more than a year. In fact, most students move out of university residences after their freshman or sophomore years. This creates a problem for conservation awareness programs because it is extremely difficult to change lifelong habits in the space of nine months.

A Brief Overview

1) Programmable lighting control

No conservation strategy works better than simply turning things off when not needed. However, solely relying on voluntary behaviour may not be an option for buildings with large, varied and temporary occupation patterns, like our residence halls. Let us consider a typical room in a typical residence hall such as Hillenbrand hall. It has a set of room lights, a vanity light, closet lights and table lights. A typical light in the room has a rating of 32 W. This means that the standard number of lights in a room total up to 256 W. The worst case behavioural scenario is when the residents leave their lights on all day, excluding 6 hours of common sleeping time (not an unusual scenario, as shown by survey report in appendix B). Let this (18 x 0.256 = 4.608 kWh) be the base usage of a single room. For 432 rooms in the entire hall, this equals to a base consumption of 1,990.656 kWh a day. The bathroom lights are separate from room lights (2x32 W). Let the baseline consumption be 24 hours, adding a further 368.64 kWh to bring total consumption up to 2,359.296 kWh for the entire hall's residential rooms. The best case scenario is when residents use room lights for only 3 hours a day and bathroom lights for 2 hours. This equals a consumption of 362.496 kWh (kilowatt-hours) a day and savings of 1,996.80 kWh.

Scenario A

A basic occupancy sensor from Legrand Wattstopper® costs $ 75[ii]. The cost of installing sensors in the all the rooms and bathrooms in Hillenbrand will be $ 50,400. Sensors can be used to control all the lights in a room except the desk lights, total of 192 W of lighting. Average daily occupancy of rooms is 8 hours and of the bathrooms 3 hours[iii]. This means that the sensor would switch off room lights for about 16 hours a day (since most sensors do not detect sleeping human beings) and bathroom lights for 21 hours. Most basic sensors are insensitive to daylight, so for them, lighting is required by the occupants 24 hours a day. This yields savings of 1,649.664 kWh a day. At 6 cents per kWh, this yields daily savings of

[ii] For a complete listing of the types of sensors available and their price range consult http://www.wattstopper.com/getdoc/1251/Sensor_Broch_Final.pdf and http://www.wattstopper.com/products/related.html?prod_id=12&id=133.

[iii] Average daily occupancy for rooms is 7 hours plus an extra hour added for the inherent lag programmed into sensors, i.e. sensors wait a few minutes before shutting off lights after detecting no occupancy. A similar time of 30 minutes was added to the bathroom sensors since they can have shorter lag times, even though they come on more frequently.

$99.00 per day. Thus, in this scenario, the sensors would pay for themselves in roughly one and a half years.

Scenario B

In this case, students are educated to turn of lights and TVs when not needed. A standard colour 19" TV has a power rating of 200 W. If we assume that TV screens are on 12 hours a day, there is still 12 hours of standby time to be considered (during which time a TV uses 75% of its power rating). Adding 18 hours of desk light usage, the total usage comes to 5.252 kWh for a single room. For the entire Hillenbrand hall, that is 2,312.064 kWh. Fridges and other common appliances such as alarm clocks cannot be switched off, so there is really no potential for savings there.

If regular, intensive awareness and education programs for residence halls are conducted by HFS, the effects could be as follows:

- **i.** Residents are motivated enough to effect a 10% reduction in usage of standard room lights, desk lights and TVs, resulting in total usage of 4,204.224 kWh a day[iv]. If compared with total lighting and TV usage of 4,671.36 kWh, this equals dollar savings of $ 28.03 a day.
- **ii.** Residents are motivated enough to effect a 30% reduction in consumption, leading to savings of $ 84.09 a day.
- **iii.** Residents are motivated enough to effect a 50% reduction in consumption, leading to savings of $ 140.14 a day.

[iv] A 10% reduction in consumption will reduce the baseline numbers to the following figures (per day):
Room and bathroom lights ➔ 90% of 2359.296 kWh
TV (one per room) ➔ [(90% of 1036.8 kWh) + (110% of 777.6 kWh)] [i.e. (On time usage) + (Standby usage)]

From personal experience, I would say even the 30% figure is optimistic at best. It is outside the scope of this project to calculate the yearly costs of sustained conservation awareness programs. However, these cannot be ignored as the abovementioned reductions are unlikely to happen without such programs.

Scenario C

If sensors are used on the room lights (reducing consumption by room lights to 709.632 kWh) and residents are motivated to switch off lights and appliances as well, I estimate the savings to be as follows:

i. From a baseline total usage of 4,671.360 kWh, a voluntary 10% reduction in consumption would lead to savings of $ 112.85 a day[v]. In this case, the sensors would pay for themselves in about a year and 3 months.

ii. Residents are motivated enough to effect a 30% reduction in consumption, leading to savings of $ 140.60 a day. Sensors would pay for themselves in less than a year.

iii. Residents are motivated enough to effect a 50% reduction in consumption, leading to savings of $ 168.34 a day. Sensors would pay for themselves in a little over nine months.

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[v] Sensors coupled with a 10% reduction in consumption will reduce the baseline numbers to the following figures (per day):
After savings dues to sensors ➔ 1649.664 kWh
After savings from behaviour modification ➔ 261.849 kWh

Savings per Day in Hillenbrand Hall Rooms

			Purdue implements technological solutions	
			Yes	**No**
Residents change behaviour	**Yes**	**10%**	$112.85 (Sc. C – I)	$28.03 (Sc. B – I)
		30%	$140.60 (Sc. C – II)	$84.09 (Sc. B – II)
		50%	$168.34 (Sc. C - III)	$140.14 (Sc. B – III)
	No		$99.00 (Sc. A)	$ 0

Table 2.1

As predicted, Scenario C is most desirable, followed closely by A and B, which are more or less equal depending on the optimism of the scenario chosen.

