Princeton University
Center for Environmental Studies
School of Engineering

ENERGY UTILIZATION IN A RESIDENTIAL COMMUNITY*†

Richard A. Grot and Robert H. Socolow

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Abstract

Twin Rivers, New Jersey, a Planned Unit Development now under construction and already occupied to the extent of 1500 dwelling units, is being used as a laboratory to understand energy usage in residential communities. The consumption of gas and electricity is being monitored and correlations are being established with weather data, housing type, architectural design, mechanical subsystems, and demographic characteristics of the residents. In parallel, an extensive study of the consequences for energy utilization of decision-making by the builder, architects, contractors, and public and utility officials is underway. Preliminary results indicate that there is a large variation in energy usage even when identical units are compared. The influence of such variations as architectural design, thermopane windows, and dwelling orientation on gas consumption for space heating is perceptible; however, the magnitude of the differences is not always in agreement with standard heat load calculations. There seems to be little correlation, at least in the sample of townhouses analyzed, between gas consumption and electrical consumption. Advanced data collection schemes are currently being deployed to provide a more detailed temporal and spatial resolution than is available from meter readings and weather records.

I. Introduction

The decision to study how energy is ordinarily used in housing is motivated by the perception that there is a critical need to improve the data and methods commonly employed in the determination of energy requirements in the residential sector. The existing state of knowledge of energy utilization in a residential community is relatively primitive. The data describing the consumption of energy are generally either based on the detailed study of the performance of a dwelling in hypothetical or controlled situations or are based on the requirements of some average household living in some standard unit. The quantitative modeling of the performance of individual structures, as represented by standard heat load calculations, ASHRAE procedures, or various computer codes such as the so called "Post Office Program" or GATE, has never been verified in detail in a real-life situation. The numerous studies of utilities' aggregated data on sales to residential customers, though giving useful information about the range of situations encountered and trends over time, do not explicate the role of technical factors, such as house construction, in determining actual energy use.

The research program that has been initiated in the Center for Environmental Studies at Princeton University is designed to fill some of the voids in the data on residential energy usage. It was decided to study an actual community, Twin Rivers, New Jersey, to determine how energy is used there, what variables affect energy consumption, and how energy consumption can be reduced. The research has proceeded on three fronts: 1) A statistical study, based on all the utilities' data (monthly meter readings) since the town began, in conjunction with the architects' drawings, sales data on options selected, and available weather data (high and low daily temperatures). 2) An instrumentation program, designed to develop detailed information about the behavior of selected dwelling units. The first effort has been to establish a weather station at Twin Rivers. 3) A program of interviews, intended to establish how the technological reality came into being. The builders, architects, consulting engineers, public utility officials, and municipal authorities have explained which decisions they participated in, the rationale for their actions, and the factors which would have to be altered for them to choose differently.

Below, in Parts III, IV, and V, respectively, we present a preliminary account of our activities in these areas. First, part II describes the research site.

II. Twin Rivers, New Jersey

Twin Rivers is a Planned Unit Development (PUD) which occupies a little more than one square mile of what only a few years ago were potato fields, half a mile from exit 8 of the New Jersey Turnpike. (Figure 1 shows an aerial view of a portion of the site.) As New Jersey's first PUD, it is being watched closely by professional planners and sociologists for whatever special lessons it may hold. From the point of view of our research project, Twin Rivers is interesting for almost the opposite reason: from a technical standpoint it is representative of much conventional residential housing being built at this time. It possesses an example of almost every generic type of housing: there are single-family detached homes (168 units), townhouses (1626 units), and garden apartments (942 units), and there are plans for two high-rise apartment complexes. The current price range of the dwelling units is $32,000 to $41,000. The townhouses and condominium and garden apartments are of masonry bearing-wall construction with wood framing floors and roof. The single family dwellings are conventional wood frame. The construction nominally meets the various applicable codes, ordinances and FHA standards. The construction of Twin Rivers began in June of 1968 and has proceeded in four stages - called quads. At present, Quads I, II and III are completed and the construction of Quad IV is scheduled to begin in the spring of 1973. With the exception of 43 town-center apartments, all constructed units have gas space heating. There is electric central air conditioning throughout. The dwellings of Quads I and II have electric hot water heaters, electric ranges, and electric dryers, while the corresponding appliances of Quad III are gas. The town is particularly suited to be a "laboratory" because there are relatively few basic units, each repeated many times, all containing identical major appliances, except for standardized options. Thermopane windows and patio doors are also optional and these have been adopted by approximately half of the residents.

Twin Rivers is a relatively homogeneous community; its residents are drawn mainly from the mobile professional middle class.* The average income is $16,180; 65% of the heads of family have at least a bachelor's degree; the mean age of the head of family is 29 years; 96% are white; the average number of children is approximately 1.0 for the townhouses, 0.3 for the garden apartments and 1.4 for the single-family houses. It is interesting to note that 36% of the residents of Twin Rivers come from New York and approximately 51% of the heads of family work in New York. Each week-day morning, 19 buses carrying approximately 850 commuters leave the Twin Rivers Shopping Center for the 55 minute trip to New York City on the New Jersey Turnpike. The land use plan of Twin Rivers sets aside 35% of the space for residential use, 30% for industrial use, 17% for open space, 10% for commercial use, and 8% for roads.

