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A Case Study of Conservation in Space Heating Requirements of a Single-Family Home

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A CASE STUDY OF CONSERVATION IN SPACE HEATING REQUIREMENTS OF A SINGLE-FAMILY HOME

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Abstract

Energy requirements for space heating in a single-family home were studied over a period of four heating seasons. The effects of added insulation, reduced thermostat settings and other conservation techniques were measured. The potential for energy conservation in residences, under actual living conditions, was clearly demonstrated.

1. INTRODUCTION

1.1 BACKGROUND

The beginning of this study happened more by accident than by design. The author and his family lived in the test house for six years and were initially interested primarily in reducing utility costs and increasing comfort in their home. As natural gas prices started to rise and an awareness of the need for energy conservation grew, the project became more serious. Eventually, it became evident that a habit of careful record keeping had resulted in the accumulation of records that made possible some serious evaluation of the energy conservation measures that had been instituted.

1.2 THE PROBLEM

The accumulated records have made it possible to isolate the effects of specific energy reduction techniques and evaluate their cost-effectiveness in an inhabited building.

2. THE TEST BUILDING

2. INITIAL CONSTRUCTION

The house under study was built on a single-floor plan having 3 bedrooms, kitchen, living-dining room and bath on the main level. This main level was built over a garage and basement area which had its floor at grade level. The lower level was divided about equally into the garage and the unfinished basement section. The floor plan was rectangular, with the dimensions of the upper level about 26 by 42 feet and the lower level 25 by 42 feet. This represented about 1100 sq. Ft of finished living space on the upper level.

The upper level was of standard 2 by 4 stud construction on 16 inch centers. The exterior was covered with 3/4 inch wood fiber sheathing and aluminum siding. The interior walls and ceilings were covered with 5/8 inch gypsum wallboard. Both walls and ceilings were insulated with 3½ inch, R11, fiberglass rolls with a kraft paper vapor barrier.

The lower level walls were cinderblock, unfinished, except for paint, on the exterior and interior and a small section of 4 inch face brick on the front of the house. Earth was banked up to a depth of 3 to 4 feet against the cinderblock wall all around the house, except for the garage door. The garage door was of one-piece steel construction and was uninsulated.

The interior wall between the garage and the basement was of 2 by 4inch stud construction, finished with 5/8 inch wallboard on both sides. It was filled with 3½ inch, R11, fiberglass roll insulation. The garage ceiling (bedroom and bathroom floors) was also insulated with 3½ inch fiberglass and finished with 5/8 inch wallboard. The ceiling over the basement area was uninsulated and unfinished.

All windows were of single-glaze construction with aluminum frame and sash. These were fitted with triple-track aluminum storms and screens, installed with 1 inch wood strips as a thermal barrier between storms and prime windows. Both prime and storm windows were tight at the beginning of the study. There was some deterioration of the storms by the end of the study.

Space heating was accomplished by a forced warm-air furnace using natural gas as a fuel. Air distribution was through a large main supply duct running the length of the house along the garage and basement ceilings. Six-inch branch ducts ran from the main supply to floor outlets under windows in the front and rear of the house. The main supply duct was insulated with 1 inch of fiberglass on its interior walls in the garage area only.

The furnace and water heater were located in the garage. Cold air returns and the warm air plenum of the furnace were uninsulated. Cold air return openings were located in the central hallway upstairs and in the wall between the garage and basement downstairs. Natural gas was used for water heating and clothes drying,as well as space heating.

2.2 MODIFICATIONS DURING THE STUDY

During the summer of 1973 the lower level of the house was finished into a family room and den with space left for a laundry and bath to be added later. This added about 350 sq. ft. of living space. The exterior cinderblock walls were finished with 3/4 inch foam panels (R4) between furring strips and covered with 3/8 inch wallboard or 7/16 inch plywood paneling. The concrete floor was sealed and covered with foam-backed medium shag carpet. The ceiling was finished with fiberglass acoustical panels in a suspended grid.

2.3 OCCUPANTS

During the entire period of the study, the house was occupied by the author, his wife and two small children.