Common Areas

For common rooms in a building, the occupancy sensors may not show such dramatic reductions in consumption. This is because a hall of nearly 850 students will have frequent visitors to common areas. In this case, the best conservation strategy in my opinion will be to educate administrative and maintenance staff to check regularly and turn off lights when not required. As far as I am aware, this already happens in most halls.

Summary

One reasonably achievable scenario is one in which sensors are put in place in the rooms as well as residents are motivated to reduce electricity consumption by 10%. There are 15 independent residence halls on campus of varying sizes. Some, like Hawkins, are larger than Hillenbrand. Others, such as Meredith hall, are smaller. Still others such as Purdue Village and Hilltop Apartments are composed of numerous small independent apartment blocks. However, the analysis of Hillenbrand hall would be applicable within a 10-30% variation because of the variation in size of the halls under consideration.

Savings for all residence halls (Scenario C – I) – per day										
	Base		Variations (+ or –)							
%age	100%		10%		20%		25%		30%	
	$	MWh	$	MWh	$	MWh	$	MWh	$	MWh
Hillenbrand	112.85	**1880.870**	11.29	**188.087**	22.57	**376.174**	28.21	**470.218**	33.86	**564.261**
All	1692.75	**28213.056**	169.28	**2821.306**	338.55	**5642.611**	423.19	**7053.264**	507.83	**8463.917**

Table 2.2

2) Programmable indoor climate control systems

Large buildings can be programmed to have adaptive indoor climate control systems. These systems rely on feedback from occupancy, carbon dioxide and heat sensors to change air intake, flow, heating and circulation of a room/area.

For every degree the automatic thermostat lowers your heating level, you'll save two percent on your heating. This action should be promoted both to homeowners and to those who rent and pay their own heating bills. A thermostat can be manually turned down or a programmable thermostat can be used.

A programmable thermostat allows homeowners and/or renters to regulate the temperature automatically, for specific times and days of the week (e.g., they may wish to set the temperature low between 9:00 a.m. and 5:00 p.m. on weekdays when they are at work). The cost of a programmable thermostat varies from (Canadian) $40 - $140 (Home Hardware, Ottawa, Canada). The more expensive ones can also be programmed to regulate central air conditioning. A mid-range programmable thermostat with basic options (i.e., for temperature control for specific times and days) will cost between (Canadian) $75 and $80.

Depending on actual energy savings, a programmable thermostat can pay for itself within 1-2 years. Savings are highest during the night-time hours. Turning a thermostat down 10 to 15 degrees for 8 hours, can result in savings of 5% to 15% a year on heating bills (U.S. Department of Energy)... Older homes tend to have greater energy efficiency problems and can benefit more.

(Unknown, Setback Thermostats, Retrieved October 21, 2007)

Programmable systems can come on an hour or so before a room is most likely to be used, or they can simply regulate the conditions of residential rooms based on outside temperature and enthalpy. It is very important to the productivity of a building's occupants to have a constant supply of fresh air. This can be easily achieved in a centrally-controlled programmable system with carbon dioxide feedback sensors. The costs of retrofitting these systems in buildings will vary from hall to hall, generally depending on their age. However, the installation of these systems can be incorporated into existing renovation plans. While a quantitative analysis of the savings generated by these systems is beyond the scope of this paper, the benefits of such systems seem to be greater than their cost – both in terms of dollars and quality of living.

Air Delivery Systems

Variable frequency drive devices are units which vary the speed of AC motors in air handling units based off of temperature feedback (in the case of heating/cooling systems). Currently most rooms in the residence halls have 1-3 speed fans or fan-less heating through elements. These are noisy when turned up high and ineffective when turned down. Motors with variable frequency drives work like the climate-control systems of cars, shutting off the fan when not required. This not only saves energy (by reducing running times), it also enhances convenience and lowers background noise levels in rooms.

3) Design innovations

Bad design is probably the leading cause of energy wastage/consumption there is. Design incorporates structures, layouts, materials and the optimal utilization of space, among other things. Most designs are optimized for lowest first cost and most owners do not do life-cycle costing or analysis for their projects (Nies, interview, 2007). Life-cycle analysis determines the environmental impacts and costs of structures, through construction, usage, upkeep and condemnation. Life-cycle costing is the process of including a structure's operational and maintenance costs into the total estimate for a building's financial viability over its entire lifetime. As energy costs increase, long term costs will only increase. If the policy makers responsible for Purdue's infrastructure are more informed about this and made aware of the magnitude of savings available, they can be motivated to avoid looking at just short-term costs. This includes the Indiana state legislature, which supplements a large part of our budget.

Design innovations such as the use of large double-glazed windows, under-flow air conditioning systems and building orientation have the combined potential to save great amounts of energy.

- Double-glazed windows allow passive solar heating and yet trap internally generated heat inside the building.

- Under-flow air delivery systems have a more logical pattern of air flow than traditional roof-set systems. Since they are located in the floor rather than the ceiling, the hot air emanates from the ground. Thus, the air rises upwards on its own and is collected there and recycled.

- Building orientation is important in a place like Indiana where the sun is always in the south. If the major length and windows of a building face south, they are more likely to capture sunlight and warmth. The south side need not be insulated as thickly as the north side, saving material.

