ELECTRICAL LOAD CHARACTERISTICS OF SUPERINSULATED MULTIFAMILY HOUSING: A CASE STUDY

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INTRODUCTION

Springfield, Illinois

Located in central Illinois, Springfield is a city of 100,000 residents, served by City Water, Light and Power (CWLP), a municipal electric and water utility. Retail electric rates for all electric residential customers are 4.35 cents per kWh in the winter and 5.83 cents per kWh in the summer, with about a negative half cent fuel adjustment.

Seasonal temperature extremes in Springfield swing from -10 ^{o}F to 105 ^{o}F with typical heating and cooling seasons of 5654 heating degree days (HDD) and 1165 cooling degree days (CDD, base 65 ^{o}F).

Orchard Park Apartments

The Orchard Park Apartments, begun in 1983 and currently at twenty buildings at two locations, are three story, twelve unit buildings with average apartment net floor areas of 820 square feet. Along with standard apartment furnishings, Orchard Park Apartments utilize many energy efficiency features.

- Superinsulation. Walls are R-40 (double wall) and R-30 (2x6 with insulated sheathing), ceilings are R-70. Windows and doors are double glazed.

- Passive Solar. Windows comprise only 7 percent of total building surface, with 63 percent of this on the south face, with shading overhangs. Solar orientation is 15 degrees east of south.

- Heating, Ventilating and Air Conditioning. Individual units are supplied with 1 ton heat pumps with SEER's ranging from 8.2 to 9.1 and HSPF's of 5.55. Apartments also have 1 to 3 ceiling fans to supplement air circulation. Building common areas (stairwells) are not conditioned.

- Water Heating. Units are furnished with 30 gallon electric resistance water heaters. Low flow showerheads rated at 2 gallons per minute are supplied.

The developer has received various awards for his design, including the United States Department of Energy "Special Award for Energy Innovation - 1985".

Project Description

Typical utility kWh meters were installed by the developer during construction in four buildings (48 units) to submeter the heat pump and water

heater circuits of each apartment. CWLP staff read these submeters and whole apartment meters weekly during calendar year 1987.

For CWLP, this was an opportunity to learn about both multifamily end use characteristics for load research and the potential effects of extensive conservation efforts for the purposes of demand side management, all at minimal cost to the utility.

The project procedure was relatively low-tech in light of recent activities by many utilities. The number of occupants were tracked only through lease agreements and no informational surveys were taken, in order to prevent biased usage patterns. Occupants had no knowledge of the project.

The project resulted in 7488 kWh readings, which were screened and analyzed using a microcomputer spreadsheet package. Heat pump and water heater usages were read directly, with outlet usages (including lights, oven and refrigerator) deduced from the total apartment meters. This paper presents performance data and discusses some observations made during the project.

RESULTS

End Use Analysis

Figure 1 shows the weekly end use consumptions for the average of all occupied apartments in the study. Note the relatively constant outlet usage (around 65 kWh per week) over the course of the year, and the seasonal variation in the peaks and valleys of the heat pump and water heater usages.

