Reprint Paper R-2

ENERGY CONSERVATION
Residential/Commercial Sector

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ENERGY CONSERVATION
Residential/Commercial Sector

Summary, Session II
Chairman: Robert H. Socolow
Princeton University

I am reminded of some advice that was given by a friend when he and I were getting into the environmental field: Hang a shingle in front of your center with the single word, "Disaggregate". Disaggregating is a very important research strategy. The argument for disaggregation is that (1) it adds reality; (2) it avoids nonsense; and (3) it builds up intuition.

I think we are seeing this at work in three of the research programs we heard about at this session. Mr. Sepsy and Mr. Dudley were reporting on the study of a single building; Mr. Cohen reported on an intervention in a single hearing, where rather specific technical issues were being discussed; and Mr. Stein and Mr. Gold were primarily reporting about a rather small number of buildings within the school system in New York City.

There was an emphasis in all the talks on user interactions, making the point, also made in the morning sessions, that there are people in these systems, and we have to understand how they work; the systems are not running themselves. The building in Ohio State had rather remarkable use patterns (clearly ones that were amenable to change), and the report reminded us that the people who are part of these systems are not primarily or even institutionally worried about energy. Mr. Gold made another point about people in systems that I think we ought to remember: He felt that the shaking up we are now getting is good for all of us. He argued that even if the outcome is not going to be conservation of energy (in the school system in New York City), progress is likely just because people are being forced to examine their assumptions over a quite wide range of issues.

We also learned that there are a lot of places where excess use of energy has been institutionalized; both the Sepsy paper and the Gold/Stein paper point out how lighting standards have driven the use of energy. There are similar mechanisms at work in the areas of ventilation standards, air exchange standards and perhaps even in humidity standards. Each of these standards has been made increasingly demanding of energy over the years. (Of course, temperature standards themselves come first of all.) The intervention in hearings on the part of knowledgeable people like Mr. Cohen, who essentially stand outside the system as it ordinarily works, is a very positive sign. How else are we to get fresh thinking than by that type of intervention?

There was considerable reference to modeling, as in the first session. The discussion following Mr. Sepsy's paper, about the calibration of the model for the Law School building, was a bit tantalizing. I drew the lesson that the iterative procedure which is part of the calibration of any computer model ought to be made part of the public record. There is something to be learned from the fact that a researcher managed to get his model to fit the data, but what is really interesting is what he has had to do to make the model fit the data. And today this is not typically part of the presentation of the work at hand.

Mr. Mattingly made a related point in a different discussion group: we ought to be seeing more intervention in computer models, more changing of hypotheses. After all, one of the beautiful things about a computer model is that you can do sensitivity analysis; it costs very little, once the model is finally running, to see what happens when you fiddle around. One of the troubling results of a model that appeared in the hearings Mr. Cohen attended was that when you have extra insulation in the building, it becomes harder to cool it down in the summer. Essentially, the insulation adds a storage capacity. But that dovetails with the remarks of Mr. Stein that many of these models do not permit the windows of the buildings to open. When you can open the windows of a building, the "result" disappears! It may be hard to change the professional way of building buildings, but it is surely not hard to add openable windows to models.

The Oak Ridge report has still another lesson to teach us about modeling. The social impact of their optimization model for amounts of insulation has been tremendous. The OEP reports publicized their results, as did the article in Science by Charles Berg. By now, a lot of people have become familiar with their diamond-shaped graphs; the Oak Ridge models have oriented their thinking. Why? Partly because they were early, but partly because they have very good "teachability". They are easy to grasp. The Oak Ridge work is an example of very good transfer of information. Of course, there are a number of problems; there really is a trade off. The Oak Ridge work is built on static heat load calculations, which are bent to predict year-long energy consumption. This allows the possibility of substantial inaccuracy and puts undue emphasis on insulation, as opposed to control systems, air infiltration and other factors which have not been identified as critical largely because they are a lot harder to calculate.