- Transpired air collectors collect solar energy and utilize it to preheat outside air for ventilation. These systems capture 80% of incoming solar radiation and can preheat intake air by as much as 40º F. While strictly not design innovations, these need thoughtful placement and synchronization with a building's air conditioning systems to be fully successful.[vi]

(Retrieved from "Carbon Neutrality at Purdue University", 2007)

- Another option that utilizes solar radiation for heating purposes would involve the use of active solar water heating systems. A typical 120-gallon solar water heating system can provide 40%-70% of water heating requirements for six people, generating hot water equivalent of 2,500 kWh/year at a cost of about $.08/kWh.[vi]

(Retrieved from "Carbon Neutrality at Purdue University", 2007)

- Hybrid solar lighting technology, which captures and filters incoming solar radiation, is another technology that could reduce Purdue's electricity demand and carbon footprint. One of these systems powers eight hybrid light fixtures, illuminating over 1,000 square feet. One such system costs an average of $3,200 installed, and produces light at a cost of about $.074/kWh, with a cost recovery time of about 3-8 years. [vi]

(Retrieved from "Carbon Neutrality at Purdue University", 2007)

[vi] Purdue University receives 3.5 hours of usable solar radiation per day with an average radiation density of 3,500 watts per square meter ("State Energy Alternatives", 2007), the average cost of installing a large-scale photovoltaic system is $4 per Watt ("Solar Energy," 2007), photovoltaic arrays have a working lifetime of 30 years, maintaining a photovoltaic system costs on average 0.1% of the initial capital investment per year (Moore, 2005).
("Carbon Neutrality at Purdue University", 2007)

The main problem with utilising solar energy is that the technology of photovoltaic cells is not good enough to enable cheap large-scale installation and generation. Therefore, the technologies mentioned above which utilise solar power may be more practical for buildings such as those in Purdue Village and Hilltop apartments.

4) Retrofitting and renovation

The main consumption and, therefore, the most wastages of energy in buildings occur in the heating and cooling systems. Retrofitting walls with insulation and other such ‘weatherizing’ measures can save large amounts of energy in most buildings. This strategy, however, would be less effective in residence halls since these buildings are already well insulated and maintained.

Heating and cooling (generation) systems

The heating and cooling systems in the residence halls could be checked for efficiency and replaced if necessary. Many of the older residence halls rely on old technology and systems. Sometimes simply recalibrating valves causes significant reduction in energy usage. The main argument against replacing them is that the large capital outlay in replacing old systems is not recovered from the savings that result. I have an example of a retro-commissioning study conducted at Lawrence Berkeley Laboratory in 1979 by Schipper. While the percentage numbers are still more or less valid, the prices are in 1979 dollars. Energy costs have increased across the board, and so the savings estimated by this study are probably understated for today’s scenario.

At Lawrence Berkeley Laboratory we estimate that retrofits allow reduction of 20-80 percent of heating loads and 20 percent of cooling loads in homes with rates of return of better than 10 percent. For commercial buildings existing plants can be modified for about a 25 percent saving, again with an attractive rate of return … In new structures and equipment the savings are even more dramatic. Compared to today's energy intensities, new refrigerators, new water heaters, and new building shells require fractions (60, 80, 20-70 percent) of today's energy use with incremental investments of the order (10-20, 10, 1-5 percent) of total system costs, giving rates of return exceeding 8 percent. Here as in the industrial sector the effects of price controls, average rather than marginal costing, or subsidies to energy producers (such are the investment tax credit for utilities), are important. In California, for example, present residential natural gas prices (less than $2/GJ) justify attic insulation and some retrofit wall insulation, as well as clock thermostats, saving 20-40 percent of existing energy use with rates of return greater than 10 percent (see the author and Joel Darmstadter). At parity prices (about $3/GJ) wall insulation and double windows are profitable in many homes, while at marginal prices (electric heat or synthetic fuels at > $6/GJ delivered) homes would require very little energy for heating at all. Indeed it is less expensive to eliminate nearly all of the heating load in the "sunny" part of the country than to capture most of the load with solar heat. If electric and fuel prices rise to replacement costs, however, solar water heating will become the least expensive source of this important amenity, and solar space heat should penetrate the heat market somewhat.

(Schipper, 1979)

Age-related problems

According to Dan Schuster, leaking pipes (both heat and water carrying) cause significant amounts of heat loss in the older residence halls on campus like McCutcheon and Harrison. These leaks also cause the walls to radiate large amounts of heat into the rooms, which makes them uncomfortably hot. He says that the only solution to this design problem is to replace those pipes and that is expensive and time-consuming. The question, therefore, is whether the administration can commit enough money for a project like this. The answer to that is to do a benefit-cost analysis of whether the expense of putting in new pipes is justified by the energy savings and increased comfort for students.

A typical retro-commissioning of an existing building yields between 10-20% energy use reduction. If all the buildings on the Purdue campus were retro-commissioned, we estimate total on and off campus energy use would be reduced by approximately 15%… A far more exact estimate could be calculated for the

Purdue campus if individual building metering were implemented… Recent studies have shown that retro-commissioning results in significant energy savings, improved building performance, and reduced peak energy demand. The greatest investment return is usually seen on buildings larger than 100,000 square feet. In addition to energy savings, retro-commissioning has several external benefits which include extended equipment life; CO_2 emissions reduction; improved indoor air quality; reduced operating and maintenance costs; improved comfort and worker productivity; reduced chilled water, electricity, and steam peak demands; and a building staff more knowledgeable about operating building systems (Haasl, et. al., 2007).

("Carbon Neutrality at Purdue", 2007)

Windows

Most of the residence halls have very small windows – Hillenbrand hall being a case in point, where a small 3'x6' window serves a large double room. Replacing existing windows during renovation projects with larger double-glazed windows would result in myriad benefits: increase natural light in rooms, improve student wellness through increased natural light (removing the feeling of a 'dank' living space) and reducing heating/cooling costs by providing better insulation.

