OCCUPANCY AND BEHAVIORAL AFFECTS ON RESIDENTIAL ENERGY USE

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ABSTRACT

The University of Dayton (UD) currently owns about 350 residential homes that house nearly 1,700 students. House quality and number of occupants affect household electricity and gas use. In an effort to charge students fairly, the university charges each student the same amount for housing costs, even though the cost of energy may vary significantly from house to house.

Unfortunately this billing policy does not account for occupant behavior, fostering irresponsible energy use.

This paper analyzes energy use characteristics in relation to number of occupants, time of occupancy, weather, house structure quality, and occupant behavior. Building energy informatics software packages were used to help predict the energy use of a house for typical occupant behavior. Case studies were analyzed with these methods, and occupant behavior variations are presented.

1. INTRODUCTION

UD owns about 350 residential houses, a mixture of old, renovated, and new homes.

According to 2001-2002 utility billing data, UD's student neighborhoods used about 470,000 ccf of natural gas and 2,970,000 kWh of electricity during the nine month period of 9/13/01 to 5/15/02. These amounts are equivalent to about $600,000 and resulted in over 6,000 tons of CO_2 emissions.[1,2] The average student used $375 of energy, resulting in 7,000 pounds of CO_2 emissions.

Electricity use in UD houses increases with the number of occupants. But, it also varies widely between houses with the same number of occupants due to behavior.

Gas use is not as sensitive to the number of occupants in a house. However, gas use varies widely between houses with the same number of occupants, and between academic years (AY) of the same house due to behavior.

Wide variation in occupant behavior makes it difficult to predict how much electricity or natural gas a house should use. Nonetheless, understanding typical occupant behavior is necessary for a fair, unbiased, and effective billing policy. By using building informatics and energy simulation software, combined with occupant interviews and visits to the residences, a more comprehensive perspective is achieved.

Optimally, the method to charge students for their energy use should be incorporated into user-friendly software, so UD could bill students based on their behavior.

2. ELECTRICITY USE

2.1 Number of Occupants

Figure 1 shows household electricity use during the academic year (AY) versus the number of occupants per house. Electricity use increases as the number of occupants per house increases. However, electricity use per student is significantly lower in four, five and six-person houses than in other occupancy levels.

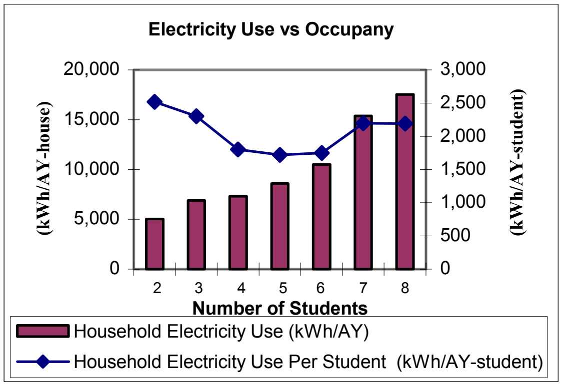

Fig. 1: Electricity use versus occupancy.

2.2 Time of Occupancy

Figure 2 shows 19 months of average daily electricity use in four and six person houses. The electricity use follows a distinct pattern. The partially-occupied periods of January, April, and May have low consumption. Electricity is virtually identical during the fully-occupied periods of February, March, October, November and December. Use drops again in June, when most students are absent. Through July and August, use increases due to air-conditioning in occupied houses. Consumption peaks during September when all students have returned, and warm temperatures encourage air conditioning. The pattern repeats itself for the next 12 months of billing data, with the exception of October 2003 due to warm temperatures and air-conditioning. The trends are the same in both four and six person houses, indicating that the electricity use trend is independent of house size.