Finally, I want to call attention to a tendency throughout the conference to accept the technological reality of today as part of our reality indefinitely. We have heard very little discussion of the potentialities of hardware. There is hardware of two kinds: 1) hardware on the shelf, ready to be deployed when the price has risen or when a standard is changed one way or another, but needing attention to deployment and development problems, and 2) hardware still undreamt of. We must explore the possibilities for new technologies in the conservation field which can bring down the price of doing some of the things that we would like to do. I am more than a little disappointed that we heard so little about that type of approach to the conservation problem, and I hope that at future energy conservation meetings good technical ideas will be pressed upon us, everything from adding water to your fuel and getting better combustion efficiencies in the furnace, to tinted glass in the windows of houses. I personally believe the list must be very long. I refuse to believe we will be forever stuck with all of the grubbiness of the system at hand.

WORKSHOP I

ENERGY CONSERVATION
Residential/Commercial Sector

William H. Wetmore

The first panel session is being chaired by Dr. Harry Brown from Drexel University. Harry has experience in both the university and government, primarily with the AEC. He received his Ph. D. in Nuclear Engineering from Stanford University in 1966. He has been with Drexel for approximately four years and he has three rather interesting jobs there concurrently. He is Associate Professor in the Department of Mechanical Engineering, he is Associate Director of the Center for Urban Research and Environmental Studies and with that he is also Director of the Energy Sources and Systems Institute. That university experience is well coupled with industrial experience as I mentioned, primarily with the AEC in working on liquid metal fuel elements. So his basic area of research in liquid metals systems gives him a very sound foundation as he addresses energy systems. And I should add that although the work has its focus in Philadelphia, in each of the cases as far as the grantees are concerned, we are trying to use those as kind of bases so that the application to other like areas in the country can be achieved, so the transfer of the data to other areas becomes very, very important. Other areas in which he has been directly involved in Philadelphia include the Mayor's Science and Technology Advisory Committee Energy Section which started in 1972 and is continuing through this time. At the Federal level he has been working with the Federal Power Commission on the Task Force on Energy Conservation. And that has been primarily in standards and practices. So, from the NSF/RANN point of view Harry brings a great deal of experience and competence in the question of energy systems and energy conservation. I am very pleased to have him as our first chairman for the session this morning.

Harry Brown, Chairman

Our first speakers for this morning will be Robert Socolow and David Harrje, who will share their 20-minute allotment for the Princeton presentation and what I will try to do is hold it to twenty minutes. Dr. Socolow has completed both his graduate and undergraduate studies at Harvard University and completed his Ph. D. in 1964. He has been on the Department of Physics faculty at Yale University and now is an Associate Professor in the Department of Aerospace and Mechanical Sciences and a member of the Center for Environmental Studies at Princeton University. He is the principal investigator for two major research activities in Princeton; the first one is "Energy Conservation in Housing," sponsored by RANN and he will be talking about that this morning. The second one is associated with the Tocks Island research project, also sponsored by

RANN. He has served on a number of energy and environmental task forces and is chairman of the Academic Advisory Council to the Energy Crisis Study Commission of the New Jersey State Legislature. He has been very active in this field for a number of years. His colleague, David Harrje, is a senior research engineer and lecturer in the Aerospace and Mechanical Sciences Department at Princeton University. He has more than 20 years experience in experimental programs in liquid propellant rockets, aerodynamic heating, and combustion and pollution related problems. During the past two years he has concentrated on weather and home energy instrumentation and optimization of home appliances. These gentlemen have been actively involved in the energy field and I think their presentation this morning should shed some light into the problems of conservation of energy in housing and commercial buildings.

ENERGY CONSERVATION IN HOUSING
The Twin Rivers Project

Robert Socolow and David Harrje
Princeton University

Robert Socolow

I will discuss the site of our research and the research areas we have gotten into. I will also make two points about external interactions. Then David Harrje will discuss the instrumentation and analysis.

Our laboratory is a town 12 miles from Princeton called Twin Rivers, New Jersey. The town is located just beside the New Jersey turnpike. It was built on a flat potato field with very, very little landscaping. The town is a Planned Unit Development, which is to say that it has residential, commercial and industrial sectors planned together. It has approximately 2,500 residential units, and for our purposes it is terribly important that there has been repetition, the same residential unit, including the same appliance package, hundreds of times.

The basic housing types are all here: townhouses, apartments and single family houses. We have standard construction. The single family houses today are selling in the low 40's and the townhouses are selling in the mid-30's. When the town first began, the units were somewhat cheaper.