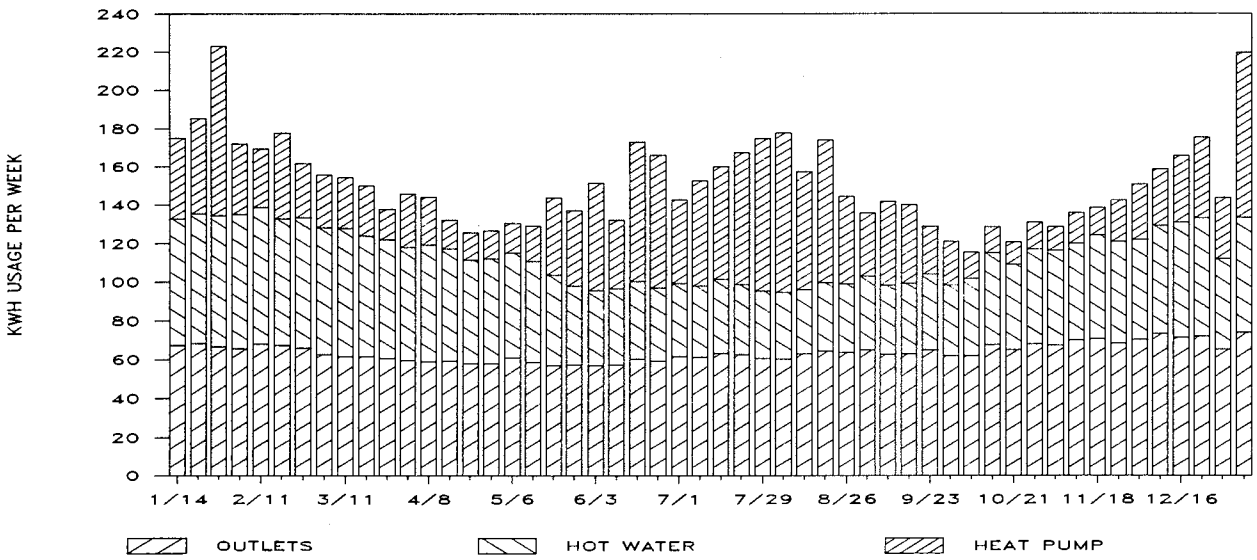

Figure 1. Weekly end use consumptions for average Orchard Park Apartment

Figure 2 shows the relationship between end use energy and outside air temperature. These usages were plotted against average temperature (based on hourly weather data) and shown with their regression model lines.

As shown in Figure 2, the outlet usage went down slightly during warmer weather. This weak correlation has little significance since this usage reduction was probably caused by reduced summertime lighting requirements, vacations and evening outdoor activities. The trend exhibited by the water

heater line was more directly related to temperature difference, since ground water temperatures and apartment internal temperatures are generally higher during hotter periods, and occupants tend to take cooler showers. The three piece linear model of the correlation between heat pump usage and outdoor temperature is much stronger due to the direct relationship involved.