III. Preliminary Analysis of the Monthly Gas and Electric Consumption

Both the gas and the electric utility servicing Twin Rivers have provided us with complete records of their monthly meter readings since the first units were occupied. They have also arranged for us to receive each new set of readings on a regular basis. The results presented here are preliminary. We have not yet analyzed all of our data, and the data for the current winter will be extremely helpful in establishing some of the uncertain features of the data we have looked at most closely.

This summary will emphasize the data on gas consumption during the 1971-72 heating season, the winter immediately preceding the inception of this project. We have defined a six-month winter season, from October 29, 1971, to April 28, 1972,** during which (based on a reference temperature of 65°F) there were 4567 degree days, 92 per cent of the annual total.

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*The data in this paragraph are drawn from Robert W. Burchell, Planned Unit Development: New Communities American Style (New Brunswick, N. J.: Center for Urban Policy Research, Rutgers University, 1972).

**The meters are read in all Quad II townhouses on each of these days.

We have further restricted our first investigation to the townhouses in the second quad. Among our reasons for this choice are:

1. Gas in Quad II is used only for heating, not for appliances.
2. In contrast to Quad I, the meters are located out of doors, so utility data include few estimated readings.
3. There are over 400 townhouses, and many fewer of the other types.
4. The single-family detached homes have not yet passed through a complete heating season.

Of the 401 Quad II townhouses, 153 are split-level townhouses ("splits") and 248 are two-floor townhouses. In both cases, the townhouses have either two, three, or four bedrooms and are 18, 22, and 24 feet wide, respectively. A single structure either contains splits or two-floor townhouses, not both, but it contains a mix of the three sizes. Figure 2 shows a building containing ten splits.

The townhouses can be further identified by whether they are end or interior units, by whether the thermopane option was exercised or not, and by their compass orientation.

The average winter gas consumption by number of bedrooms is shown in Table 1. It is apparent that the average winter gas usage is quite closely proportional to the townhouse width in the two-floor townhouses, but not in the splits; in fact, the three-bedroom splits use slightly more gas than their four-bedroom counterparts. Our tentative explanation (put forward by Mr. John Fox, a graduate student working with us) is that the additional consumption is primarily due to an architectural variation in the three-bedroom units, a projecting rectangular element on the second floor. (See Fig. 2) To isolate such a cause will require further study; the four-bedroom units have larger furnaces, for example (in both the split-level and the two-floor town houses, however). Improved statistics, for this and other investigations, accrue automatically as time passes and additional years of data unfold.

Similarly any detailed accounting for the increased gas consumption in splits relative to two-floor townhouses will require a careful comparison of architectural features. Some of the features contributing to the gas consumption are given in Table 2, which presents the results of a standard heat-loss calculation for a three-bedroom interior two-floor townhouse. It is worth emphasizing a result of this calculation that is well known

TABLE 1

AVERAGE WINTER GAS CONSUMPTION (therms[a])

	Split-Level Townhouses	(Sample size)	Two-Floor Townhouses	(Sample size)
18', 2-bedroom	728	(34)	626	(71)
22', 3-bedroom	958	(98)	836	(138)
24', 4-bedroom	903	(20)	901	(39)
All units	900	(152)	782	(248)

a: One therm = 10^5 Btu.

TABLE 2

SUMMARY OF HEAT LOSS CALCULATION FOR 3-BEDROOM INTERIOR TWO-LEVEL TOWNHOUSE
($70^{\circ}F$ design temperature difference)

Component	Area ($ft.^2$)	U-factor ($Btu/hr/ft^2/^{\circ}F$)	Heat Load (Btu/hr)
Walls	514	0.093	3400
Doors	20	0.48	700
Ceiling	723	0.063	3200
Basement			4000[a]
Windows	192	1.13[b]	17300
Air Infiltration			11600[c]
		TOTAL	40200

a. The calculation includes heat losses above ground, below ground, through two small windows, and through the floor.

b. Assuming single glass. If thermopane (U = 0.72) is used, the heat load is reduced by 6300 Btu/hr, or 16% given the other assumptions above.

c. Assumes 0.75 air exchanges per hour. This is a typical handbook value. We have not yet measured air infiltration rates at the site.

to professionals but apparently not elsewhere: heat loss through windows and heat loss via air infiltration are both at least as large as heat loss via all other means, once walls, ceiling, and basement have even average insulation (two inches in walls, four inches in ceiling). The attribution of 43 per cent of the heat load to windows and 28 per cent to infiltration justifies our continuing emphasis on these characteristics in our future research.

A naive way to predict the winter gas demand for three-bedroom townhouses would be to take the heat load, which is calculated for a $70^{\circ}F$ design temperature difference, and multiply by the 4567 degree-days in the heating season. Choosing a 75% furnace efficiency gives an average gas demand of 835 therms.* The close correspondence with the value in Table 1 is fortuitous for several reasons: 1) the average value in Table 1 includes end units and units with thermopane, 2) the heat load calculation omits any consideration of solar heating and internal heat sources (it is intended for sizing a furnace that has to operate under the worst conditions - no sun and an empty house), and 3) neither the furnace efficiency nor the air infiltration rate is yet a directly measured number. An improvement on the methodology of calculating fuel consumption that takes these factors into account is one of the goals of our study.