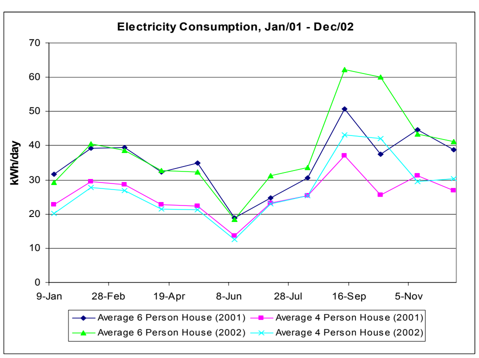

Fig. 2: Electricity consumption trends for 4 and 6-person houses.

Based on the trends identified above, electricity use can be divided into four periods with different energy use characteristics. The periods are the fully-occupied period (Feb., Mar., Oct., Nov., Dec.), the partially-occupied period (Jan., Apr., May.), the air-conditioned occupied period (Sept.), and summer months (June, July, Aug).

2.3 Occupant Behavior

We have shown that the number of occupants and times of occupation affect energy use. Even with these factors accounted for, there is wide variation in electricity use.

Figure 3 shows monthly electricity use over a 19-month period at one household, 449 Kiefaber, compared to the average electricity use for four-student houses. During the first academic year, from January 2001 to May 2001, the students used much *more* electricity than the average house. During the summer of 2001, the house was probably unoccupied. During the next academic year, from September 2001 to May 2002, a new group of students occupied the house and used much *less* electricity than the average house. During the final summer, from June to July 2002, the house was occupied and air-conditioned.

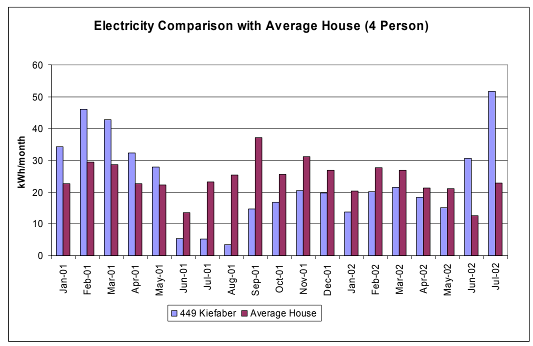

Fig. 3: Electricity use at 449 Kiefaber.

Figure 4 shows electricity use for a different house, 453 Kiefaber, versus average electricity use for a 4-person house. The electricity consumption pattern is reversed compared to 453 Kiefaber in Figure 3.

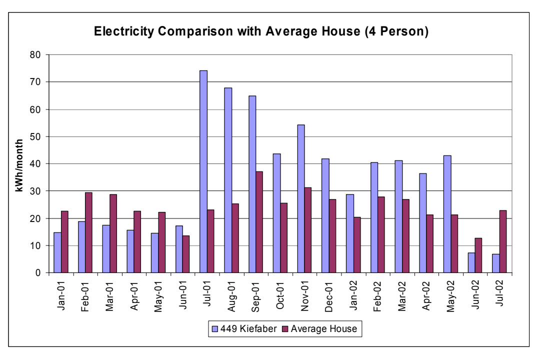

Fig. 4: Electricity use at 453 Kiefaber.

Figure 3 and Figure 4 demonstrate that electricity use variation is not due solely to weather trends and differences in housing structure, but also occupant behavior.

Table 1 shows average household electricity use, standard deviation, minimum and maximums for each occupancy level of housing in kWh per month. The coefficients of variation of standard deviations are always over 20%, showing the wide variability of electricity use between houses of similar occupancy in the same AY.

TABLE 1: ELECTRICITY VARIABILITY BETWEEN HOUSES

Occupancy	Average Household Electricity Usage (kWh/month)	Standard Deviation (kWh/month)	Coefficient of Variation of STD %	Minimum (kWh/month)	Maximum (kWh/month)
2	560	130	0.23	266	931
3	767	220	0.29	492	1,200
4	813	305	0.38	353	2,010
5	956	236	0.25	442	1,677
6	1,165	376	0.32	338	2,275
7	1,709	558	0.33	824	2,522
8	1,949	419	0.21	1,499	2,491

Electricity use for three AY's were compared for individual houses. Table 2 shows the average use, average standard deviation and the maximum standard deviation from year to year for each occupancy level. The coefficients of variation of standard deviation between groups of students for a particular house are almost always above 20%, demonstrating that wide variability of electricity use between different groups of students is not solely due house structure or equipment.