There is gas heating throughout the town, as well as electrical central air conditioning, and there are standard variations. There are either gas or electrical appliances, or a mix of the two, depending upon the portion of the town. There is a double-glass window option: when the individual buys the house, he indicates whether or not he wants to spend a few hundred dollars additional for double-glass windows. If he does, the unit is the same, the frame is the same, and the double-glass panels are set in after construction is completed.

Construction is conventional, typical of what one finds all over the Northeast--wood frame and masonry walls. The last section of the town is being completed now, whereas the earliest section was completed approximately four years ago. So there are areas in the town that will have four years of continuous occupancy data.

The residents of the town have urban backgrounds primarily. In most instances, this is their first home, and most families have one or two children. The town is increasingly homogenous as far as standard socio-economic categories are concerned. This certainly has some shortcomings for some types of investigations. But, as you will see, our conclusions at this point are that a strictly socio-economic approach to residential behavior is going to have severe shortcomings.

The research areas of our project can be divided broadly into a technical area and a social science area. A considerable portion of our investigation at first was based on the monthly gas and electrical meter readings. (We have acquired all of them since the town began, having received superb cooperation from the two utilities involved.) What you see in Figure 1 is the gas consumption during the two consecutive winters in approximately 200 townhouses, and the data appear quite reproducible. In general, this is the same family living in the same house. (There have been very few moves; houses where there have been moves form an interesting sample for further study.) In Figure 2 you will see that, in a given winter in a set of units where gas is used exclusively for heating, there is a very substantial variation (for the extremes, a ratio of two to one) in the gas consumption. A statistical measure of the variation is the ratio of standard deviation to mean, approximately 0.16, which is quite large. The ratio persists when you look at a subset where we have controlled for certain variables. The subset in Figure 2 is a set of units which are not end units, which have the same orientation east and west, and which do not have double-glass windows.

Figure 3 shows what happens when we plot gas against electrical consumption in the same unit. You might have expected to see the curve slant from upper left to lower right, if you were scientifically inclined, for if a resident uses more electricity you might expect him to use less gas, since the electricity is an internal source of heat. On the other hand, if you were sociologically inclined, you might have expected a slant from the lower left to upper right, since you might expect a resident who is profligate with one fuel source to be profligate with another. In fact, both factors seem to be present. You get this remarkable scatter, which indicates that we are dealing with a very complex situation.

We have observed a statistically significant energy penalty for being located on the windward side of the town, equivalent to having one half an extra outside wall. I think it could be regarded as an argument for landscaping. Here is a connection between energy conservation and forestry, which is not often made. Another area of our technical research which I think will be of interest to many of you here, but that is just beginning, is our study of commercial computer codes. These exist primarily for office buildings, and we are asking the question, how could they be adapted for the residential field? David Harrje will talk to you in a couple of minutes about the instrumentation for the on-site technical study. What I was talking about are primarily off-site programs.

