Design, Implementation and Evaluation
Of University Housing Energy Reduction Contests

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ABSTRACT

The University of Dayton (UD) owns over 350 houses. The quality of the housing stock is highly variable. The university charges a uniform housing fee to each student, which includes all utility costs. As a result, students have no incentive to reduce energy use. This is a common scenario; 12.8% of all U.S. households have all or some of their energy costs included in their rent. To address this situation, the student-run Sustainability Club instituted two energy contests to reward households that used the least energy. This paper describes the design, implementation, and evaluation of the contests.

In designing a contest, a principal task was to determine how to quantify behavior-driven energy savings over diverse housing types with a transient occupant population. This paper describes how utility billing data were normalized for occupancy and weather affects to create utility allowances. Household energy use during the contest period was then compared to the utility allowances to determine savings and contest winners. Financial incentives were developed for contest winners.

During the implementation phase, contestants were provided with energy-conservation educational materials and internet-based feedback about how each house was performing. This paper describes the nature of the educational materials and the feedback, and discusses contestant response to these features.

During the evaluation phase, participating houses were compared to a control group of non-participating houses to determine the overall energy savings. Follow-up surveys describe specific actions by contest participants to reduce energy use, and what new habits participants formed.

Introduction

UD owns about 350 residential houses. About 1,700 upper-class students live in these houses. The houses range in age from brand new to about 100-years old. House occupancy ranges from two to 12 persons. In addition, the houses receive new occupants every year. As a result, monthly electricity and gas use for each house is highly variable.

Average annual household electricity use increases with the number of occupants per house (Figure 1). It also varies widely between houses with the same number of occupants. The coefficient of variation of the standard deviation (CV-STD) of annual electricity use in four-person houses is about 38%. This means that electricity use varies from the mean by over 38% in about one third of all houses. Electricity use also varies widely between groups of students that lived in the same house. The CV-STD of annual electricity use in the same house over a three-year period is 33% (Seryak and Kissock, 2004). Thus, the main source of electricity use variation is not a result of house structure or appliance quality, but of behavior. The effect that occupant behavior can have on residential electricity use has been discussed before regarding air conditioning use (Kempton et al., 1992; James et al., 1996). In addition, during non-summer months, weather does not affect electricity use.

Household gas use is relatively insensitive to the number of occupants in a house (Figure 2), but varies widely between houses with the same number of occupants. For example, the CV-STD of annual gas use in four-person houses is about 37%. Unlike electricity, however, the CV-STD of annual gas use in the same house over a three-year period is a relatively low 14%. Much of this variation results from variations in weather from year to year. Thus, in contrast to electricity use, household gas use is highly dependent on the condition of the house and typically relatively independent of occupant behavior (Seryak and Kissock, 2004). However, occupant behavior can have a dramatic affect on both space heating and DHW gas use (Kempton, 1988).

Figure 1. Electricity Use Versus Occupancy

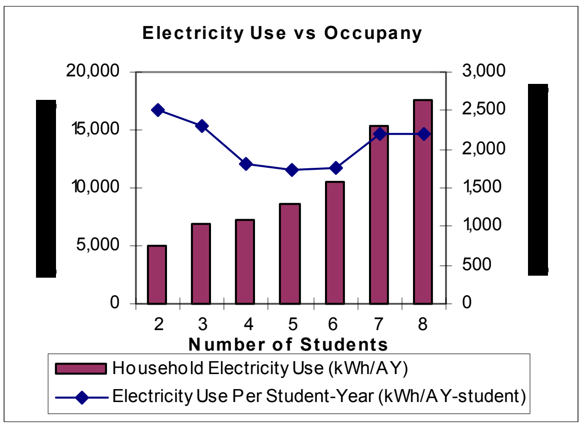
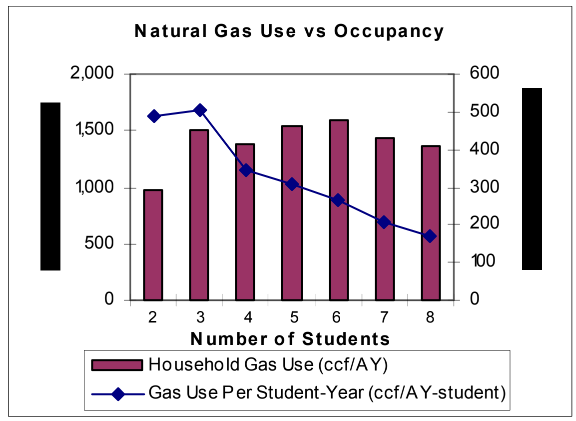