The number of degree days per month correlates closely with the average gas consumption, confirming that a reference temperature of $65^{\circ}F$ for calculation of degree days is a good choice.** The correlation coefficient between the average consumption of gas in the splits and the monthly degree days (adjusted for actual dates of meter reading) is 0.997, calculated from twelve months of data.

Averaged over all of the splits, the electric consumption for almost the same six-month interval (the meter reading date is slightly

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$$^{*}\frac{40{,}200\ \text{Btu/hr}}{70^{\circ}\text{F}} \times \frac{24 \times 4567\ \text{hr-}^{\circ}\text{F}}{0.75} \times \frac{1}{10^{5}\ \text{Btu/therm}} = 835\ \text{therm.}$$

**Let T be the average temperature on a given day; the degree days in a time interval are found by summing (65 - T) for all days where this is a positive number.

different) is 253 therms (7409 kw-hr), 28 per cent of the gas consumption. The coefficient of variation (the ratio of the standard deviation to the mean) is somewhat larger for the electric consumption (60.9 therm standard deviation, coefficient of variation of 0.24) than for the gas consumption (162 therm standard deviation, coefficient of variation of 0.18) as one would expect, given the larger number of ways in which individual behavior can influence electric consumption. What came as a surprise was the total lack of correlation between gas and electric consumption in the same unit. A scatter plot of gas and electric consumption for 152 units is shown in Fig. 3; the coefficient of correlation is 0.24. Apparently, of the two contradictory "explanations" - 1) those who are profligate with one energy source will be profligate with another, and 2) more heat generated by electricity means less heat generated by gas - both are operating.

From the fact that the thermal content of the electricity consumed during the winter period is 28 per cent of the thermal content of the gas consumed in the same period, it is apparent (assuming about 30 per cent efficiency in electricity generation and delivery) that roughly equal quantities of fossil fuels are involved in the production of the gas and the electric services for these homes in winter. The gas consumption in summer (April 29-October 28) is about 9 per cent of the consumption in winter, but the electric consumption in summer is about 125 per cent of the electric consumption in winter, a result, of course, in substantial measure of the air conditioning. This large summer electric load will become an increasingly important focus of our further research.

One of our major objectives is to identify the factors that account for the variations in gas and electric consumption in similar units. When previous studies based on utility sales data have confronted large variations, they have sometimes ascribed these variations to differences in "life-style"; it is occasionally intimated that with people so unpredictable and individualistic, alterations in building practices, appliance design, control systems, and other aspects of the technological reality in which people function, cannot be expected to affect aggregated energy consumption substantially (as much, for example, as campaigns to alter each resident's consciousness of how his own decisions are affecting his energy consumption). In our study, where many of the technological factors are standardized, we were prepared to discover that nearly all of the "life-style" effect had vanished, in which case we would have been in a position to emphasize the role of technology and to deemphasize the role of individual behavior.

It is already clear that the truth lies somewhere in the middle. As each technological variable is separated out, the observed variation in gas and electric consumption is reduced, but when many of the technological variables of which we are currently aware are separated out, considerable variation remains. In Fig. 4, a histogram of gas consumption in all split-level townhouses is shown, and, within it, a histogram of that subset of the large sample having no thermopane, having windows facing east and west, and not occupying end positions. In this subset, the ratio of standard deviation to mean has dropped somewhat, but it is still substantial, as seen in Table 3, which also gives the corresponding data for electric consumption.

We have attempted to extract the energy cost associated with being an end unit and with not having thermopane windows and patio door. We have done a multiple regression analysis on a sample of 98 three-bedroom splits and on a sample of 138 three-bedroom two-floor townhouses, using the expression Winter Gas = Constant + A x (Cost of Being an End Unit) + B x (Cost of No Thermopane) where A and B each take on the values 0 or 1, depending on which unit is being considered. Our results are shown in Table 4.

When we attempt to add the compass orientation to the multiple regression, using the simple form of a weight of 0 for windows facing north and south and 1 for windows facing east and west, the improvement in fit is not significant for the townhouses and is barely significant for the splits. (Except for the constants, the values in Table 4 change by less than 5 therms.) On further study, we find that the modeling of the solar load term needs to be done quite carefully - we estimate that the shading of the windows by projections and overhangs can easily make a difference of 50 therm in the winter gas consumption. With the help of our weather station, which records direct and indirect solar flux, we hope to study the solar effect on winter heating load in considerable detail.