Laundry Facilities

Many of the appliances used in the laundry facilities of residence halls are old and inefficient compared to new machines available with Energy star ratings. A standard vertical-axis design washing machine wastes large amounts of energy and water in agitating clothes and trying to mix soap. Horizontal-axis machines often use 40-75 percent less water and have shorter, faster spin cycles. Thus they save energy, while preventing damage to clothes by rotating rather than agitating them. When clothes come out of such washers, they are less wet than conventional machines because rotating clothes dries them somewhat.

Many new driers come pre-installed with moisture sensors. These switch off the hot air flow in a drier when it detects negligible moisture in the clothes. This prevents damage to clothes because hot, dry air can weaken fibres[vii]. A system of drying which charges one for as long as it takes to dry a load would be very convenient and user-friendly.

The table below[vii] uses average utility prices across the nation to compare the life-cycle costs of a conventional vertical axis washer with an Energy Star® approved washer. Purdue pays only marginally lower prices than the national average.

[vii] Source: ENERGY STAR® program of the US Environmental Protection Agency and the US Department of Energy. <http://www.energystar.gov/index.cfm?c=clotheswash.clothes_washers_save_money>

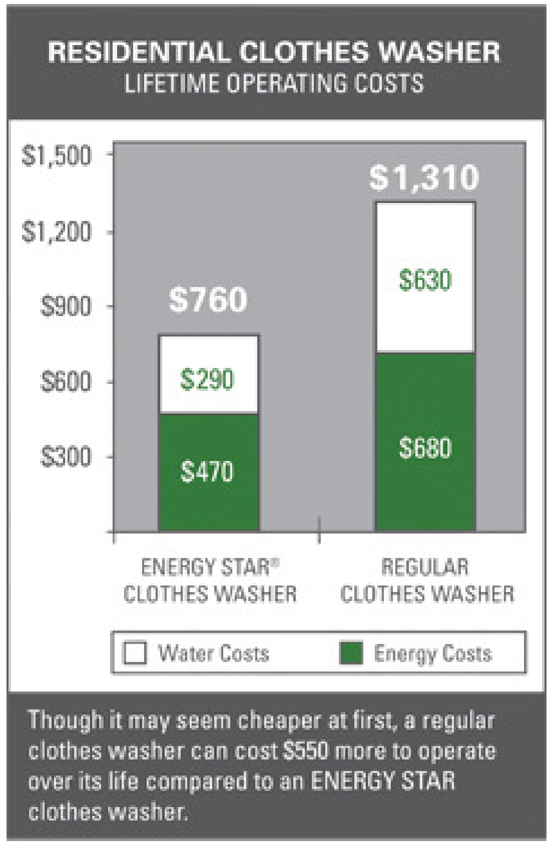

Table 2.3

The Energy Star® webpage goes on to say that these washers save, on average, about 7,000 gallons or 26,500 litres every year. Hillenbrand alone has 20 washers and 24 dryers. If the same assumptions are made regarding scaling the savings to the entire residence halls network as were made in the section on lighting, approximately 2,100,000 gallons or 7,950,000 litres of water will be saved every year. At $ 0.50 /kgal, that will save about $ 1050 every year for the university. This is not significant on its own, but using the savings estimated in Table 20.1, the annual savings could be as high as $ 165,000. A look at various electronics retailers reveals that Energy Star® compliant washers cost more or less the same as conventional ones. In my opinion, however, the savings generated by these are not significant enough to replace functioning washers. Rather, HFS should adopt a policy of buying only Energy Star® appliances[viii].

Toilets

The water-flushing toilets used in residence halls today use large amounts of water and energy. As of now, there are few water-less urinals used in the residence halls. Thus, the potential for saving energy and water through using composting and excreta-separating toilets is immense. Replacing functioning toilets does not make sense. However, replacing broken toilets with the composting or separating variety costs less than replacing with a conventional toilet, assuming the plumbing has to be often replaced as well, especially in the older buildings.

PART III – IMPLEMENTATION

Metering

Metering is, effectively, the root and the life-blood of most of my technological recommendations. Installing meters for measuring electricity, water and gas consumption on the campus will allow for the identification of inefficiencies in the grid and buildings[ix]. This will also enable accurate assessments of the impact of various technologies. While costly and

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[viii] Energy Star® approval is only available for certain specific types of appliances. Dryers do not receive this rating.

[ix] The US Department of Energy's National Renewable Energy Laboratory has published a paper (US D.O.E., 2003) which provides an overview of options in metering technology, system architecture, implementation, and relative costs. It provides advanced metering systems information to help potential users specify, acquire, use, and expand systems. It addresses basic security issues and provides case studies and information resources. Purdue's physical facilities department could review the experiences of this and other case studies available to justify the importance of metering to the Board of Directors.

with no direct payback, meters on campus will enable us to optimize implementation and ensure the potential of various programs is fully realized.

> Without baseline measurements of energy use in individual buildings and by individual users, it is not possible to quantitatively suggest the future benefits of any of the institutional or individual consumption management suggestions. Once meters are installed it will be possible to make targeted suggestions of the most cost effective and high-impact projects Purdue University can undertake.

("Carbon Neutrality at Purdue University", 2007)

Meters require monitoring and regular collection of data. Somebody has to collect and analyze this data. Creating positions to do this will increase costs, but they will be essential to gaining accurate estimates of the effects of any measures undertaken by the university. This is especially true for the social measures I propose in this project, since they all rely on being able to measure the consumption of various residence halls individually.

> Dormitories and buildings (with classrooms an office space) encompass the largest amount of square footage on most campuses, suggesting that schools might give priority to sub-metering facilities in these two categories. Electricity consumption and demand can account for up to 80 percent of the total energy costs on campuses. Because electricity sub-metering is less expensive than steam, chilled water, and

natural gas sub-metering, many schools begin by metering electricity and subsequently meter other energy sources.