Figure. 2: Natural Gas Use Versus Occupancy



In the past, the university issued utility bills directly to students. Students that were assigned to old, poorly-insulated houses paid much higher gas bills than students assigned to newer, well-insulated houses. In addition to this unfairness, the system was difficult to manage. Thus, the university currently charges a uniform housing fee, which includes gas and electricity costs, to all students living in UD houses. While this has addressed the problem of billing students for something beyond their control (the affects of weather and house quality), it obscured the link between energy use and occupant behavior. As a result, students have no idea how much energy they use and no incentive to reduce energy use. This fosters an energy-ignorant environment. For example, the average UD house uses about 14,100 kWh of electricity and 146 MBtu (million British thermal units) of gas per year, compared to 9,200 kWh and 92 MBtu per year for the average mid-western residential house (DOE, 2002). Thus, the typical UD house uses about 1.5 times as much energy as an average residential house.

Prior to the energy contests, 164 surveys were administered to students in the residential neighborhood. The survey questioned students on behavior, attitudes towards energy conservation, and energy billing. Surveyed student comments include:

- "People in UD housing have no concept of energy use/abuse because they don't get a monthly bill. They do not associate housing costs with energy use."
- "We waste (energy) because we don't directly pay (for it), if we paid we wouldn't use as much." (Seryak, Holloway and Earnhart, 2003)

To address this situation, the student-run Sustainability Club created a contest to reward the houses that use the least energy based solely on the affect of behavior.

Contest Design and Implementation

The contest was designed to influence occupant behavior, and to measure the changes in energy use that may occur as a result of changing behavior. We believed that influencing occupant behavior required incentive, education and feedback. The contest was not specifically designed to test the effects of incentive, education and feedback. However, there was a control group and different levels of education and feedback. This resulted in limited insight into the effects of education and feedback on reducing energy use, which is discussed here.

Measuring changes in energy use due to occupant behavior required identifying other factors that affect energy use, and normalizing for their effect. The design and implementation of influencing occupant behavior, and measuring changes in energy use, will be discussed in turn.

Influencing Occupant Behavior

Contest recruitment and registration. For the first energy contest, participants were recruited indirectly via email and at a registration table in the student cafeteria. This effort resulted in 77 participating houses. This method of soliciting contestants may have resulted in registering houses that were already inclined to use less energy than the typical house. For the second energy contest, Sustainability Club members went door-to-door to register houses. This resulted in registering 170 houses. Generally, students appeared more inclined to register for the contest when directly solicited door-to-door than through indirect email and registration solicitation. Door-to-door solicitation was perceived as a more random method of soliciting clients. Table 1 shows the number of houses registered for each contest as well as the percentage of participating houses as a function of total houses.

Table 1. Number and Percentage of Houses Registered for the Energy Contests

Energy Contest	Solicitation Method	Registered Houses	Participating Students	Registered Houses /Total Houses (%)
Energy Contest I	Indirect (email, table)	77	381	22%
Energy Contest II	Direct (door-to-door)	170	735	49%

Incentive. As noted above, without incentive to reduce energy use, an energy-wasteful environment is created. Stern et al. (1986) discussed the effectiveness of incentives for residential energy conservation. To create incentive, within a month of the end of each energy contest, about $2,000 was distributed in refunds by the Residential Services and Residential Properties departments. The total refund amount of $2,000 was agreed upon by the UD administration and Sustainability Club members, and was less than what the energy contest saved. This created a revenue-positive activity, or monetary incentive, for UD helped gain university support. A successful contest must provide incentive to all parties involved.

Refunds were deposited in the students' Bursar Accounts. The refunds could be distributed to the students electronically, limiting costly hours of administration support. The refunds were constrained to be between $10 and $25 per person. Refunds less than $10 could not justify the time spent issuing the refund. Refunds over $25 required special tax paperwork. The $2,000 total refund amount was distributed to the top 30 houses in increments of $10, $15, $20, and $25 per person. Sustainability Club students determined contest rankings and refund amounts for winning students, limiting administration support to refund distribution. Designing the contest around administrative constraints, and student management of the contest reduced the time commitment of the administration, further encouraging UD to support the contest.

Education. Incentives alone are not completely effective in changing behavior. For example, the second floor of many houses gets too warm in the winter. Because students are unaware of how to position duct dampers, many households control the upstairs temperature by opening second floor windows. Thus, we presumed that educating students on how to reduce energy was vital to the success of the contest. For the first energy contest, all students were invited to a half-hour educational meeting. The contest objective and rules were explained, and students were educated on pollution, global warming, and non-renewable resources. Students were given a tip sheet with ways to reduce energy use. For the second energy contest, due to increased participation, students were simply given the same tips sheet at the time of registration, but did not attend a meeting (Seryak, Holloway and Earnhart, 2003). Thus, the level of education was much greater in the first contest. This may have resulted in reduced gas savings during the second energy contest. The tips included:

- Turn off appliances/lights when not in use.
- Turn off computers if they will not be used for a long time.
- Enable the "sleep" mode on computers.
- Make sure all windows and doors are shut tightly.
- Adjust vent or duct dampers rather than opening windows in winter.
- Turn down thermostats at night and when the house is unoccupied.
- Turn down thermostats and water heater settings when on vacation.