Figure 1

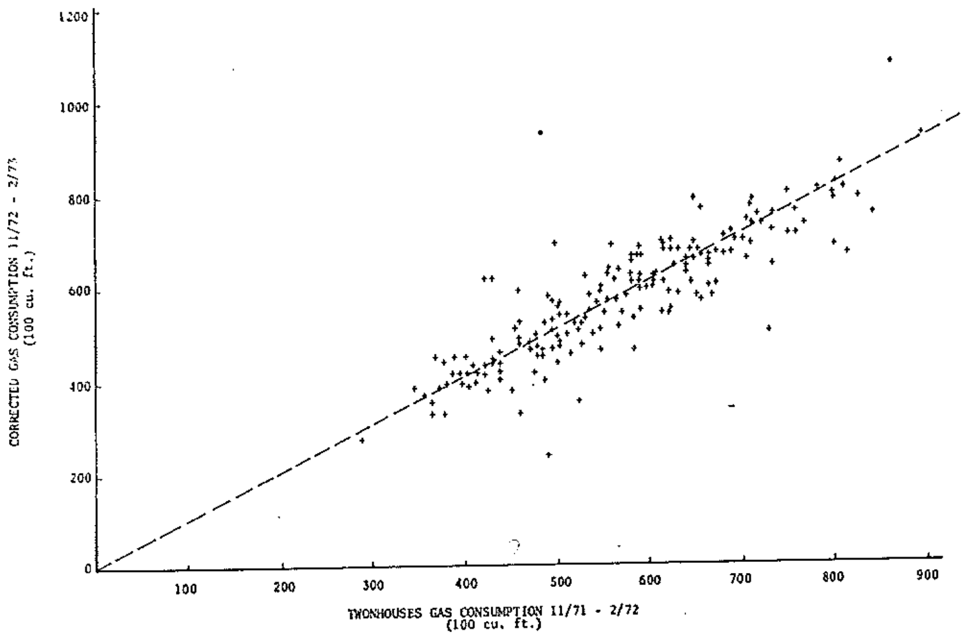


Figure 2

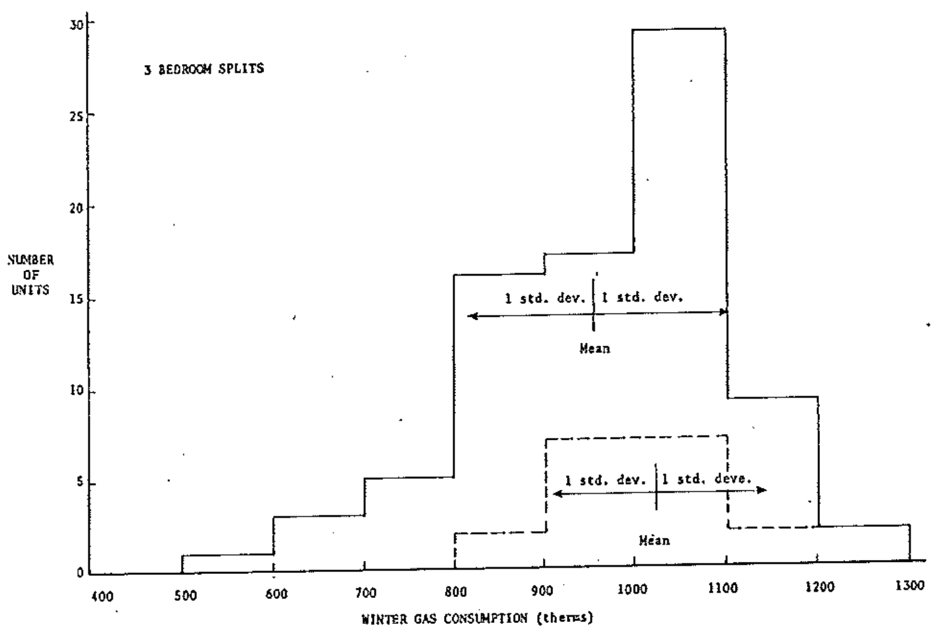
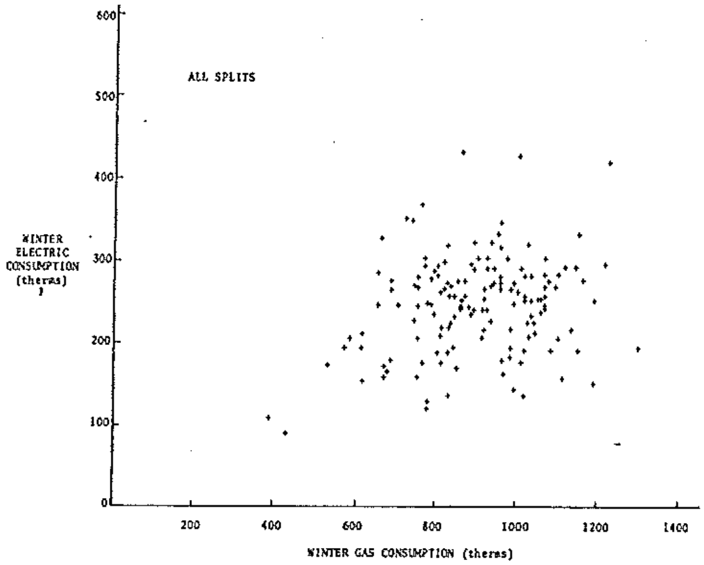