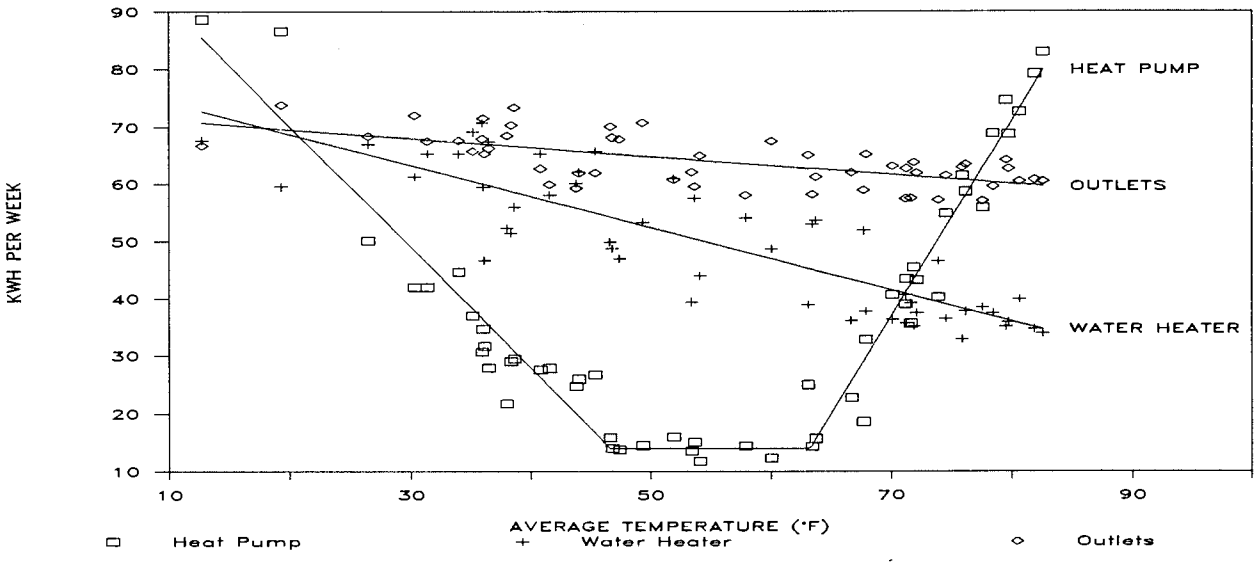

Figure 2. Relationship between end use energy and outdoor air temperature

Consumption Totals

Table I below lists the kWh consumption totals for the year by end use for apartments listed. Dollar amounts are based on an average electricity price of $.05 per kWh.

Table I. Orchard Park Apartments 1987 energy consumption totals (in kWh).

	Heat Pump	Water Heater	Outlets	Apartment Total	Apartment Total ($)
Minimum Apartment	1,099	1,704	1,387	4,190	$210
Maximum Apartment	2,818	5,790	5,165	13,773	$689
End Use Averages	1,965	2,579	3,328	7,862	$393
End Use 1st Quartile	1,686	1,705	2,463	6,214	$311
End Use Median	2,024	2,558	3,092	7,745	$387
End Use 3rd Quartile	2,253	3,130	3,857	9,326	$466
Standard Deviation	491	1,055	1,244	2,323	

The numbers in Table I show that on the average, outlets accounted for 42 percent of total apartment usage, with heat pump and water heater usages accounting for 25 and 33 percent, respectively.

Energy Utilization Indices (EUI)

The study of Orchard Park Apartments yielded a Total Energy Index (TEI) of 9.59 kWh/ft^2 (32,700 Btu/ft^2) during the 1987 study period. Corrected for normal weather conditions, the TEI number becomes 9.65 kWh/ft^2/year (32,900 Btu/ft^2/year).

Energy used by the heat pump exhibited EUI's of 0.20 Wh/ft^2/HDD (0.68 Btu/ft^2/HDD) for heating, and 0.96 Wh/ft^2/CDD (3.28 Btu/ft^2/CDD) for cooling. The per capita annual energy index for water heating was 1400 kWh/person/year and outlet usage was 1800 kWh/person/year.

COMPARISONS AND DISCUSSIONS

Thermal Performance Variations Between Floors

It was observed that the basement level apartments required more heating and less cooling than the middle and upper level apartments. Although there was a thermal break of insulation between floors, the buildings exhibited a thermal stratification, much like that which exists in tall, open buildings. This condition is most likely caused by variations in infiltration and exfiltration rates due to pressure differences between floors and conduction of heat from lower level to upper level apartments.

In an effort to examine this phenomenon, linear models were developed for the heat pump energy usages for the average of 16 basement, middle and upper level apartments and shown in Figure 3. Data points were omitted for clarity.