Feedback. At the end of each monthly billing period, contestant rankings and savings were posted on the Sustainability Club website (UDSC, 2003). The savings were shown in terms of kWh, ccf, lbs CO_2 emissions and dollars. For the first energy contest, the website received 200 hits after each posting. For the second energy contest, over 500 hits were received after each posting. Assuming each hit was from a separate student, the number of students that checked feedback for the first and second energy contests were 52% and 68% respectively. Thus, when supplied with a feedback mechanism, students will check their progress in reducing energy.

Internet feedback occurred after each billing period for the second energy contest, while only during the last month of the first energy contest. Average electricity savings were greater in the second contest than in the first contest. This may be a result of increased feedback frequency during the second contest. Reducing electricity use does not appear to require as much education as reducing gas use. Most students understand that turning off lights and appliances reduces electricity. However, the consistent feedback reminds and encourages students to change their habits.

In addition to providing feedback for students, UD administration was consistently updated with estimates of energy savings from the energy contests, as well as other energy reduction efforts sponsored by the club. This kept the university informed, and helped build a relationship of trust between club members and administration.

Ranking Household Energy Use

Electricity allowances. Inspection of electricity billing data indicates that household electricity use is primarily affected by occupant behavior, the number of occupants per house, and whether the house was occupied for the entire month. If the house was occupied for the entire month, we called it "fully-occupied"; if it was occupied for only part of the month due to vacations, we called it "partially-occupied". However, electricity is not affected by weather during the billing periods when school is in attendance. In addition, because not all houses have air conditioning, it was categorized as a "non-allowable end use" (HUD, 1998). Thus, houses that use air conditioning were penalized in the energy contest.

Because the contest sought to reward occupants for reducing energy use by changing their behavior, it was necessary to remove the effects of the number of occupants and whether the house was fully or partially occupied. To do so, the houses' billing data was segregated into "allowance categories" based on the number of occupants and on whether the billing period was fully or partially-occupied. We developed indices of typical household electricity use for houses based on the allowance categories.

These indices are similar to "utility allowances" used by Public Housing Authorities (HUD, 1998), and we have adopted this nomenclature. The electricity allowance for each category of house was calculated as the mean monthly electricity use for that category of house over three years. The electricity allowances for fully and partially-occupied periods for two through eight-person houses are shown in Table 2.

Table 2. Fully and Partially-Occupied Electricity Allowances for 2 to 8 Person Houses

Occupancy Level	Fully-occupied Electricity Allowance (kWh/day during Oct., Nov., Dec., Feb. and Mar.)	Partially-occupied Electricity Allowance (kWh/day during Jan., Apr., May, Aug)
2 person	20.5	17.4
3 person	26.7	20.8
4 person	30.9	23.2
5 person	36.0	27.0
6 person	40.9	30.9
7 person	52.3	40.4
8 person	72.7	56.5

Individual houses were then ranked according to the difference between the appropriate allowance and actual electricity use. For example, average electricity use in the four-person house at 409 Lowes was 28.8 kWh/day during fully-occupied months and 19.9 kWh/day during partially-occupied months. Thus, for 409 Lowes, the deviations from the utility allowances were:

D_{elec} = (Utility Allowance – Actual Consumption) (kWh/day) x N (days/month) / P (people)
$D_{fully\ occupied}$ = (30.9 – 28.8) kWh/day x 30 days/mo / 4 persons = 15.8 kWh/person-mo
$D_{partiallyoccupied}$ = (23.2 – 19.9) kWh/day x 30 days/mo / 4 persons = 24.8 kWh/person-mo

For houses participating in the contest, deviations ranged from –232 kWh/person-month to 149 kWh/person-month. Thus, this house would fall near the middle of the range.

Household electricity use could also be compared to baseline electricity use determined by an electrical equipment survey, or individual baseline electricity load profiles for each house. However, neither of these methods is advantageous in this situation. Creating a baseline electricity load based on electrical equipment requires so much time as to be prohibitive. In addition, electrical equipment condition is not a main factor in the variance of residential energy use. As noted before household electricity use varies so much from year to year, that creating a baseline electricity use profile based on a house's historical use would be inaccurate.