TABLE 3

THE SLOWLY DWINDLING VARIABILITY OF GAS AND ELECTRIC CONSUMPTION AS MORE NEARLY IDENTICAL SUBSETS ARE CHOSEN

Sample	Sample Size	Mean Winter Gas (Therms)	Standard Deviation in Winter Gas (Therms)	Coefficient of Variation for Gas	Mean Winter Electric (Therms)	Standard Deviation in Winter Electric (Therms)	Coefficient of Variation for Electric
All splits	152	900	162	0.180	253	61	0.241
All three-bedroom splits	98	958	141	0.147	251	58	0.231
All three-bedroom interior, non-thermo-pane, east- or west-facing splits	20	1,023	119	0.116	255	58	0.227

TABLE 4

MULTIPLE REGRESSION FOR EFFECT OF BEING ON END, HAVING NO THERMOPANE, ON WINTER GAS CONSUMPTION

	Splits	Two-floor Townhouses
Sample Size	98 units	134 units
Constant (base gas consumption)	879 therms	714 therms
Added Cost for being an End Unit	60 therms	110 therms
Added Cost for not having Thermopane	98 therms	37 therms

In our study of solar load, we have come upon one result which appears not to be widely known: a vertical surface facing south receives more incident solar radiation over a clear winter day than an identical vertical surface facing east or west, and it receives less incident solar radiation over a clear summer day, for 40° latitude. The difference lies in the fact that the sun is enough higher in the sky in summer than in winter to reduce the heating of a south-facing surface from a value above to a value below the value for the morning heating of an east wall or evening heating of a west wall. Hence glass on the south walls is advantageous relative to glass on east or west walls, both from the point of view of winter heating and from the point of view of summer cooling.

The cost in Table 4 for being an end unit should have been roughly the same for the splits and the two-floor townhouses, because the end wall is virtually identical. An elementary calculation like the one for the total gas consumption discussed earlier (see Table 2) gives an estimated winter energy cost of 108 therm for the end wall;* it is not clear to us why the "cost" of an end wall on a split is so much smaller. The cost for extra outside walls is real, however, and confirms the desirability, from an energy standpoint, of multiple-family relative to single-family structures.

The cost in Table 4 for not having thermopane should have turned out (and did turn out) larger for the splits than for the two-floor townhouses because a larger area of the splits is glass. (For the same reason, the base gas consumption for the splits is larger.) A direct calculation of the difference in the conduction losses through thermopane is cited in Table 2: a 16 per cent reduction in the heat losses is predicted, versus a 10 per cent reduction in average winter gas consumption in the splits and a 5 per cent reduction in average winter gas consumption in the two-floor townhouses. Thus our tentative conclusion is that the thermopane is less effective in reducing winter fuel consumption than naive calculations would predict.

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*Assumptions: 4567 degree days; 556 sq. ft. of wall of U-value 0.093; 9 sq. ft. of glass of net U-value 1.24; 12 cubic feet per minute infiltration through cracks; 75% furnace efficiency.

In dollar terms, a 100-therm reduction in winter gas consumption corresponds to a saving of $12.80 per year, which is about 3 per cent of the cost of the thermopane option for the Twin Rivers townhouses (between $400 and $500, depending on window area). To this return on investment one needs to add the dollar saving for reductions in summer air conditioning (not yet estimated) and the advantages in comfort from not having cold interior surfaces.

Once we have factored out the effects of architectural style, size, orientation, thermopane, and end wall, considerable variation remains. (Recall Fig. 4) Of course, this variation, too, must have an explanation in terms of technological variables. A critical distinction is between variables over which the consumer has little control and variables that the consumer dominates. We will be extending our research in the next months, hoping in the process to understand what part of the residual variation is attributable to variables of the first kind that we have not yet studied (like variations of tightness of fit of windows and variations in performance characteristics of "identical" furnaces) and what part is attributable to variations of the second kind (like variations in thermostat settings and in frequency of door openings).

Among the factors that are not proving helpful in analyzing variations in energy consumption are the family income and the family size. The family income and the family size are inversely correlated, in part because there are often two incomes when there are no children, and in part because wealthier large families would have bought larger homes. But even among families with children there is no perceptible increase in gas consumption and only a small increase in electric consumption as the number of children increases, holding number of bedrooms constant. Our (by now familiar) population of twenty three-bedroom interior splits without thermopane and with windows facing east and west has annual family incomes ranging from $15,000 to $34,000 and family size ranging from 2 to 5, yet other than the inverse correlation of family size and income, no correlations of either winter gas or winter electric consumption with either family income or family size are statistically significant. A correlation matrix for these four variables for this twenty-unit population is given in Table 5.

TABLE 5

CORRELATION MATRIX FOR SPECIAL POPULATION[a] OF 20 IDENTICAL SPLITS

	Winter Gas Consumption	Winter Electric Consumption	Number of Occupants	Family Income
Winter Gas Consumption	1.00	0.14	0.13	-0.24
Winter Electric Consumption	0.14	1.00	0.31	-0.20
Number of Occupants	0.13	0.31	1.00	-0.57
Family Income	-0.24	-0.20	-0.57	1.00

a. Three-bedroom, interior, non-thermopane, windows facing east or west.

Note that for a 20-member population correlations as large as 0.44 occur randomly 5 per cent of the time.

IV. Future Plans for Data Acquisition

Early in this project it became apparent that there was little hard data on the usage of energy in residential communities and that readily available data sources such as gas and electric bills would probably serve only a limited objective. There is a need for data that could 1) describe how energy is used in urban communities, 2) be utilized to evaluate various proposed technological and socio-economical innovations which would affect energy consumption and 3) be used to generate data statistically for other urban mixes. Though the components of the Twin Rivers project that will be described briefly here are still mainly in the planning or development stage, a knowledge of the methodology employed and the data being generated may be useful for those planning similar projects on other aspects of urban communities and for those attempting to evaluate the effects of specific modifications in energy technology. For example, the data that will be collected should provide a base for evaluating modular integrated utility systems and will be compatible, hopefully, with data that will be collected by the National Bureau of Standards in its evaluation of the total energy plant at the Jersey City Operation Breakthrough site.