TABLE 2. VARIABILITY WITHIN HOUSES

Occupancy	Average Household Electricity Usage (kWh/month)	Average Standard Deviation Between AY Averages (kWh/month)	Average Standard Deviation Between AY /Average Electricity Use %	Maximum Standard Deviation Between AY Averages (kWh/month)
2	560	149	0.27	309
3	767	191	0.25	384
4	813	268	0.33	917
5	956	260	0.27	994
6	1,165	290	0.25	875
7	1,709	297	0.17	729
8	1,949	420	0.22	775

3. NATURAL GAS USE

3.1 Number of Occupants

Figure 5 shows AY household and student gas use versus number of occupants. In contrast to electricity use, houses with higher numbers of occupants do not use more natural gas than houses with fewer occupants, implying that gas use is influenced more by house characteristics than occupancy level. Gas use per student falls off dramatically as the occupancy of the house increases, due to more shared space heating among students.

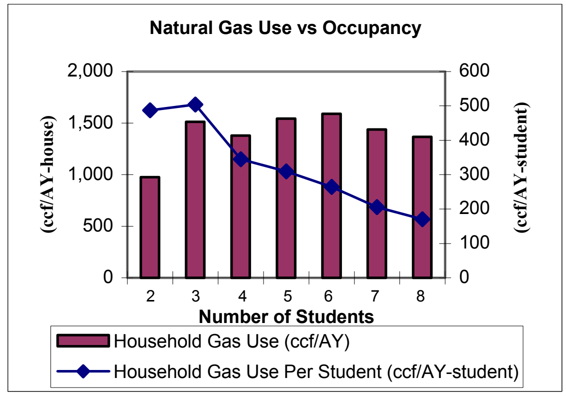

Fig. 5: Natural gas use versus occupancy.

3.2 Time of Occupancy

Figure 6 shows average monthly temperature and natural gas use in four and six person houses over a period of 24 months. As expected, natural gas use increases during cold weather and decreases during warm weather. The non-zero summer gas use is attributed to hot-water heating.

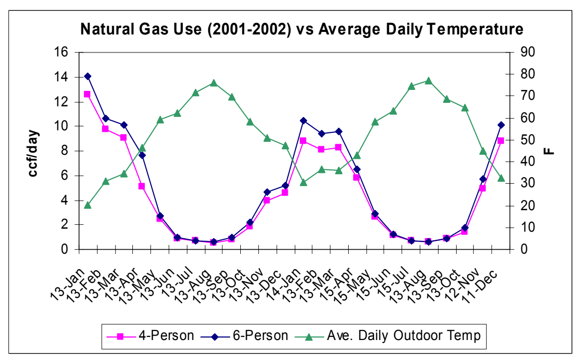

Fig. 6: Average monthly temperature and natural gas use in four and six-person houses

3.3 Occupant Behavior

Table 3 shows average household gas use, standard deviation, minimum and maximums for each occupancy level. The coefficients of variation of standard deviations are always over 25%, showing the wide variability of gas use between houses of similar occupancy in the same AY, due to house characteristics.

TABLE 3. GAS USE VARIABILITY BETWEEN HOUSES

Occupancy	Average Household Gas Usage (ccf/month)	Standard Deviation (ccf/month)	Coefficient of Variation of Standard Deviation %	Minimum (ccf/month)	Maximum (ccf/month)
2	975	548	0.56	320	2,627
3	1,512	590	0.39	743	3,493
4	1,391	514	0.37	359	4,315
5	1,545	472	0.31	828	3,828
6	1,592	451	0.28	318	2,867
7	1,433	779	0.54	602	2,587
8	1,294	718	0.55	419	2,272

4. QUANTIFYING CHANGES IN HOUSE ENERGY USE

4.1 Electricity Use

To accurately describe the affect of behavior on electricity use, the occupancy level and occupied period should be taken into account. Electricity use should not be compared to the previous occupants' behavior, but to average electricity use for a chosen occupancy level and occupation period.