Natural gas allowances. Inspection of natural gas billing data indicates that household gas use is primarily affected by occupant behavior, the thermal efficiency of the envelope and heating equipment, domestic hot water (DHW) and cooking, and outdoor weather conditions. Because the contest sought to reward occupants for reducing energy use by changing their behavior, it was necessary to remove the effects of houses' thermal efficiency and changing weather. To do so, we developed a statistical three-parameter heating (3PH) model of space heating, DHW and cooking gas use for each house using billing and outdoor air temperature data (Kissock, Reddy and Claridge, 1998). The models were constructed using two years of historical gas billing data and average daily temperature data (UD/EPA, 2000).

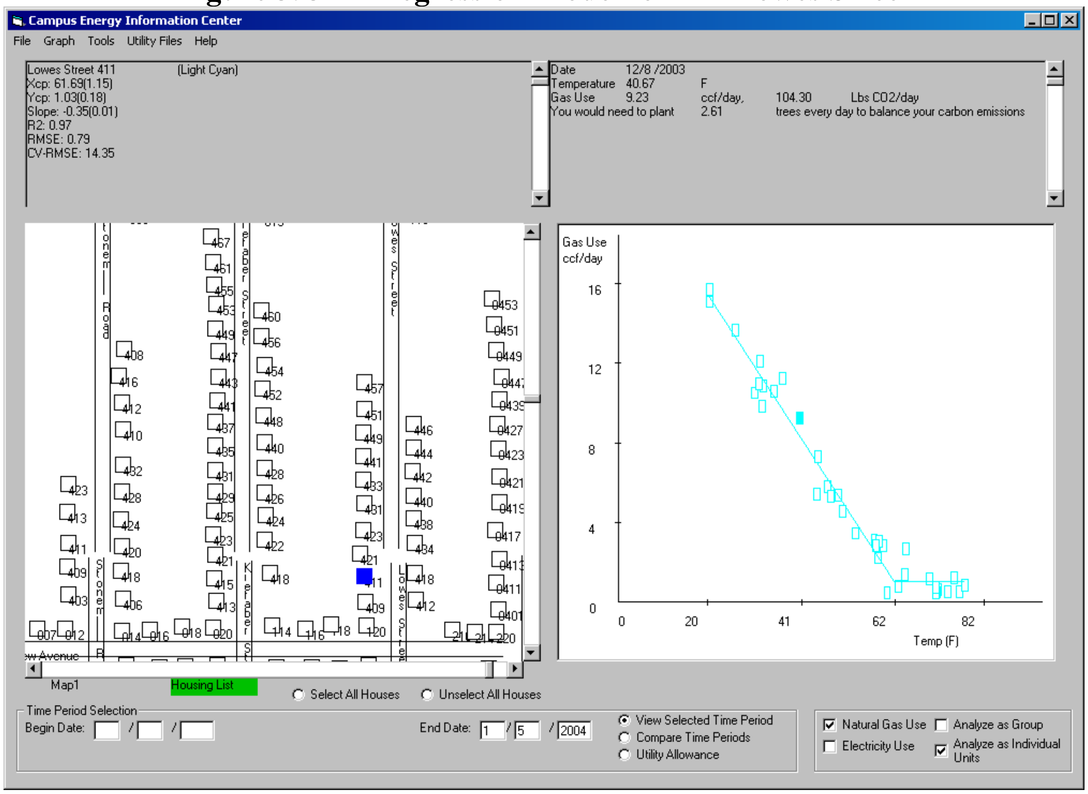
Figure 3 shows the software developed to track and analyze energy use of large campuses of buildings. The software was also used to manage the energy contests (Seryak, 2003). The left window shows a map of the student neighborhood with individual houses. A data base of household energy use is linked to this view. The window on the right displays various views of the data. In Figure 3, the right window shows a 3PH regression model of gas use versus outdoor air temperature for the house at 411 Lowes. The gas allowance for this building is calculated using the coefficients of the 3PH regression model with the following equation:

$$\text{Gas (ccf/day)} = \text{Ycp (ccf/day)} + \text{Slope (ccf/day-F)} \times [\text{Xcp (F)} - \text{Toa (F)}]^{+}$$

where Ycp, Xcp and Slope are regression coefficients and Toa is the average outdoor temperature for the billing period. The + indicates that the parenthetical value is only used when positive. Each regression parameter can be interpreted as a physical characteristic of the house. The Ycp represents the DHW and cooking baseload gas use. The Xcp represents the house balance-point, and the Slope represents the UA-value of the house. Toa is found from the average daily temperature data.

The model has a CV-RMSE of 14.4% and an R^2 value of 0.97 indicating a very good fit to the data. Gas allowances were created for each house based on regression equations. Similar fits were achieved in virtually all cases.