(Sub-Metering Energy Use in Colleges and Universities: Incentives and Challenges, 2002)

Charging end users for energy consumption directly is probably the best way to lower consumption (Schuster, personal communication, 2007). However, this is a tall order for residential facilities at Purdue. University residences house close to 7500 students in close to half as many rooms (assuming an average of two people per room/unit). Sub-metering rooms is impractical and prohibitively expensive. Metering entire buildings, however, is an achievable goal. University residences could then hold competitions amongst residence halls rewarding, for example, the lowest energy consumption per capita.

Incentives

Climate change is a fairly strong motivation for both Purdue as well as the student body. The scientific community is almost unanimous in its opinion that climate change is happening. However, it is still difficult to link individual events/abnormalities to climate change (Nies, interview, 2007). This does not mean, however, that an institution like Purdue should not take the initiative. A climate change centre and other such policy centres are well and good, but we must realize that until the administration seriously decides to redesign our infrastructure into a lean, efficient avatar, the larger savings will remain in the realm of 'potential'.

Educating the maintenance and administrative staff of various residence halls should be a key part of programs to reduce consumption. To ensure maximum effectiveness, a scheme could be worked out which would monetarily reward maintenance staff for energy saved from a baseline measurement. The less energy a hall uses, the larger bonus the staff receive. This kind of incentive is the opposite of charging end-users and will work better in our residence halls, mainly because maintenance and administrative staff will be kept out of the loop in the latter. Also, it is unfair to charge an entire residence hall for its usage and then divide that equally amongst the residents, because consumption varies widely from resident to resident.

Barriers to Adoption

The most serious barrier to adopting and implementing new technologies is initial cost. However, I ask the administration to consider this: the energy needs of the campus are only increasing, especially with increased residential space, research buildings and academic areas. Many of our existing buildings are also undergoing expansion and renovation. This means that soon we will either have to undertake major expansions of our existing power plant or increase our dependence on outside suppliers[x]. While I agree that putting in new technologies requires investment, expanding the Wade utilities plant, building a new power

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[x] Currently, Purdue purchases approximately half of its electricity from the Duke Energy Corporation and all of its natural gas from the Vectren Corporation (Schuster, 2007). The outsourced electricity and natural gas is utilized by on-campus buildings, student residence halls, off-campus buildings that host official Purdue activities, and many farm and agricultural research areas owned by Purdue University throughout Tippecanoe County. Residences include various dormitories as well as Purdue Village and Hilltop Apartments, both of which are Purdue-owned apartment-style residences. Tenants of the apartment residences maintain individual natural gas accounts. Off-campus buildings include buildings that sponsor groups, activities, or events that contribute to the academic, athletic, and/or cultural climate of the University. Examples include the Black Cultural Centre, Housing and Food Services (HFS), and the Athletic Department facilities. Many of these facilities maintain individual natural gas accounts, and some also maintain electrical accounts outside of the Purdue University grid.
The amount of electricity and natural gas purchased by the University from outside sources is documented by Purdue Physical Facilities. According to these records, in 2005Purdue purchased 153,510,279 kilowatt-hours (kWh) of electricity. Duke Energy Corporation provided the majority of the electricity, but smaller amounts were provided by Tipmont REMC, Warren County REMC, and Boone County REMC (Schuster, 2007). (“Carbon Neutrality at Purdue University”, 2007)

plant or continuously buying more energy over long periods of time costs even more. Especially since energy and fuel prices are expected to increase exponentially. The Wade utilities plant currently runs on maximum capacity and has no reserve capacity to take over in case of breakdowns[xi]. Instead of increasing supply capacity, if we decrease demand, the same purpose is achieved with less expense[xii].

In many big institutions, there is decision inertia in unfamiliar territory, mainly as a result of the wide diffusion of the decision making process amongst multiple layers. A case in point is energy planning in Indiana, where policy makers have been loathe adopting novel technologies because of the ease of availability and processing in using coal.

PART IV – CONCLUSION

Results

I will now translate the savings achieved in one of the scenarios discussed in the section about programmable lighting systems into dollar savings over a decade. In the following tables, I will present my estimates of achievable savings from various levels of

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[xi] Wade Utility Plant generates approximately 50 - 60% of the electricity and the majority of the steam and chilled water consumed by campus buildings connected to the Purdue Power Grid. Wade consists of two coal-fired stoker boilers, one coal-fired fluidized bed boiler, and one oil and gas-fired boiler. Together, these four boilers burn over 153,000 metric tons of coal and a limited amount of natural gas and oil each year to generate over 3,000,000 klbs. (1.16x1020 kBtu) of steam. The natural gas and oil boilers are only put into operation during peak load periods, such as very cold or very hot weather, and therefore burn a much smaller amount of fuel than the coal boilers. The university's infrastructure is dependent on the generation of steam to meet the majority of heating and cooling demands on campus.
("Carbon Neutrality at Purdue University", 2007)

[xii] Purdue has recently obtained approvals from the Board of Trustees and the State to design a new boiler, which will be somewhere between $45 and $60 million. This boiler should add some capacity and will be cleaner burning than Wade's oldest boiler. It will take 2-3 years to finish installation.
(Schuster, Personal Communication, 2007)

voluntary conservation along with sensors. I will place my numbers within a sensitivity band of 25% due to variation in housing choices and contract length across the Purdue campus. Also, the main academic year lasts for 9 months so a bulk of consumption occurs during this time. I will assume a cost of 6 cents per kWh as mentioned earlier for 2007 and a rise of 2% every year[xiii].

As is obvious from the figures generated below, the importance of conservation programs is without doubt. However, using them to supplement sensors is a better idea for most residence halls. The only problems, from personal experience, could be in multi-room flats managed by HFS (such as those in Purdue Village), where one sensor would not be able to detect human presence in the entire house.