Figure 3



We have an additional program of research in the social sciences, and the characteristic of it, which we have sustained, is that it is not being done by engineers but by professional social scientists. We have two studies of this kind. One is a study of what happened so that the town was built the way it was, a study of "the development process." We carried out over 30 interviews during last year, interviews of the developers, architects, utility officials, and others, and we have come up with a substantial report which indicates how a town today in the East will tend to be put together, specifically in terms of decisions with energy consequences. To pick out one from its many conclusions, the report identifies the need for institutional mechanisms to promote consciousness of energy utilization at an early stage in the development process. Often, critical decisions are made such that everyone is locked into certain technologies and designs. Something like an energy impact statement, which would require the consideration of alternatives at the very opening of the project, would be the kind of institutional change which could promote and develop a whole new concept. It would make the professionals take energy conservation much more seriously.

The other social science project is a study of the residents. It has gotten underway over the last few months. The psychologist working with us developed a ten-page questionnaire with questions like "Would you rather listen to records or dance?" to get to the attitudes that correlate with energy use. Because we see so much variation in a town which does not have very substantial socio-economic variations, we conclude that there are very important issues which have to be arrived at outside of the typical approaches of sociology and economics. I think a fruitful approach will lie more in the direction of psychology. I am very interested in learning what things people actually think about that determine how they interact with the energy system in their homes. Closely associated with this phase of our research is an anthropologist who spent a summer living in the community and continues to work there on a very regular basis.

I would like to make a point that may be unpopular in this group here today. There is an issue of transfer of research to the University, whereas we are always talking about transferring results out of the universities. The Twin Rivers project is a very popular one at Princeton: it is sensitive in many aspects, and it represents an existence proof with skeptics, because it is going forward and has not foundered as many people thought it would. The project acts to transfer a research style to the University, so that the next RANN/University program is easier to locate.

We have received extraordinary cooperation, from all parties, even as far back as two and a half years ago, when energy conservation was not popular. The National Bureau of Standards has been our most important collaborator in the Governmental sector. We have been working very closely with them in every phase of the project, and we are jointly funded by the RANN program. The people we have dealt with to obtain data, such as utilities, the town and state governments, and the builders and architects, all have been extremely helpful. They share an appreciation for research, and continually provide us with insights into the full ramifications of the complex problem of housing.

To our delight, we have also received the generous assistance of the Twin Rivers residents, and we come to rely increasingly on their participation in the research. The residents express a growing awareness that their house is a technical system, and they want it to work properly. This may be a most significant development: an increasingly sophisticated consumer is willing to endorse new dimensions for regulation.

David Harrje

First I would like to familiarize you with the instrumentation systems that are being utilized at Twin Rivers in order to provide the data that we need so as to be able to answer the many energy-related questions. Throughout the town, which is at various stages of construction, we have located a number of instrumentation points. Central to the overall instrumentation plan is the weather information that is collected from our weather station atop the bank and fed back to us at the University. In Quad 2, we have three heavily-instrumented townhouses which provide 60 channels of energy-related information on an hourly basis. We also have three single family homes which will soon receive this very detailed instrumentation treatment. Over in Quad 4, construction is still in progress. We have been monitoring that construction with our architect, Professor Fraker, and his students and then we follow up with in-house surveys which are now in progress. George Mattingly is conducting these unoccupied building tests so that we can factor out the human element in home energy use. Throughout the town we are using more mobile instrumentation means to evaluate the magnitude of air infiltration within the homes, or evaluate the qualities of the insulation using infrared techniques in cooperation with NBS. The following are the goals of this monitoring effort which are to determine:

1. the load data for the residential energy consumption;

2. the major components of heating and cooling loads via experimental means;

3. the efficiency and adequacy of the mechanical distribution system;

4. the significance of thermal storage on energy consumption;

5. the effect of internal environment on appliance operation;

6. the effect of variation of temperatures throughout the home;

7. the frequency and importance of occupant-induced events on energy consumption.

In order to answer some of the questions associated with these goals, Figure 4 depicts what we had to do as far as instrumentation.