Figure 3. 3PH Regression Model for 411 Lowes Street



Individual households were then ranked according to the difference between actual gas use and the gas allowance. For example, actual 411 Lowes gas use during this period was 9.23 ccf per day. Thus, the deviation from the gas allowance would be about:

D_{gas} = (Utility Allowance – Actual Consumption) (ccf/day) x N (days/month) / P (people)
D_{gas} = (9.83 -9.23) ccf/day x 30 days/month / 6 people = 3 ccf/person-mo

Contest Results and Evaluation

Energy Contest I: Quantifying Electricity Savings

Pre-disposition to energy-efficient behavior and subsequent electricity savings can be determined by constructing normal probability plots of deviations from utility allowances (D_{elec}) of the contest and control houses. The control group consisted of all UD houses not participating in the contest. Figures 4 through 9 show probability plots and regression lines of the contest and control houses' deviations from utility allowances. For each graph cumulative normal probability marks the y-axis and deviation from the electricity allowance marks the x-axis. Each data point represents one house's deviation from its electricity allowance. Plots are shown for the non-contest months of November 2002 through January 2003, and for the contest months from February 2003 through April 2003. In all cases, the contest houses' regression line is lower than the control houses'.

Figure. 4. November 2002

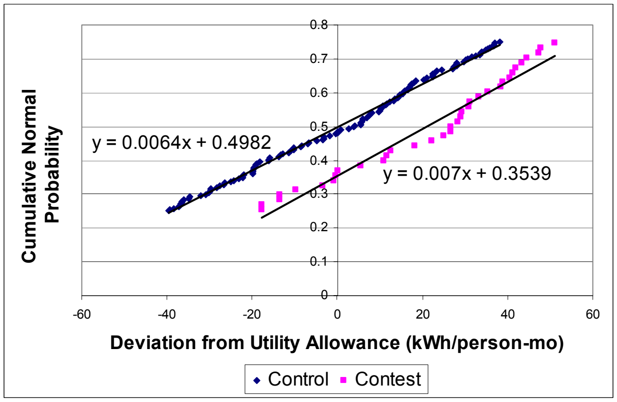


Figure. 5. December 2002

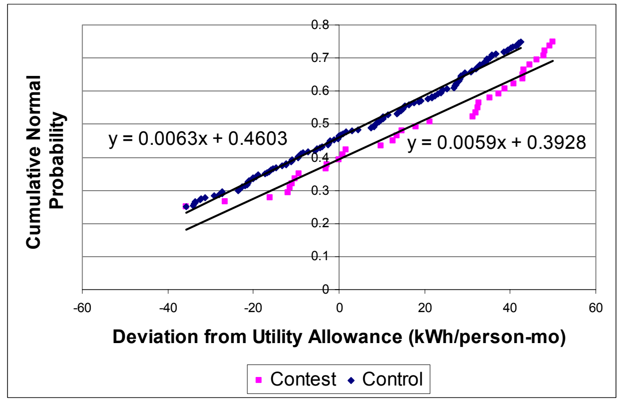


Figure. 6. January 2003

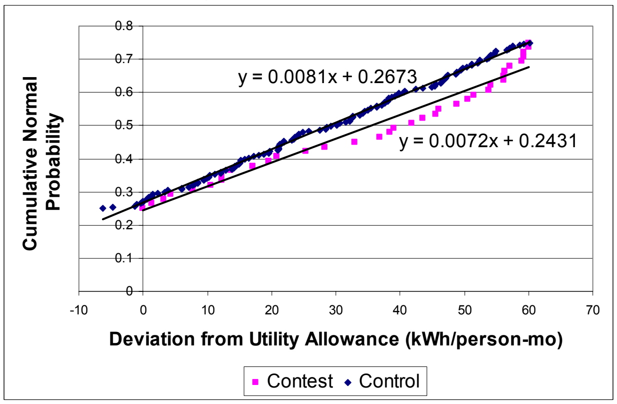


Figure. 7. February 2003

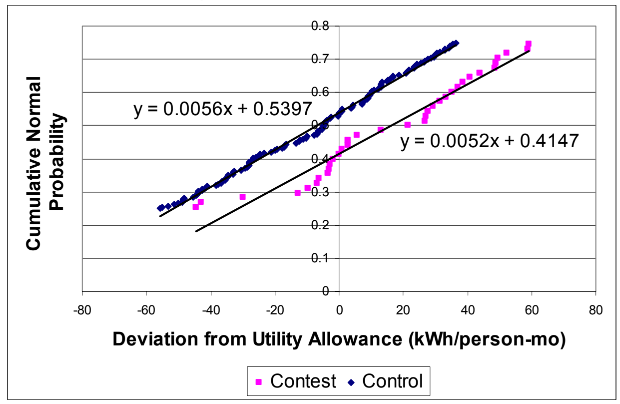


Figure. 8. March 2003

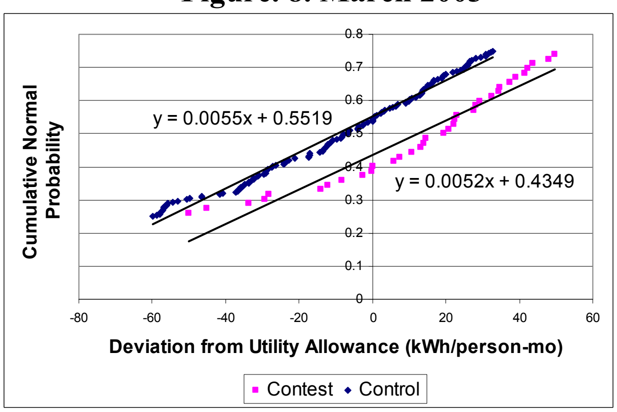
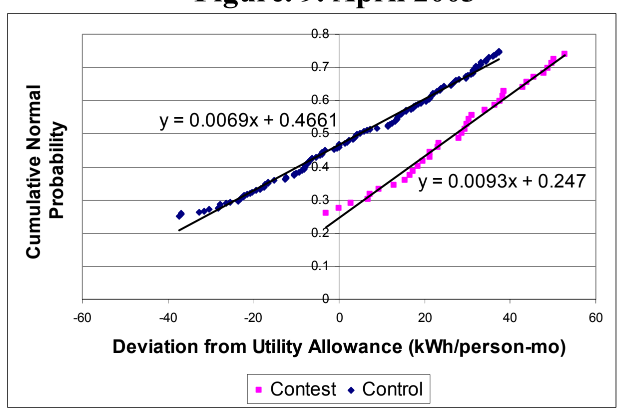


Figure. 9. April 2003



Using the equations of the regression lines, we can infer certain characteristics of the sample populations (Montgomery, 2001). The mean deviation, $D_{elec,mean}$, of the population can be calculated from the regression coefficients and 50th percentile as:

50th percentile = 0.5 = slope x $D_{elec,mean}$ + y-intercept.

The fact that the regression lines for contest houses are lower than the regression lines for the control houses, even before the contest begins, indicates that the contest houses were pre-inclined to use less electricity than the control group. This supports the idea that indirect solicitation results in a non-random, or self-selected, group. The mean deviations of both groups are shown for each month in Table 3 below. Positive values indicate that the mean house used less electricity than their utility allowance, while negative values indicate that the mean house used more electricity than their utility allowance.

Table 3. Contest and Control Houses' Mean Deviation from Electricity Allowance

	November	December	January	February	March	April