[xiii] This figure is based off material and statistics available on the US Energy Information Administration's website. <http://www.eia.doe.gov/emeu/steo/pub/contents.html>

Savings 2007 – 2016 (10%, Scenario C – I)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cost of electricity ($/kWh)	0.06	0.0612	0.0624	0.0637	0.0649	0.0662	0.0676	0.0689	0.0703	0.0717
Savings (GWh)	10.298	11.437	12.462	13.385	14.216	14.963	15.636	16.241	16.786	17.277
Savings (1000 $)	617.87	699.95	777.95	852.27	923.25	991.23	1056.52	1119.37	1180.07	1238.84

Table 4.1

Total savings over the decade (2007 – 2016) = 142.702 GWh +- 35.676

Total savings over the decade (2007 – 2016) = $ 9,457,311.00 +- 2,364,327.75

In the fiscal year 2005-06, the university consumed 280,021.126 kWh[xiv] of electricity. Over a decade, assuming no increase in demand, the total consumption will be 2,800.21126 GWh. I am making this assumption because I have no estimate of the increase in demand due to new and proposed buildings across campus. Therefore, I have found that Scenario C – I will yield a savings equivalent to **5.10 (+- 1.28) %** of the **university's projected consumption over the next decade.** Also, using these estimates, the university will save **$9,457,311.00** over the next decade. If one assumes that each residence hall on campus will require the same number of sensors as Hillenbrand hall, the sensors installed across campus would pay for themselves in little over a year.

[xiv] Figure obtained from the webpage of Purdue University's Wade Utility Plant. <http://www.purdue.edu/utilityplant/plantoperation.htm>

Savings 2007 – 2016 (30%, Scenario C – II)

	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Cost of electricity ($/kWh)	0.06	0.0612	0.0624	0.0637	0.0649	0.0662	0.0676	0.0689	0.0703	0.0717
Savings (GWh)	12.829	15.488	17.349	18.651	19.563	20.201	20.648	20.961	21.180	21.333
Savings (1000 $)	769.77	947.85	1,082.97	1,187.56	1,270.53	1,338.23	1,395.18	1,444.64	1,488.92	1,529.69

Table 4.2

Total savings over the decade (2007 – 2016) = 188.202 GWh +- 47.051

Total savings over the decade (2007 – 2016) = $ 12,455,300.00 +- 3,113,825.00

Making the same assumptions for Scenario C – I, Scenario C – II will yield a savings equivalent to **6.72 (+- 1.68) %** of the **university's projected consumption over the next decade.** Also, using these estimates, the university will save **$ 12,455,300.00** over the next decade. If one assumes that each residence hall on campus will require the same number of sensors as Hillenbrand hall, the sensors installed across would pay for themselves in less than a year.

Savings 2007 – 2016 (50%, Scenario C – III)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cost of electricity ($/kWh)	0.06	0.0612	0.0624	0.0637	0.0649	0.0662	0.0676	0.0689	0.0703	0.0717
Savings (GWh)	15.361	18.526	20.108	20.899	21.295	21.493	21.592	21.641	21.666	21.678
Savings (1000 $)	921.67	1,133.78	1,255.23	1,330.71	1,383.02	1,423.78	1,458.94	1,491.52	1,523.09	1,554.44

Table 4.3

Total savings over the decade (2007 – 2016) = 204.258 GWh +- 51.065

Total savings over the decade (2007 – 2016) = $ 13,476,180.00 +- 3,369,045.00

Making the same assumptions for Scenario C – I, Scenario C – III will yield a savings equivalent to **7.30 (+- 1.83) %** of the **university's projected consumption over the next decade.** Also, using these estimates, the university will save **$ 13,476,180.00** over the next decade. If one assumes that each residence hall on campus will require the same number of sensors as Hillenbrand hall, the sensors installed across would pay for themselves in approximately nine months.

Conclusion to project

As I have said before, Purdue, by virtue of being a preeminent and influential science and engineering research institution, must take the lead in changing our society to save the earth. While we are known for our contribution to the exploration of outer space, we must also be known for our championing of the earth we live on – the earth we cannot abandon and run off into space from. Great changes are often made up of small steps, to paraphrase one Purdue alumnus, and we must set an example in our buildings. These measures will not only save energy and money over time, they will also set an example for students who live and work in these buildings. This will hopefully produce generations of graduates who care enough about the environment to not let apathy and initial costs cloud their vision.

Measures to reduce energy consumption vary widely depending on the type of building being talked about. For example, I noticed that the lights and televisions in the Hillenbrand dining hall were left on throughout the night. When I wrote to the manager about this, he replied promptly, saying he would look into the matter. After that, I have noticed that most lights and all televisions are switched off when the cleaning personnel leave for the night. Simply telling the staff to do this saved close to 5-6 hours of usage a night! If pursued, this could lead to educating the entire staff about switching off lights and appliances when not needed – reducing consumption further. On the other hand, reducing electricity usage and water wastage in individual rooms will require a multi-pronged strategy involving educators, energy ambassadors (students who act as peer information sources for energy conservation) and new technologies discussed above (such as climate control, trip switches, compost toilets).

There is nothing more important to a program as long term commitment. Half-baked, half-hearted measures undertaken in fits and spurts will yield insignificant results and consume disproportionate amounts of resources. In fact, these will probably build a negative image for conservation as students realise the inefficacy and costs of measures undertaken by the administration. To prevent such counter-productive effects, we must develop a long term plan with adequate resources and co-ordination amongst various departments (such as the physical facilities department, the office of the university architect and the bursar's office). Purdue already has incorporated into its long term goals reduction of carbon emissions and other pollutants with the expectation that they will be taxed in the not too distant future. This is a great goal to start with, but lofty goals are often reached by tweaking the smallest maintenance or renovation program. The best conservation of energy and reduction of our carbon footprint will come from diligent and thoughtful applications of various technologies and systems in our buildings. In the long run conservation efforts will free up energy money for other projects the university would like to pursue for the betterment of the campus and Purdue family.