Thus, mean models from fully-occupied periods, and one from partially-occupied periods should be generated for each occupancy level. Fully-occupied periods, air-conditioned occupied periods, and summer months will be compared to mean models of average fully-occupied periods. Comparing air-conditioned periods to fully-occupied periods means that students will "pay" for their air-conditioning. Partially-occupied periods will be compared to mean models of average partially-occupied periods. Figure 7 shows mean fully-occupied period use for four-person houses (bottom), versus mean fully-occupied period use for 453 Kiefaber (top).

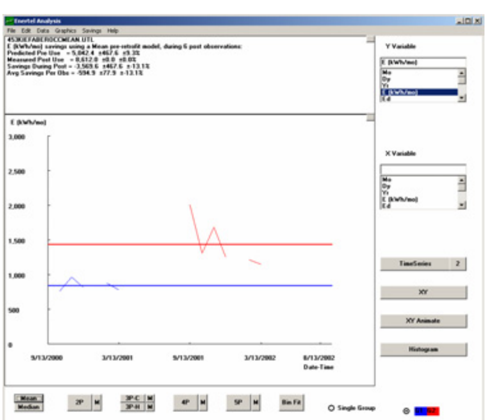

Fig. 7: Fully-occupied period mean comparison

Figure 7 shows that compared to the typical four-person house, the occupants of 453 Kiefaber used 595 kWh per month more for fully-occupied periods. Not shown, 453 Kiefaber used 456 kWh per month more for partially-occupied periods, a total of 4,938 kWh more for the AY.

4.2 Natural Gas Use

Knowing that gas use is dependent on house characteristics, each house must be considered individually. Typical gas use for a specific house can be determined from previous gas billing data.

Figure 8 shows two three-parameter models for the residents of 327 Kiefaber, one for the 2000-01 AY, and one for the 2001-02 AY. A three-parameter model consists of two intersecting lines. The flat line represents gas use for heating water. The sloped line is the amount of gas needed to heat the home at a specific outdoor temperature. The intersection of these two lines is the balance-point temperature of the house, the maximum outside temperature for which the house needs heating.[3] The 2001-02 residents, shown to be the steeper three-parameter model to the right, actually used 738 ccf per AY more than the prior residents would have for similar weather patterns.

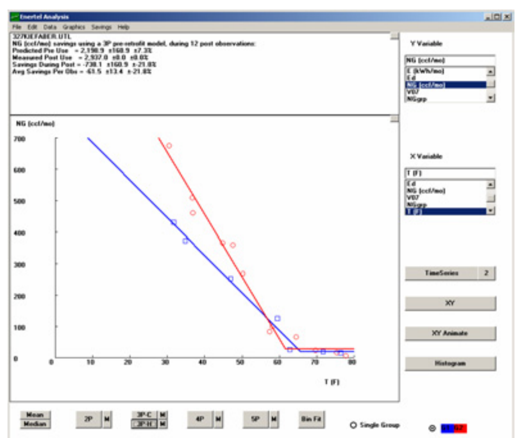

Fig. 8: 327 Kiefaber actual gas use

The steeper left slope of the house during the 2001-02 AY indicates that the house structure or the student's behavior changed.

In general, residents are unaware that dampers exist in the ductwork in their basement. Thus, to correct uncomfortable 2nd floor temperatures, the thermostat is often turned down, and the 2nd floor windows are opened. Turning down the thermostat would decrease the balance point, and opening windows would increase infiltration which in turn would increase the left-side slope. Both of these changes are shown in Figure 8.