3. CONSERVATION MEASURES

3.1 INSULATION

During the summer of 1973 the cinderblock walls in the lower level basement area were insulated with3/4 inch, R4, foam panels covered with 3/8 inch wallboard or 7/16 inch plywood paneling. During November, 1974 an additional 3½ inches, R11, fiberglass roll insulation was added to the existing R11 in the ceilings.

3.2 THERMOSTAT SETTINGS

The thermostat, located in the upstairs hall above the cold air return vents, was reduced in small steps from 75 deg F to 68 deg F during the course of the study. Day and night settings are shown in Figure 1.

Figure 1. Thermostat Setting (deg F).

Heating season	72-73	73-74	74-75	75-76
Day	75	73	71	68
Night	75	73	71	65

3.3 HEATING SYSTEM BALANCE

While thermostat settings show nominal temperatures, actual temperatures in some rooms were kept at somewhat lower values. These temperatures were controlled by adjustment of outlet vent settings in individual rooms. The master bedroom outlet was kept completely closed during the last 2 years of the study, allowing temperatures as low as 58-60 deg F in cold, windy weather. The other 2 bedrooms were adjusted to maintain temperatures around 65 deg F. The living areas of the house were all maintained at or near the thermostat setting, except for the lower level during the first year of the study. During this year the lower level was maintained at about 67-68 deg F.

3.4 OTHER TECHNIQUES

During the first year of the study(1972-73), a loosley-fitting vent in the main supply duct in the garage was kept closed. This allowed garage temperatures to remain above 50 deg F at all times. This vent was closed and sealed with heavy duty aluminum foil during the second year and thereafter. With this vent sealed, garage temperatures often dropped to near 40 deg F in cold weather.

During all heating seasons, except 1972-73, the bathroom exhaust fan was disconnected during the months when additional humidity was needed in the air.

4. DATA

4.1 DATA SOURCES

Data used in this study were largely extracted from regular gas bills provided by Northern Illinois Gas Company. The degree-day data were also provided by Northern Illinois Gas.

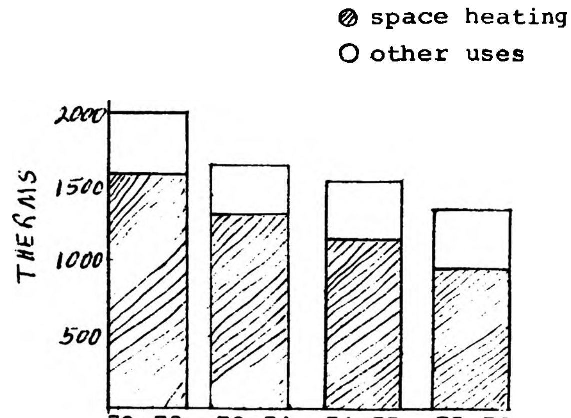
Data on costs of energy conservation measures were taken from receipts and record maintained by the author.

4.2 GAS USE DATA

Figure 2 shows total gas used and gas used for space heating during each heating season. A heating season was defined to be the one-year period beginning July 1 and ending June 30 of the following calendar year. Total gas use figures include space heating, water heating and clothes drying.

Gas use for space heating was obtained by subtracting 6 times the mean July-August gas use figures for the years 1972-76 from the total gas use for the year. The July-August figures were used as a base, since this is the only billing period of the year in which there are normally zero heating degree-days (65 deg F base) in the Chicago area. The base load of 67 therms/billing period , or 402 therms/season, is conservative, since hot water use was relatively constant through the year, while clothes drying was done outside during the summer. The July-August gas use figures are relatively constant through the period of the study, as shown in Figure 3, which further supports their use as a base-load figure.

Figure 2. Natural Gas Used, 1972-73 To 1975-76 Heating Seasons.



Year	72-73	73-74	74-75	75-76
Total therms	2012	1706	1555	1358
Heating therms	1610	1304	1153	956

Figure 3. July-August Gas Use, 1972-76.