Group	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)
Contest	20.9	18.2	35.7	16.4	12.5	27.2
Control	0.3	6.3	28.7	-7.1	-9.4	4.9
Difference	20.6	11.9	7.0	23.5	22.0	22.3

Based on the data in Table 3, the average difference ($D_{elec,mean}$)for non-contest and contest months was 13.2 and 22.6 kWh per person-month, respectively. To quantify savings, the difference in $D_{elec,mean}$ for the contest months is compared to the difference in $D_{elec,mean}$ for non-contest months. The electricity savings during the contest were about 10,744 kWh, or $967.

In Figures 4 – 9, the slope of the regression line indicates the variance of the population. Thus, the increased steepness of the contest line during April indicates that the variance declined. Close inspection of the data indicates that the households with the least success reducing electricity use in March became more successful in April. We believe this is because the first internet rankings were posted at the end of March, and contestants used this feedback to improve their energy use practices.

Energy Contest I: Quantifying Gas Savings

3PH regression models were created of the cumulative monthly gas use of the contest and control houses. Again, the control group consisted of all UD houses not participating in the energy contest. Essentially, a group gas allowance was created for the contest and control groups. Actual and predicted gas use, with deviation and the CV of the deviation are shown in Table 4 below. The November through December 2002 results are from before the contest, and the February through April 2003 results are from during the contest. January 2003 was not considered, as an experimental thermostat turndown program was not equally distributed among the contest and control groups, thus altering the data.

Table 4. Gas Savings Evaluation

Billing Period Ending	Contest Houses				Control Houses			
	Predicted (ccf/day)	Actual (ccf/day)	Deviation (ccf/day)	CV-Deviation (%)	Predicted (ccf/day)	Actual (ccf/day)	Deviation (ccf/day)	CV-Deviation (%)
Nov-02	464.7	373.6	91.1	19.6%	1656.2	1357.3	298.9	18.0%
Dec-02	731.5	649.7	81.9	11.2%	2649.8	2465.1	184.7	7.0%
Feb-03	995.7	886.6	109.2	11.0%	3633.5	3493.2	140.3	3.9%
Mar-03	870.1	798.2	71.9	8.3%	3165.9	3110.5	55.4	1.7%
Apr-03	460.5	423.8	36.7	8.0%	1640.6	1629.8	10.8	0.7%

For November 2002, the contest and control groups' total gas use deviated from predicted use by 19.6% and 18%, respectively. In December 2002, the contest and control group's total gas use deviated from predicted by 11.2% and 7%, respectively. Thus, both group's gas used deviated from predicted use due to factors other than outdoor temperature. However, the deviation value for both groups was similar. Thus, the factors that caused the deviation were likely equally distributed among the contest and control group. Such factors could have been solar radiation or wind speed.