By type, the data being collected at Twin Rivers can be classified as describing energy consumption, local meteorology, physical characteristics of the town and of individual residences, the internal environment of the dwelling, and household characteristics. In each instance, we are beginning with the readily available data (when it exists), then refining it by limited sampling and field studies, and finally, where it seems warranted, preparing a large-scale monitoring effort. The various stages and components of this scheme are depicted in Table 6.

We have just finished installing an automatic weather station atop the bank at Twin Rivers. The station has the capability of measuring wind velocity, total wind run, wind direction, air temperature, ground temperature, barometric pressure, dew point, rainfall, total solar flux, and diffuse solar flux. Normally this data is gathered and digitized hourly and transmitted from Twin Rivers to the Engineering Quadrangle at Princeton University where it is recorded on paper tape to be processed later on a computer. Several field studies are currently being initiated, primarily on air infiltration measurements, heat flow

TABLE 6 DATA SOURCES

1969-1973 Available Data	1973-1974 Limited Sampling	1974-1975 Large Scale Monitoring
Consumption Gas and electric utility bills	Consumption Temporal record from electrical primaries and gas mains Temporal record by use in 2 to 8 units	Consumption Expand number of units monitored
Meteorological Data Daily maximum and minimum temperature (Hightstown)	Meteorological Data Hourly air temperature, humidity, wind velocity, wind direction, rainfall, barometric pressure, total solar flux, diffused solar flux, ground temperature	Meteorological Data Possible spatial resolution Add net radiation, measure of turbulence
Physical Characteristics of Units VA-FHA "Material Description" Architectural drawings Sales records Observation of construction	Physical Characteristics of Units Field study of air infiltration, heat flow, air flow Laboratory evaluation of furnaces and appliances	Physical Characteristics of Units Modification of several units, Monitoring of furnaces and appliances
Internal Environment No data	Internal Environment Field study of 2 to 8 instrumented units	Internal Environment Expand number of units monitored
Household Characteristics Size, age, income, occupation for some units	Household Characteristics Usage of appliances	Household Characteristics Usage of appliances Door and window openings

losses, and temperature variations within dwellings. Three single-family homes have been instrumented to give a continuous record of gas consumption and electricity used for hot water. This work is being done in conjunction with Hittman Associates, Columbia, Md. Our data will be used to evaluate a computer program that they have been using for residential energy consumption. The data also provides us a preliminary indication of the details of energy use, which allows a more rational means of planning future instrumentation.

A furnace and some of the appliances used at Twin Rivers have been installed in a laboratory in the Engineering Quadrangle, for the dual purpose of checking instrumentation and evaluating performance. One or two prototype data acquisition systems for monitoring the internal environment, energy consumption and user habits are being assembled for installation at Twin Rivers in a few months. The quantities that will be measured are listed in Table 7. The idea is to instrument a few homes in detail in order to determine what will be required in a large-scale effort.* Finally with the electric and gas utilities we are planning instrumentation of the mains and the primary distribution system.

V. The Program of Interviews

In an effort to untangle the web of ideas, decisions, and actions that resulted in the creation of Twin Rivers, we are carrying out a series of interviews that are producing a mass of material, an oral history of the decision-making. We are emphasizing the *decisions* made by the interviewees, particularly those affecting energy. Since both large and small decisions can become important factors in energy consumption, the information is somewhat difficult to organize into a coherent pattern and flow. We are trying to pin down decisions about site size, location and density, fuel sources, house design and orientation, HVAC equipment and appliances, landscaping, maintenance, and more. An extensive narrative is in preparation at this time. In

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*This work is being done in collaboration with the National Bureau of Standards, which has a supporting grant from the National Science Foundation.

TABLE 7 PROPOSED MEASUREMENTS IN INDIVIDUAL UNITS

1. Temperature

   a. air temperature in each room
   b. air supply temperature in each room
   c. exterior wall and window temperatures (inside, outside, and difference)
   d. basement temperatures
   e. garage temperature (if applicable)
   f. attic
   g. main return duct
   h. supply duct at furnace
   i. hot water temperature
   j. cold water temperature
   k. furnace flue gas temperature (also gas hot water heater flue if applicable).

2. Humidity

   a. kitchen
   b. bathrooms
   c. main return duct
   d. living room
   e. upstairs
   f. main supply duct.

3. Electric Consumption

   a. range (if applicable)
   b. refrigerator
   c. hot water heater (if applicable)
   d. clothes dryer (if applicable)
   e. total living area
   f. furnace fan
   g. air conditioner compresser
   h. air conditioner condenser fan.

4. Gas Consumption (pulse meters and counters)

   a. furnace
   b. hot water (if applicable)
   c. range (if applicable)
   d. clothes dryer (if applicable).

5. Water Consumption

   a. cold
   b. hot.