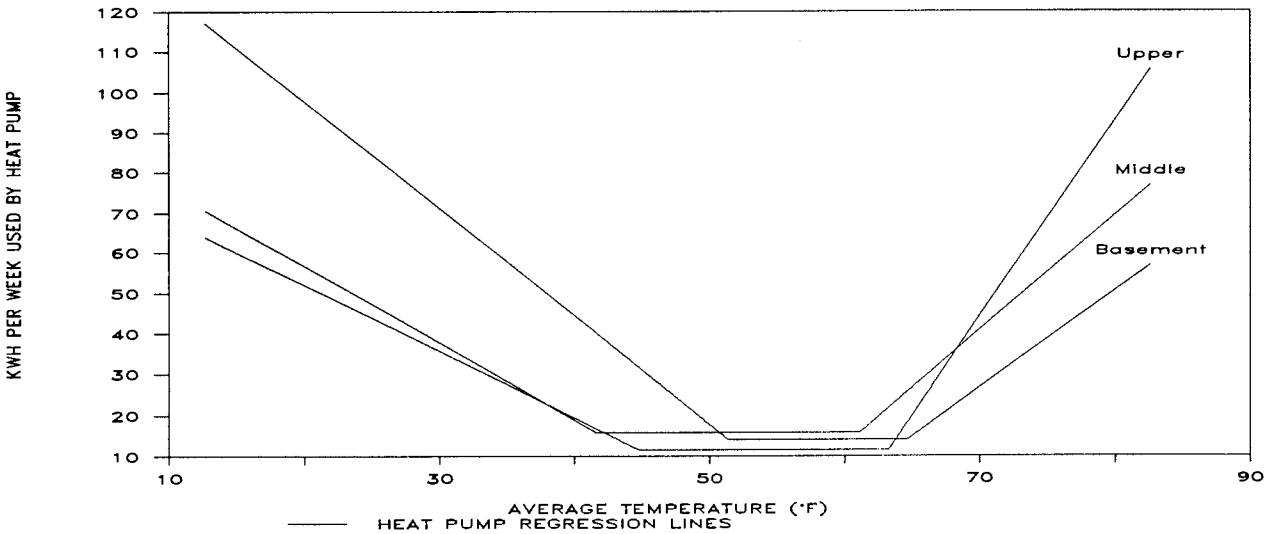

Figure 3. Examination of thermal performance variations between floors

At the extreme temperatures, performance is as may be expected, with the basement requiring the most energy for heating and least for cooling. Surprisingly, the middle level is only slightly more temperature sensitive than the upper level in the heating region. This may be due to the smaller amount of exterior surface area involved. For the year totals, the differences between floors is minimal (basement-2050 kWh total, middle-1878 kWh, upper-1997 kWh), because the seasonal variations seem to counteract each other.

The horizontal bands in the middle of Figure 3 indicate the ranges of balance temperatures, those external temperatures which require virtually no heating or cooling, exhibited by the apartment levels. The middle level apartments exhibited the widest range of balance temperatures.

Occupancy and Behavioral Effects on Consumption

Two identical houses in the same climate can exhibit very different energy usage patterns, due to the varying life-styles of their occupants. With the relatively small energy requirements of superinsulated apartments, these variations become proportionately more apparent. As shown in Table I above, the maximum usage apartment consumed nearly three times as much energy for heating and cooling over the course of the study as did the minimum usage apartment, while the apartments were virtually identical. Similar observations can be made for the other end uses.

While occupied, the apartments ranged from 1 to 4 occupants each, (average 1.8 occupant/apartment). Four building (48 units) weekly occupancy ranged from 83 to 92 persons (88.5 average).

Internal loads, while often neglected in heating load sizing estimation, are very significant in heating and cooling these apartments. Interestingly, one basement apartment required no heat pump electricity for heating through the fall of 1987, until the middle of December, when the average outdoor temperature for the week was only 36 ^{o}F. Closer examination revealed that the outlet load during this period was averaging 160 kWh/week (compared to 64 kWh/week average for all apartments). The occupants were heating their apartment with their appliances and water heater. Similarly, high outlet and water heating internal loads in the summer in other apartments were nearly always accompanied by correspondingly higher cooling usages.

2x6 Versus Double Wall Construction

Some of the earlier Orchard Park buildings (including one of the study buildings) were built with 2x6 frame walls, with one inch insulated sheathing (R-30 total). The 2x6 building performed virtually as well as the buildings with twelve inch thick double walls for heating and cooling (within 4 percent). The 2x6 walls were discontinued in Orchard Park, not because of inferior performance, but because of **higher** construction costs.

Orchard Park Management found it to be less expensive to build double walls because of the lower indirect costs associated. Plumbing and electrical work was easier on the inside of the building with double walls, while exterior siding installation was also facilitated. These indirect cost savings offset the incremental direct costs of material and installation of double walls.

DEVELOPER'S PERSPECTIVE

Orchard Park Management has enjoyed high (99 percent) occupancy rates with its quality, energy efficient construction. Built during a time of relatively low and stable energy prices, these buildings are successful in minimizing energy costs and increasing comfort levels, while being profitable to the developer to build and rent. The developer plans to add buildings at a rate of four to six per year for the next several years.