To verify this theory, we simulated energy use on an hour by hour basis, visited the residence, and interviewed current and past residents. We simulated and calibrated energy use for 327 Kiefaber to utility and weather data for the 2000-01 AY. Then, we changed the thermostat set-point in the simulation model from 73 F to 71 F, and infiltration rate from 1 ACH to 2.5 ACH, and simulated energy use for the 2001-02 AY.

Figure 9 shows a three-parameter model of the simulated gas use verses outside temperature for 327 Kiefaber. The steeper three-parameter model on the right is for the 2001-02 AY.

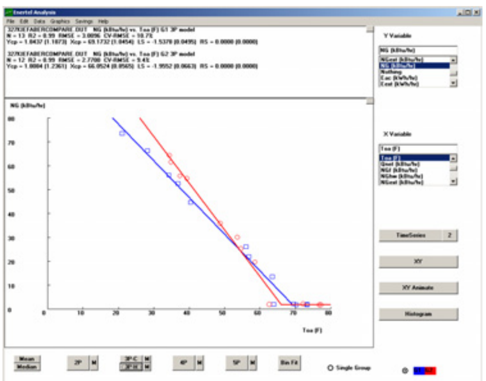

Fig. 9: 327 Kiefaber simulated gas use

The similarity between Figures 8 and 9 strongly suggest that the decrease in natural gas use was due to a lower thermostat setting and increased infiltration. Upon visiting the home and consulting with the current residents, it was discovered that the 2^{nd} floor gets extremely warm. To correct this, the thermostat was turned down. In addition, we discovered a two-inch gap between a second floor window and the house frame. Based on interviews with 2000-01 residents, this gap was not present during previous AY's. Thus, our theory of a warm second floor, with increased infiltration and lower thermostat setting is verified through simulation and observation.

Not all year-to-year comparison of gas use is this disparate. Figure 10 shows monthly natural gas use verses outdoor temperature for the 2000-01(right) and 2001-02(left) AY's for 625 Irving. The difference in the balance-point could be a difference in thermostat setting between years.

The 2001-02 residents consciously set their thermostat to the lowest temperature possible, while still maintaining comfort.

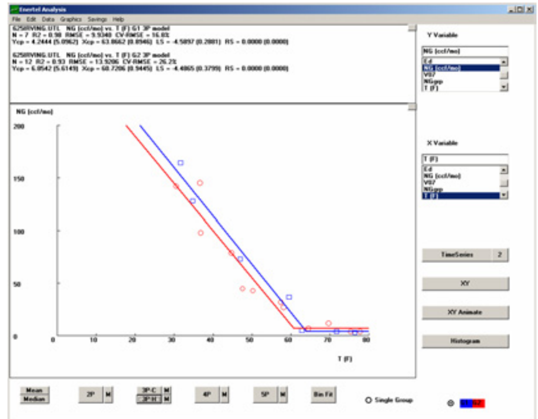

Fig. 10: 625 Irving actual gas use

To verify that a lower thermostat setting was indeed the cause of the lower gas use, we simulated 625 Irving energy use and calibrated it to measured utility and weather data for the 2000-01 AY. Once the model was calibrated, the thermostat set point was decreased from 70 F to 66 F and run for 2001-02 AY weather data. Figure 11 shows simulated monthly natural gas use verses outdoor temperature for the 2000-01(right) and 2001-02(left) AY's for 625 Irving.

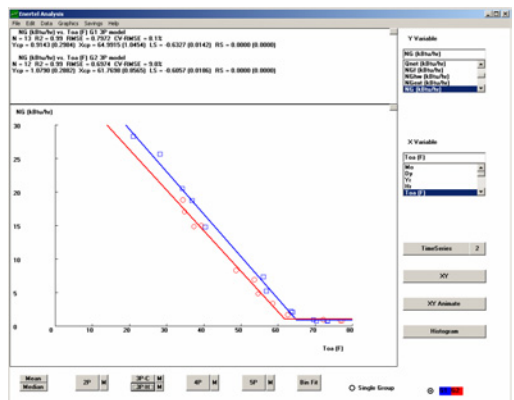

Fig. 11: 625 Irving simulated gas use

The similarity between Figures 10 and 11 strongly suggest that the decrease in natural gas use was due to a lower thermostat setting.