6. Air flow

   a. supply ducts
   b. return duct
   c. exhaust fans.

7. Time of Usage

   a. various appliances
   b. door open time
   c. windows
   d. fans.

8. Pressure across Exterior Surfac

9. Heat Flow

   a. exterior walls
   b. glass
   c. basement walls
   d. ceiling
   e. through flue.

10. Continuous Monitor of Air Infiltration.

the space available here, it is impossible to do justice to the tapestry of relationships that we have found. We will mention only a few of the areas of concern that we are exploring.

The interviewee often states that a consideration of "costs" has determined his decision. A closer scrutiny is showing that much more is implied than the customary financial balance sheet of labor, materials, interest rates and the like. The town did see more than tax revenues, the developer more than profits. Certain social costs surfaced early, though they now seem obscured, even forgotten, as issues. The large creative idea "what kind of community will we build?" was in the forefront of the original developer's thought - while for the town the same question shaped itself as nagging worry and threat of forever altering the character of a rural community. Sometimes it is possible to sort out economic from social circumstance. Often enough, determinations appear thoroughly muddled together.

While we knew we were dealing with an uncommonly strong developer, we underestimated the shadow he cast. For example, we assumed the financial backers would have much to say about the design and execution of the project. On the contrary, they accepted the developer's package, including his time table, without modification. Initially the financial backers did oppose the townhouse idea, which was an untried idea in New Jersey, but they quickly yielded. The backers' firm was chosen to supply heating equipment, but this concession is viewed by parties to the transaction as a minor courtesy (later withdrawn), extended largely because their product was competitively priced. In sum, the developer was able to achieve financing for his own plan, with the backers' exerting fiscal controls only.

The developer was also solely responsible for the choice of energy source. He found gas cheapest in installation and running cost. No question about availability of fuel or its conservation arose back in 1969-70 when negotiations with oil, gas, and electric utilities were first undertaken.

The developer's architect has played a small role. He did schematics on the units and elevations. He told us that decisions on the size of the units and their orientation were essentially builder decisions. (For example, the developer's marketing man takes credit for the presence of a basement.) An earlier developer, his architects, and the township planning board had shaped the master plan, including the balance between residential, industrial, and commercial areas. Those architects were more fully involved as physical planners; they had been the architects for Reston, Virginia.

A particularly important occasion for the exchange of information was the Model House Conference, during which the prototype house was rebuilt several times. The vertical flow of information from and back to the developer was augmented on that occasion, when architect, developer and mechanical people interacted closely. Aesthetics and cost considerations were joined momentarily in lively interchange. Window sizes were reduced in deference to maintenance costs. Ducts were wrapped around both to achieve ease of installation and to solve aesthetic problems. Design changes were made by the architect to achieve simplicity in construction.

There is rivalry between the gas and electric utilities to capture the largest possible share of the domestic heating, hot water and appliances. No exchange of information has occurred between them. Though the utilities do their own layouts up to the site, one of the negotiable items is whether the developer will do his own trenching at the site. For each quad, the decision about what will be gas and what will be electric is made anew. The utilities have presented a cost package to the developer, and he has chosen and chooses still between them as costs, revenue credits, and now perhaps supply conditions alter.

A contract system in general binds sub-contractors to contractors and builders to contractors. But it is perceived by our informants as no better than the parties to the agreement, and the real cement of the business relationship comes from confidence in the reputation and character of the parties to the agreement.

Performance is protected in two ways. One is the chain of guarantees which underpins the system. The house is guaranteed by the builder for a year to the purchaser. Its components in turn are guaranteed by the installers and manufacturers to the builder. Thus, the responsibility for defective construction and equipment is passed along whenever possible. The financial backer even gets guarantees from the developer on his own heating and cooling system.

Second, construction standards are checked by inspectors and foremen. Persons with both generalized and specialized responsibilities are at the site. Inspectors representing the State Department of Community Affairs, the township, the gas and electric utilities, and the builders are there continually. They appear to interact primarily as a team - not, as one might have supposed, in jealous regard for their particular constituency. A significant checkpoint in the installation of the heating system, for example, is the gas company's inspection prior to connecting up a unit.

The record is full, and we are returning to some of our informants for a second time now as we try to clarify details. Our hope is to lay out the detailed pattern of the decision-making process. We hope that an understanding of this pattern will be of assistance when we seek realistic strategies to implement ideas for the reduction in energy consumption that are suggested by other portions of our research project.

Acknowledgements

The data discussed in this report could not have been gathered without the willing cooperation of many people in Jersey Central Power and Light Company, Public Service Electric and Gas Company, the Twin Rivers Holding Corporation, the Township of East Windsor, and the architectural firm of J. Robert Hillier. We are also grateful to Mr. Edward Pickering, who contributed his personal weather records. The inventiveness, care, and teamwork of John Fox, Harrison Fraker, Jr., David Harrje, Norman Kurtz, Elizabeth Schorske, and Douglas Zaeh are everywhere in evidence in this report.

Figure Captions

Figure 1. Aerial view of Twin Rivers.

Figure 2. View of a building containing ten split-level townhouses in Quad. II. The box-like projection on the second floor is characteristic only of the three-bedroom units.