FIGURE 4

VARIABLES MONITORED IN INSTRUMENTED HOMES

I. DISTRIBUTION SYSTEM (temp., humidity and air flow for all ducts, supply and return).

II. INTERNAL TEMPERATURE (every room including attic and basement).

III. GAS CONSUMPTION (furnace).

IV. ELECTRICAL CONSUMPTION (house and range, hot water, A/C).

V. APPLIANCE CONSUMPTION.

VI. DOOR AND WINDOW OPENINGS.

VII. VENT FANS.

VIII. THERMOSTAT SETTING.

IX. WATER DATA.

Within the heavily-instrumented homes we are looking thoroughly at the heating/cooling distribution system, the duct temperatures, humidity, air flows. We have to find out why 75% efficient gas furnaces in the basement transmit only some 60% of the total theoretical energy into the homes themselves. The temperatures throughout the townhouses, including attic and basement, are vital to that question. Furnace gas consumption, and blower on-time are other parameters we monitor. The electrical energy consumption for the house is broken down into individual items such as the range, water heater, air conditioner and so on. Other, smaller appliances are monitored with individual plug-in boxes. We also obtain information as to when doors and windows open, when the vent fans are on and how the individuals vary the thermostat setting during the day. The final item is information on water usage which fits together with some of the studies being made by the NBS.

The key to our whole instrumentation approach is to know the local weather; some 18 weather variables are transmitted to us on an hourly basis from the top of the bank, a highly protected location, where we can rely on the instruments being there from one day to the next.

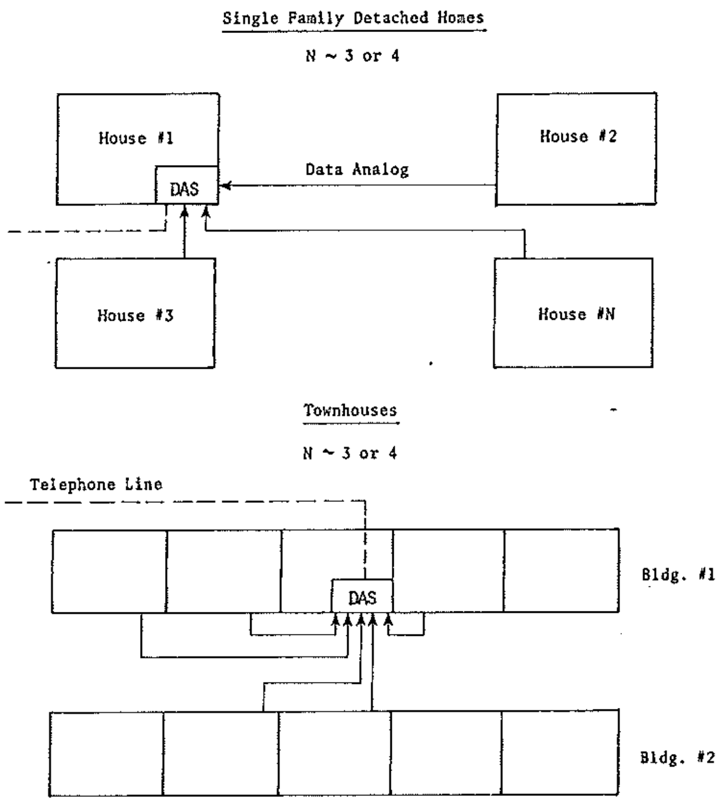
There are three townhouses that we are looking at in great detail, including an end unit. Inside the typical instrumented townhouse we have just taken the electrical distribution system and broken it down to major circuits with individual meters, and therefore, for example, we can determine exactly how much the range is being used with all its various settings.

Instrumentation not quite so obvious is one of many thermister probes which supply temperature data throughout the house. Still less obvious are small fan-type anemometers functioning inside the heating ducts themselves. We get information on the exact air speed and can calculate the exact mass flow rates through the ducts.

The data collection unit to which all our information is funneled is located in the middle house of the three and here we have our various electronic circuits, our integrating circuits, our tachometer cards and timing motors for events. Information is gathered here on electrical and gas consumption and other energy-related events throughout the house. The three lower units of electronic equipment is the data acquisition system which takes the 200 channels of information, (60 channels plus from each of the three homes) and transmits it in line, with numbered channels, over the telephone cable back to us at the University where we record it on magnetic tape and can analyze it on our computer. In the adjacent houses, a much smaller data collection unit is required, the top three shelves of the central unit; this satellite unit is cable-connected to the central unit. This modular concept is shown in Figure 5, which depicts the telephone hookup as well as the townhouses just described. One data acquisition system serves each group of homes sending the information back where we can handle it at the University.