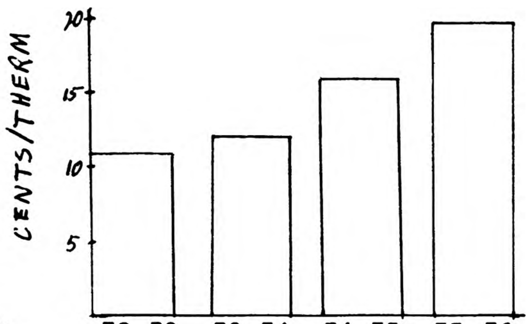
Year	72	73	74	75	76
Use (therms)	79	82	74	48	68

4.3 GAS COST

The average cost of natural gas for each heating season, in cent/therm, is given in figure 4. These figures were obtained by dividing the total gas bill by the number of therms billed. A case can be made for going back to the utilities rate structure and figuring savings on the basis of the last unit billed. The effect of this will be to reduce apparent savings by a small amount, since the last unit billed is usually the cheapest. This method is unsatisfactory, unless state and municipal taxes are added back at the end of the computation. Reductions in taxes are real savings as much as reductions in utility company charges. In this case the optimism of savings dollar estimates should help to balance the conservatism ofgas savings estimates.

As can be seen in figure 4, the cost of natural gas rose steadily during the period of the study. The average cost, by season, rose over 74%, while for individual billing periods in the last year of the study, the cost/therm had risen to as high as 24.5 cents, an increase of well over 100% above the 1972-73 figures.

Figure 4. Gas Cost in Cents/Therm For the 1972-73 To 1975-76 Heating Seasons.

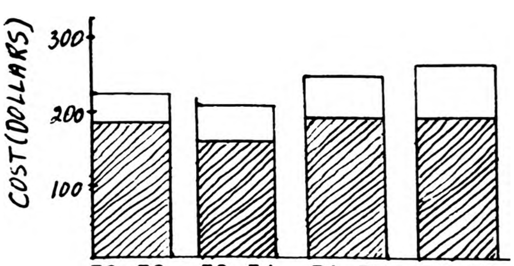


Year	72-73	73-74	74-75	75-76
Cost/therm	11.14	12.22	16.11	19.44

The total cost of natural gas for space heating purposes and the cost for all uses are shown in Figure 5. The total cost figures were taken directly from the gas bills. The cost for space heating was computed using the number of therms used for space heating each season from Figure 2 and the unit cost figures from Figure 4.

Figure 5. Cost of Natural Gas For Space Heating and All Uses For the Period 1972-76.

▨ Space heating
○ Other uses



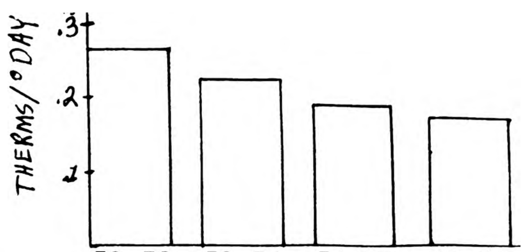
Year	72-73	73-74	74-75	75-76
Total cost (dollars)	224	208	250	264
Heating cost (dollars)	179	159	186	186

It is apparent from Figure 5 that space heating costs were held nearly constant through the period of greatly increased unit cost of gas. The figure also shows that gas costs for water heating and clothes drying were becoming an increasing percentage of the total gas cost.

4.4 HEATING EFFICIENCY

The heating efficiency of the house was defined to be the number of therms gas used per season divided by the number of heating degree-days per season. This therms/deg-day figure is specific to the building and is sensitive to the activities of the occupants, as well as to more specific energy conservation measures, such as insulation and thermostat settings. It also accounts for the severity of the weather in each heating season. The average heating efficiency of the test house and the number of heating degree-days for each season are shown in Figure 6.

Figure 6. Heating Efficiency for the 1972-73 to 1975-76 Heating Seasons.