The average incremental deviation for the contest group was 2.9%. This suggests that the contest group was only slightly pre-inclined to use less gas than the control group. During the energy contest, the average incremental deviation for the contest group was 7%. Thus, during the contest period, something other than the usual factors affected gas use among the contest houses, while not the control houses. This factor was likely behavioral changes. The gas savings during the energy contest were 2,861 ccf or $2,146.

Energy Contest II: Electricity Savings

Figures 10 through 13 show normal distributions of the contest and control groups during the second energy contest. The figures are for the non-contest month of October 2003, as well as contest months, November and December 2003, and January 2004.

Figure. 10. October 2003

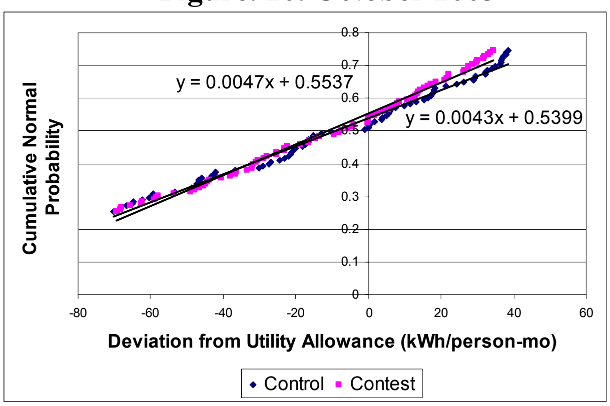


Figure. 11. November 2003

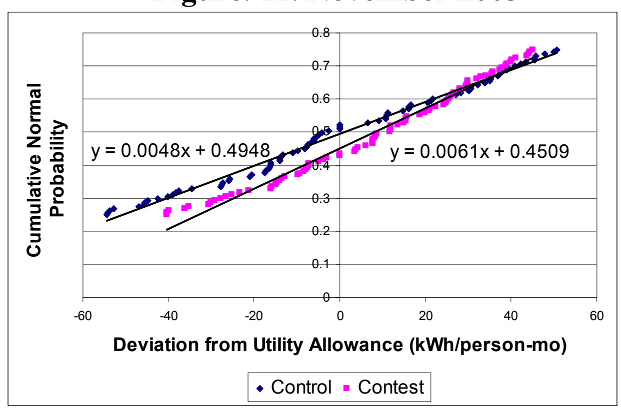


Figure. 12. December 2003

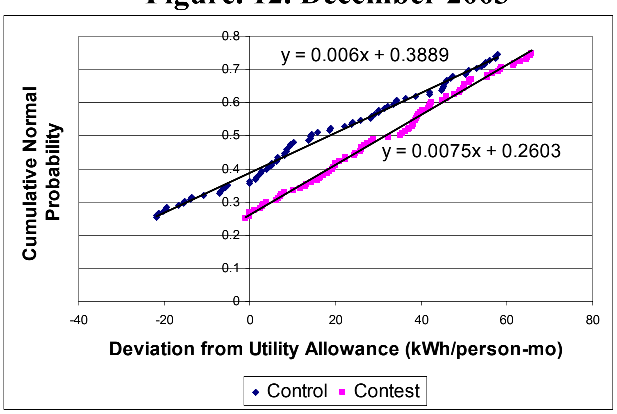
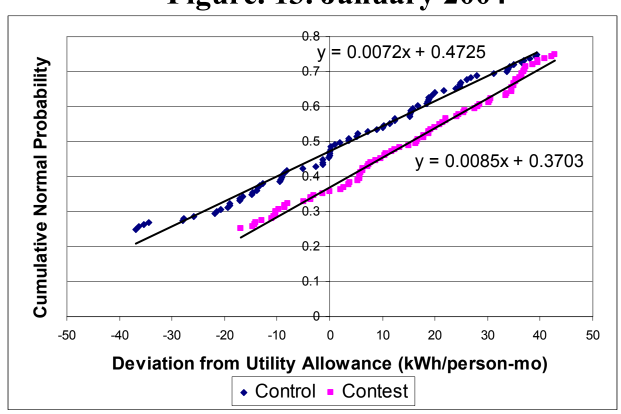


Figure. 13. January 2004



Earlier, we postulated that the direct door-to-door solicitation of participants for the second contest would result in a more random group of participants. This may be supported by the normal probability plot for October 2003, where the contest and control samples savings distributions are virtually identical. It is unclear whether this is because of the solicitation method, or because a larger sample of houses was registered. However, the larger sample of houses was likely a result of the solicitation method. Thus, the randomness of the contest group is dependent on solicitation method, whether directly or indirectly.