Less consumption means less generation and less wastage, saving money and preventing carbon emissions. One phrase hits the proverbial nail on the head: waste not, want not.

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Appendix A – Interviews

- **Loring Nies**, Associate Professor, School of Civil Engineering

1) What do you think are the biggest problem areas in household energy consumption?
2) Do you feel technology can offer better solutions than education?
3) How does information affect usage behaviour?
4) How can people be motivated to look at long-term costs instead of short-term costs only?
5) Will energy audits and the like have significant effects on household energy consumption?
6) What viable technologies would you suggest for homeowners and residence halls in Lafayette to minimize energy consumption?
7) Do these technologies have any major costs? If yes, how can they be offset?
8) Are there any non-financial costs of these technologies, i.e. space constraints, aesthetic, maintenance?
9) Can Purdue implement a large enough program of sustainability in use and generation of energy that we can look to sell carbon credits?
10) Does Purdue do an energy audit? If yes, does it help (or do we implement it)?

Answers:

1) The most important part of any construction/project is **design**. Bad design is probably the leading cause of energy wastage/consumption there is. Design incorporates structures,

layouts, materials, and optimal utilization of space, among other things. Most designs are optimized for lowest first cost. This does not take into account operations costs, maintenance costs, etc., i.e. most owners don't do life-cycle costing. However, home owners cannot be expected to do life-cycle costing, because the costs of costing will probably never be covered in small-scale projects. Institutions can afford it though, and must do it. The main consumption and, therefore, most likely wastages for buildings occur in the heating and cooling systems.

2) I would say both are equally important. Technology is better utilized and better sought out with education. However, to a certain extent, technology can overcome shortfalls in education.

3) Information definitely affects behaviour, if people care, that is. However, information can be used to make people care, especially through making them aware of the consequences of their actions and decisions. These consequences could be financial, environmental or cultural. Also, incentives and punishments can help. For example, charging for energy usage in the dorms.

4) As energy costs increase, long term costs will only increase. If people are informed about this and made aware of the magnitude of their savings, they can be motivated to avoid looking at just short-term costs.

Climate change is a fairly strong motivation. The scientific community is almost unanimous in its opinion that climate change is happening. However, it is still difficult to link individual events/abnormalities to climate change. For example, West Nile virus has recently made its way to Indiana. Nobody would have thought this possible 10 years ago because we are fairly removed from the tropics, and the West Nile virus is a tropical disease. There are other effects like a decrease in crop yield, change in the standard of living, which can be used to motivate people to act.

5) Again, the audits will have effects, if people care. Giving information to people who just aren't concerned produces no effect. Institutes like Purdue can influence behaviour to a large extent (mostly through incentives and punishments).

Purdue does not measure individual usage of energy for buildings and, therefore, has no way of detecting where and why wastage is happening. However, a project to this effect has been started and should be fully operational in three to five years.

One proposal for implementing some program of this nature is as follows:

Purdue will decide baseline consumption amount for every building/department based on historical usage. Then, if a building/department manages to keep their energy usage below this, they will get some kind of rebates. Conversely, if a department overshoots their allowance, they will be charged for it.

Although it is not a rule, but it is a safe bet to say that people will behave more responsibly about their energy consumption if they had to pay for every bit of it.

6) The most important technology is people. People can adjust thermostats, switch off unnecessary appliances, lighting and plumbing fixtures.

Large buildings can now be programmed to have adaptive cooling/heating systems. These can cycle up and down based on expected usage.

Another technology is to use under-flow systems. Traditionally, most buildings are heated or cooled from the ceiling down. Under-flow systems are a different way of thinking about air-flow systems – putting everything below the floor. This way, the circulation of air is more logical and maintenance is easier too. Also, under-flow systems tend to be more flexible for design.

Geothermal-based systems are an alternative. These utilize the earth's sub-surface temperature to warm/cool air. One viable system for Indiana is to cycle air through pipes located about 2 m below the surface. The temperature of that area is a constant 55 degrees Fahrenheit or so, regardless of season. This can thus be used to pre-heat or pre-cool air before it's fed into the buildings system – saving it a fair amount of energy.

Electronics, computers and instruments which are more efficient in their power usage tend to have a multiplier effect on savings. Low-consumption will require less cooling because they will produce less heat. Even maintenance costs go down for energy-efficient machines.

7) For technologies to gain widespread, especially institutional, acceptance, the long-term costs have to offset the initial extra expenditure. Institutions like Purdue may not be able to implement technologies until they have enough incentives to do so. Individuals, though, do take actions which might not have even long term monetary benefits. For example, a person may choose to buy a hybrid car, even though the initial difference in cost cannot be made up in fuel savings until fuel process rise to 3-4 times their current levels. However, people still buy hybrids just because they believe it is the right thing to do.

8) Certain green technologies do require more space than their conventional counterparts, e.g. geothermal, solar panels and wind mills. There are also aesthetic issues sometimes, especially with wind mills and solar panels.

9) I don’t think so, at least not in the next few decades. Carbon trading is still evolving and we don’t know who can decide the baseline usage allocation for Purdue.

10) Yes, to the best of its ability. The program to meter all buildings on campus will help. We have been working on conservation for a long time now.