Figure 3. Winter gas and electric consumption, in therms, for 152 splits. (The 153rd split was not occupied until midwinter.) The coefficient of correlation for this population is 0.24.

Figure 4. Distribution of winter gas consumption for 82 three-bedroom splits and for a subpopulation of 20 three-bedroom interior splits without thermopane and with windows facing east and west.

FIGURE 1

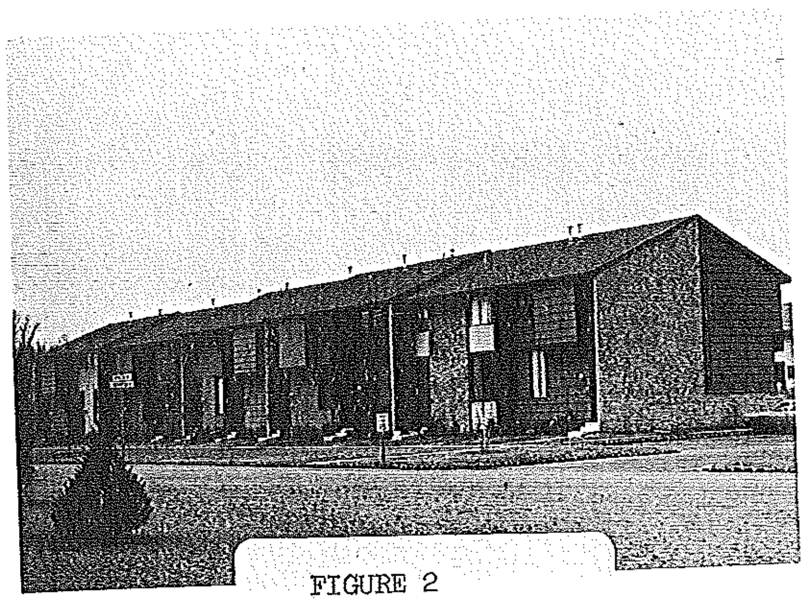