In the figures above, it is visually apparent that the contest sample savings are larger in December and January than during November. We believe that this increase occurred because the savings results were first posted on the internet in late November. This suggests that not only did the participating houses reduce their energy use, but that they reduced their energy use more after receiving feedback. The mean deviations from utility allowances, $D_{elec,mean}$, of both groups are shown in Table 5 below.

Table 5. Contest and Control Houses' Mean Deviation from Electricity Allowance

	October	November	December	January
Group	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)	Delec,mean (kWh/person-month)
Contest	-11.4	8.0	32.0	15.3
Control	-9.3	1.1	18.5	3.8
Difference	-2.1	7.0	13.4	11.4

The difference between Delec,mean for the non-contest month of October was about -2.1 kWh per person-month. The average difference in Delec,mean for the three contest months was 10.6 kWh per person-month. The electricity savings during the contest were 28,224 kWh or $2,540.

Energy Contest II: Gas Savings

Actual and predicted gas use for the second energy contest, with deviation and the CV of the deviation, are shown in Table 6 below. As before, the contest started after the October 2003 billing period.

Table 6. Gas Savings Evaluation

Billing Period Ending	Participating Houses				Non-participating Houses			
	Predicted (ccf/day)	Actual (ccf/day)	Deviation (ccf/day)	CV-Deviation (%)	Predicted (ccf/day)	Actual (ccf/day)	Deviation (ccf/day)	CV-Deviation (%)
Oct-03	321.7	345.7	-24.0	-7.5%	358.9	366.6	-7.7	-2.2%
Nov-03	533.2	465.1	68.1	12.8%	594.6	533.7	60.9	10.2%
Dec-03	1100.5	1054.7	45.8	4.2%	1226.5	1115.3	111.2	9.1%
Jan-04	1489.0	1313.0	176.0	11.8%	1659.4	1470.9	188.5	11.4%

During October 2003, the contest and control group's total gas use deviated from the allowances by -7.5% and -2.2%, respectively, a difference of -5.3%. This suggests that the contest group was pre-inclined to use more gas than the control group. During the energy contest, the average incremental deviation for the contest group was -1.9%. The gas savings during were 3,185 ccf or $2,867.

Total and average electricity and gas savings, and percent reduction from average UD house use for each energy contest are shown in Table 7.

Table 7. Energy Contest Net Total and Average Electricity and Gas Savings

	Energy Contest 1				Energy Contest 2			
	Elec. (kWh)	Gas (ccf)	Lbs CO_2	Savings ($)	Elec. (kWh)	Gas (ccf)	Lbs CO_2	Savings ($)
Total Savings (/3-month contest)	10,744	2,861	57,040	$3,113	28,224	3,185	100,906	$5,407
Ave. Savings (/mo-house)	47	12.4	247	$13.50	55	6.2	197	$10.50
Average Total UD House (/mo-house)	1,175	182.5 (8 mo)			1,175	182.5 (8 mo)		
% reduction from Ave. Use	4%	6.8%			4.6%	3.4%		

Participant Feedback

When asked what specific actions they took to reduce energy use, students responded:

- "We turned the thermostat down and redirected some vents so the heat would flow more evenly throughout the house."
- "We turned lights off and turned down the heat."
- "We turned down our water heater, and kept mini fridges on a lower setting."

When asked what habits were formed as a result of this contest, students responded:

- "I am more conscious about keeping the electricity off when I am not in the room."
- "I still make an effort to turn the lights off when I leave."
- "I put lids on pots when boiling and cooking."

Conclusions

About 12.8% of all US households have all or some of their energy costs included in their rent (DOE, 1993). Thus, the situation at UD, in which the link between energy use and occupant behavior is not well understood is quite common. The energy contests were designed to help students understand this link and determine whether occupant behavior could measurably reduce energy use.

The two energy contests saved over $8,000 in energy costs. The average contestant household reduced energy use about 4%. This demonstrates that occupant behavior can be influenced to reduce energy use. In addition, participant feedback suggests that energy-efficient habits were formed by participants. In our view, the ingredients of a successful energy-reduction program include education, feedback and incentive to participants. Data analysis software and the internet were essential tools for providing quick feedback to contest participants. The success of the energy contests presented here suggests that greater education, larger incentives and quicker feedback could influence occupant behavior even more. In addition, this paper suggested methods to identify and quantify electricity and gas savings due solely to behavioral changes.

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