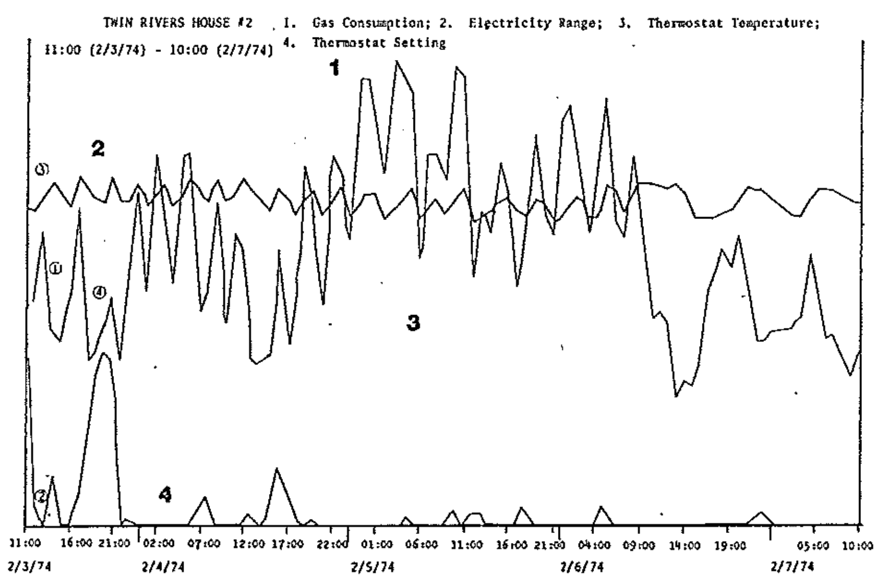
Figure 6 indicates some very preliminary data coming out of the program in the first few weeks of full instrumentation operation. Item No. 1 is the hourly temperature variation we are seeing within the home. Item No. 2 we see the variation as in gas consumption associated with furnace operation. Item No. 3 we can see how the individual in the home has been adjusting his thermostat up and down during a three-day period. Finally in

Figure 5



MODULAR CONCEPT FOR DATA ACQUISITION FROM GROUPS OF DWELLING UNITS

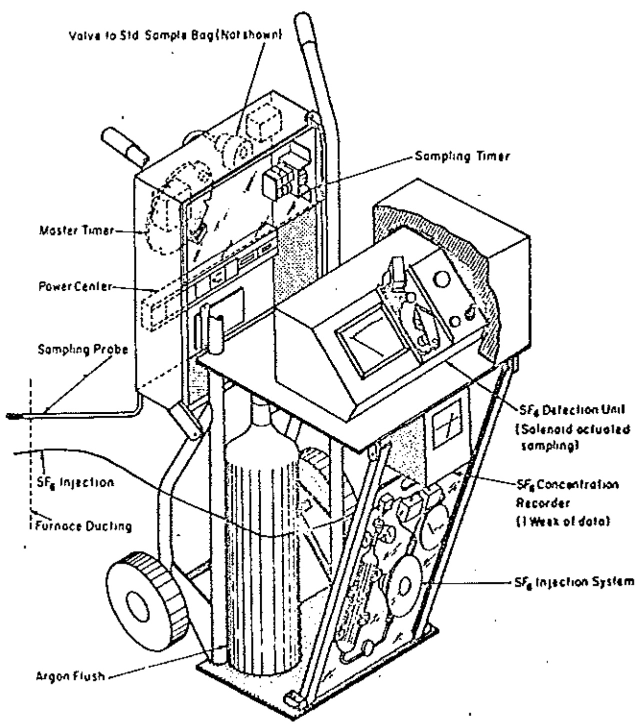
Figure 6



Item No. 4 we see a typical appliance-type load. Here we can see exactly when the individual turned his range on and off and we are discovering some very interesting living habits where sometimes at 4:30 in the morning the range comes on to cook an early cup of coffee.