We have thought about contests and other programs for users to try and reduce consumption. Residence halls are probably not the main culprits in the campus, but programs in the residence halls can often have the greatest impact because the consumption there is largely user-based. Laboratories may use much more energy, but there is only a limited amount we can change there – mostly, to try and use more efficient systems. If cooling/heating systems in residence halls are more efficient, controllable and intelligently programmed they will consume much less energy. Users are often forced to adopt wasteful practices because their air systems either overheat or over-cool their rooms.

- **Dan Schuster**, Project Engineering Group Manager, Engineering Utilities and Construction Department, Purdue University

1) Could you tell us about the building metering program currently being implemented at Purdue? Specifically:

a) Objectives (beyond just monitoring)

b) Time frame

c) Costs

d) Scope

How do you intend to achieve those objectives?

2) What are viable technologies/solutions that can be implemented on the Purdue campus to reduce energy consumption?

3) What steps are you taking, apart from this program, to lower energy consumption in Purdue buildings?

4) What kind of support/sanction do you receive from the Board of Trustees or the President for energy usage-reduction programs?

5) Who makes conservation plans for Purdue and how can students get involved in that, if at all?

Answers:

1) We have a co-generating power plant (Wade) which supplies most of our buildings on campus with electricity, heated and chilled water. It is approximately 76% efficient in its processes. So we know what the entire campus consumes but not individual buildings.

The first phase of the campus-wide metering program, already underway, will allow us to monitor the consumption of 12 major buildings. This is expected to cost about $ 300,000. Budget constraints limit funding for maintenance and overhaul operations, thus metering takes a backseat to renovation and repair. Meters require maintenance too, so they're not just a one-time expense. Data collection is an issue. Just having a meter is not enough, we need ways to collect, store and analyze data. This also requires dedicated manpower, which we can hardly spare. We have water meters installed on campus and these have a drive-by collection function, so that is a possible method for the electric meters as well.

We have ten million dollars worth of energy-saving projects underway all throughout the state campuses. We have two contractors coming in soon to monitor and analyze building usage, energy consumption and water use patterns. They will do cost-benefit analysis for potential projects, help us maximize the efficiency of existing resources. We have calculated that for an energy-saving project to be viable for implementation here, it has to pay for itself in ten years, keeping in mind operational costs. Siemens is also helping Purdue identify wastage/usage in buildings and ways of reducing them.

An interesting fact, the Purdue grid loses less than 5% (per cycle) of the energy input into the energy/water circulated about campus. This is better than most campuses throughout the nation. Also, Purdue's energy costs per gross square foot are probably cheapest in the Big Ten.

2) Changing housing contracts so that students pay for the electricity they use, rather than the flat housing rates we have today, would be a very effective strategy in my opinion.

We could appoint people on campus as energy advocates – persons who promote conservation among student, faculty and staff through information and persuasion.

Solar panels on the buildings would be financially unviable since they would have a 30-40 year payback period. Wind generation, on the other hand, will be too small-scale and unreliable when put on campus buildings.

3) 90% of the lighting fixtures on campus are either CFLs or high-efficiency bulbs (efficient T8s instead of the older T12s). Many restrooms have sensors which automatically turn off the lights when unoccupied. Some buildings have programmable or digital controls. These use sensors to change the rate of heating and refreshment of air, and turn off the air systems when no occupants are detected.

4) The board of trustees has approved about ten million dollars, as I mentioned earlier. They are also in the process of approving more work at the West Lafayette campus. We intend to ask for three-four million dollars more by the year-end.

The board is forthcoming and supportive for the most part. I can't say anything about the President yet, because she's new.

5) Student movements can achieve a lot. The cheapest conservation is reduction, so we must focus on that. Student can get access to decision-makers and can influence decisions. Students must get involved, because they can really make a big difference.

Decisions for new buildings are often based on sponsor's wishes, state allocations, who pays for what, etc.

Appendix B – Survey

I conducted a survey of 15 students living in residence halls across campus. I tried to get a broad cross-section of respondents to avoid any gender, cultural or location bias in my figures. The questions asked were as follows:

1. How often do you leave the TV on when not watching it (i.e. as background noise, when not in room)?
    a. Never
    b. 1-2 hours per day
    c. 3-5 hours per day
    d. 6-10 hours per day
    e. 11 or more hours per day
2. How likely are you to watch your favorite shows in a group of more that two people?
    a. Never
    b. 1-2 times per week
    c. 3-4 times per week
    d. 5 or more times per week
3. On average, how many hours per day do you keep the lights on in your room?
    a. 0-2 hours per day
    b. 3-5 hours per day
    c. 6-10 hours per day
    d. 11-15 hours per day
    e. 16 or more hours per day
4. How often do you use natural light (i.e. sunlight) during the day as opposed to turning the lights on?
    a. Never
    b. Rarely
    c. Sometimes
    d. As often as possible
5. When you are not using your computer, which of the following do you do?
    a. Leave it on
    b. Put in stand by mode
    c. Put it in hibernation mode
    d. Shut it down
6. If you have air conditioning, at what temperature do you keep your room?
    a. No Control
    b. 60-65 degrees
    c. 66-70 degrees
    d. 71-75 degrees

   e. Above 75 degrees
7. On average, how many hours per day do you run a fan?
   a. Never
   b. 1-5 hours per day
   c. 6-10 hours per day
   d. 11-15 hours per day
   e. 16 or more hours per day
8. Do you run the fan when you are not in the room?
   a. Yes
   b. No

The results of the survey were as follows:

Tally - Residence Hall Survey					
Question #	**A**	**B**	**C**	**D**	**E**
1	9	3	0	2	1
2	4	7	3	1	-
3	1	6	4	2	2
4	3	4	3	5	-
5	8	2	2	3	-
6	1	4	2	6	2
7	8	4	1	0	2
8	7	8	-	-	-