Year	72-73	73-74	74-75	75-76
Deg-Days	6083	5927	6227	5585
Efficiency (therms/deg-day)	.2647	.2200	.1852	.1711

4.5 COST OF CONSERVATION MEASURES

The additional R11 insulation in the attic was added at a cost of $96 for materials. The work was done by the author, so there was no labor charge. If labor costs had been necessary, the installation cost would have been approximately doubled.

Reductions in thermostat settings were done at no cost. Night-setback was done manually, again at no cost.

Closing and sealing the heat supply duct in the garage required a 12 by 12 inch piece of heavy-duty aluminum foil, obtained from the kitchen at negligible cost (under 5¢).

Disconnecting the bathroom vent fan required removal of the cover grill and pulling the plug behind it. This was a 5-minute job, accomplished at no cost.

Balancing the heating system is best done with a thermometer located in each room, away from exterior walls and heat supply openings. It is best to have several thermometers, since adjustments in one room may affect temperatures in other rooms. The author had thermometers available at no cost. Adequate thermometers can be purchased for under $2 each.

4.6 ANALYSIS OF PAYBACK PERIODS

The cost of materials to add R11 attic insulation to the existing R11 was $96. There was no labor charge for installation. The improvement in heating efficiency of the house between the 1973-74 and 1974-75 heating seasons was from .2200 to .1875 therms/deg-day (from Figure 6). In a normal 6161 deg-day heating season, the expected savings in gas would be 214 therms (6161x(.2200-.1875)) per season at a 1975 gas cost of 16.11 cents/therm. This represents a savings of about $34 per season. Approximately 2% of the 15% increase in heating efficiency may be attributed to a lower thermostat setting. Most of the remaining 13% can be attributed to the additional insulation. This suggests that about $29 of the fuel cost savings can be associated with additional insulation. With increases in the cost of gas in the following seasons, a payback period of about 3 years is reasonable.

If labor cost are included, a payback period of about 6 years could be expected.

None of the other conservation techniques involved any direct, out-of-pocket expenses, so the financial return was immediate.

5. CONCLUSIONS

5.1 SPACE HEATING EFFICIENCY

The space heating efficiency of the test house was improved by almost 35% over a 4-year period. These data clearly demonstrate the feasibility of reducing energy requirements for space-heating homes of typical construction, under actual living conditions. In addition the energy conservation methods used require no more than a low level of technical skill for the do-it-yourself homeowner.

5.2 PAYBACK PERIODS

The conservation methods used often required minimal expenditures and therefore had an almost immediate return on any small investment made. For buildings with minimal insulation in a Chicago-area climate, payback periods are short enough to be attractive even to homeowners who expect to sell the home within a few years. Since both gas cost and insulation cost have risen since the period of the study, This conclusion should still hold.

Small investments are generally paid back quickly. A $2 thermometer used to balance a room at 2 deg F below the rest of the house will pay for itself in gas savings in approximately one year.

5.3 COST FACTORS

Significant energy savings can be obtained at no cost in the case of reduced thermostat settings. This does, however, require some adaptation in the lifestyle of the occupants, especially in terms of indoor dress.

5.4 ADDITIONAL CONSERVATION TECHNIQUES

The possibilities for energy conservation in the test building were far from exhausted. Since the furnace and water heater were located in the garage, which was heated only incidentally, insulation of the hot-air plenum and the cold-air returns would likely be productive.

The data show that non-space heating uses of natural gas were an increasing percentage of total gas use. This suggests that increases in the efficiency of the water heater and clothes dryer are desireable. An additional fiberglass insulating blanket on the water heater is one possibility. Any technique that reduces hot water use, such as flow restrictors on shower heads and faucets is also desireable. Additional methods of reducing clothes dryer use, such as hanging clothes outside over a longer season, could be helpful.

THE AUTHOR

Robert M. Boeke is Assistant Professor of Mathematics and Physical Sciences at W. R. Harper College. He holds a B.S. in physics from the University of Dayton and an M.A.T. in science education from Northwestern University. He teaches courses in physics and energy conservation and is an active public speaker on the subject of energy conservation. He is also an independent consultant in residential energy conservation, working with homeowners and homeowners associations.