FIGURE 2

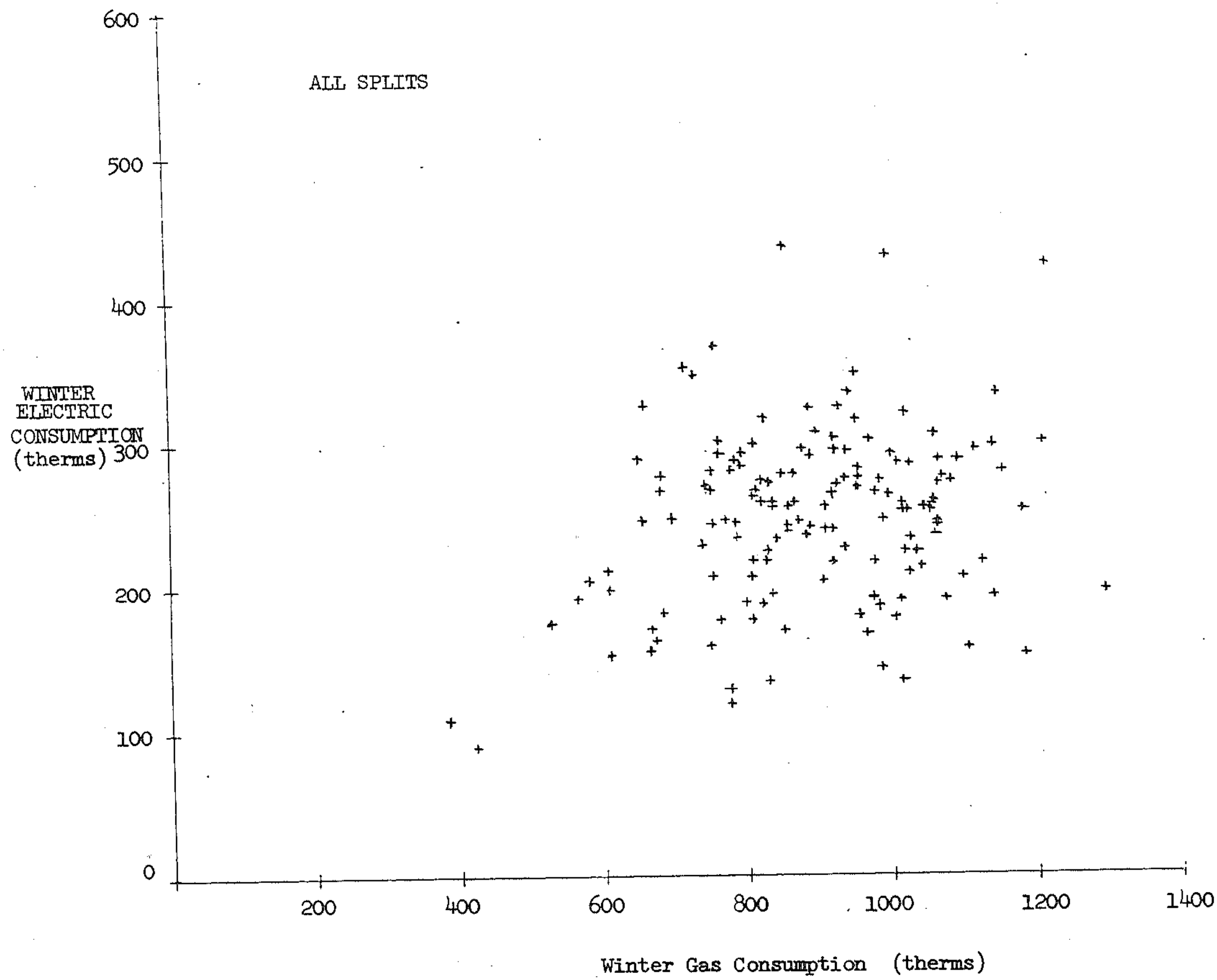
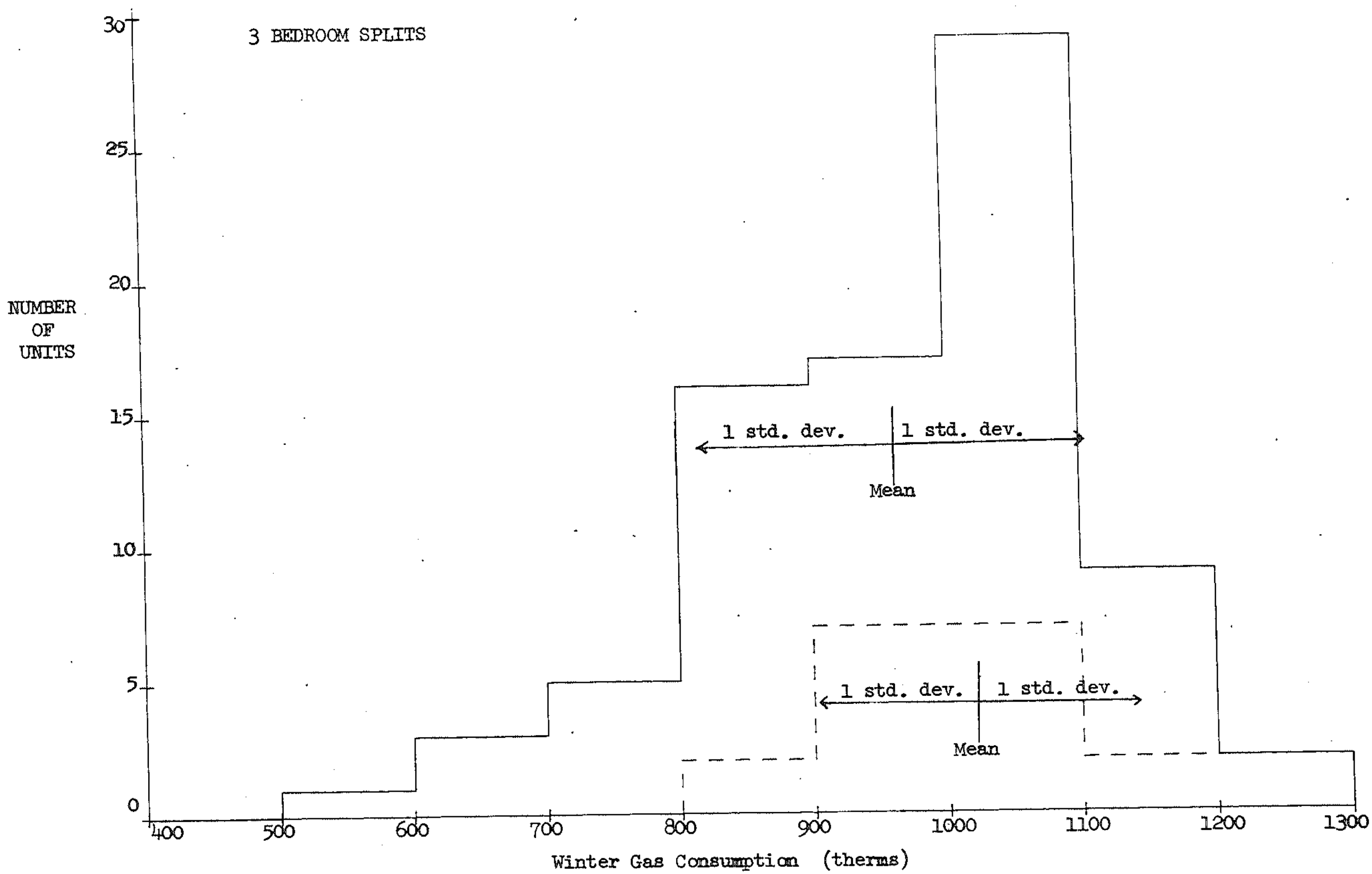

600
500
400
300
200
100
0
ALL SPLITS
WINTER
ELECTRIC
CONSUMPTION
(therms)
200
400
600
800
1000
1200
1400
Winter Gas Consumption (therms)

FIGURE 3



3 BEDROOM SPLITS
NUMBER OF UNITS
30
25
20
15
10
5
0
1 std. dev.
1 std. dev.
Mean
1 std. dev.
1 std. dev.
Mean
400
500
600
700
800
900
1000
1100
1200
1300
Winter Gas Consumption (therms)

FIGURE 4