Figure 12 shows monthly natural gas use verses outdoor temperature for the 2000-01(right) and 2001-02(left) AY's for 440 Lowes. The 2001-02 AY residents of 440 Lowes claimed to have their thermostat set at 67 F during occupied hours and at 62 F when the residents were away from the house in class, and lowered their water heater setting. The residents performed these actions during the second semester of the academic year.

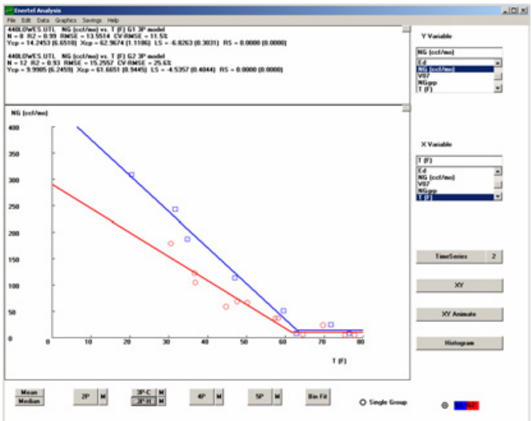

Fig. 12: 440 Lowes actual gas use

To verify that these changes could be the cause of the gas use trend, we simulated and calibrated 440 Lowes energy use to measured utility and weather data for the 2000-01 AY. Once the model was calibrated, the thermostat set point was decreased from 72 F to 67 F, with an unoccupied setpoint of 62 F, and run for the second semester of 2001-02 AY weather data. Also, the set point of the water heater was decreased. Figure 13 shows simulated monthly natural gas use verses outdoor temperature for the 2000-01(right) and 2001-02(left) AY's for 440 Lowes.

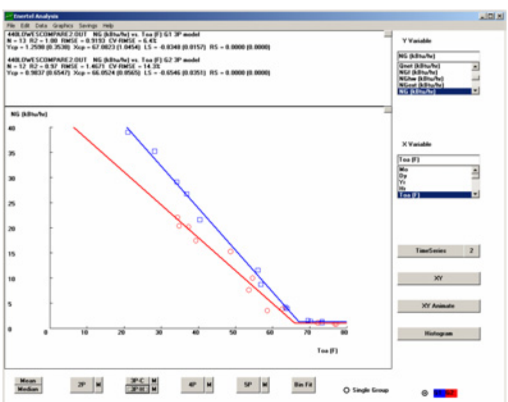

Fig. 13: 440 Lowes simulated gas use

The similarity between Figures 12 and 13 strongly suggest that the decrease in gas use was due to a lower thermostat setting, unoccupied thermostat set-back, and a lower water-heater setting.

5. CONCLUSIONS

Household electricity use rises with increase in the number of occupants. Unexpectedly, four to six person houses use less electricity per person than two, three, seven and eight person houses. Time of occupation, outside temperature and behavior also affect electricity use. Within an occupancy level and between houses, and within a specific house and between residential groups, coefficients of variation of standard deviation are always greater than 20% due to behavior. To accurately quantify the affect of occupant behavior on electricity use, monthly use should be compared to mean models of average fully or partially-occupied periods.

Natural gas use is not affected by the number of occupants, and is more a function of house structure and volume, outside temperature and behavior. Within an occupancy level and between houses, coefficients of variation of standard deviation are always greater than 25%. There can be significant differences in gas use within a specific house and between residential groups. For gas use, a three-parameter regression analysis of billing data can show changes in resident behavior or house structure. Simulations, house visits, and resident interviews are important for verification of behavioral analysis.

Finally, energy use can be reduced by energy conscious behavior, exhibited by the residents of 625 Irving and 440 Lowes. Because behavior can have dramatic influences on household energy use, understanding and pursuing initiatives that affect behavior are of great importance.

6. REFERENCES

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