So far I have talked about more-or-less conventional instrumentation in the home, although we have made use of the most modern electronic instrumentation advances in order to best collect and transmit these data. When we come into a house and try to get information on a parameter such as air infiltration, which accounts for approximately one third of the heat loss in the house, we have to go to a little more exotic instrumentation methods. Figure 7 shows such instrumentation which uses SF_6 as a tracer gas. Three functions are performed: first, every three hours a small quantity of SF_6 is injected into the duct system (the duct system distributes the gas throughout the house). Every 15 minutes, a master timer allows three individual samples of SF_6 gas concentration to be taken and recorded using the SF_6 detector unit and strip chart recorder. Strip chart and gas supplies last for a period of a week unattended on site. In the system there is also an additional standard concentration container that allows the unit to recalibrate once every three hours to make sure that the system has not drifted. Using this automated air infiltration unit, developed at Princeton based on pioneering work at NBS, we will be better able to get an overall picture of air infiltration and resultant heat loss. Now we can collect data over one week where data in the past was limited to a few hours.

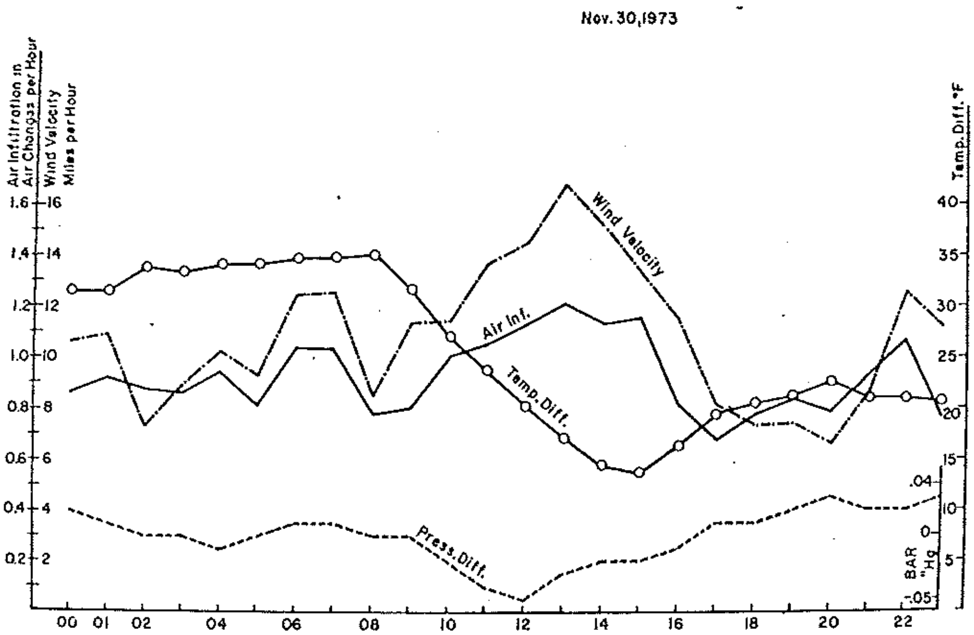
Figure 7



AUTOMATED AIR INFILTRATION UNIT

Figure 8 shows some preliminary data using this air infiltration unit in a townhouse; we have also plotted here typical parameters normally associated with air infiltration. The pressure differential, the wind velocity, the temperature differences (inside minus outside) and the air infiltration itself are shown versus time. I will have to say that the air infiltration from this and more recent findings is following the wind velocity most closely and certainly we recognize from the NBS tests that it also is a function of the temperature differential as well. The pressure difference, however, seems to have little influence on air infiltration.

Figure 8



Returning our attention to the original architectural concepts in a development such as Twin Rivers we have to remember that planned unit developments are becoming more and more prevalent in the country; just in the small state of New Jersey there are 67 communities planned. The backbone of the PUD plan is the townhouse; it is important that we should look at the details of the floor plan. One of the very key points of this floor plan is the party wall (fire wall) that separates one unit from the other and the construction details right at that location. Here we are attaching a masonry wall to a frame structure and the photographs taken by our students indicate that there are great problems as far as working out an adequate seal in such cases; indeed this is one of the topics that we want to probe more closely during the coming weeks. The NBS team is working with the Thermovision system to infrared scan the wall. The infrared scanning technique is a very accurate way to determine surface temperature variations. The camera is focused right on the inside, lower front corner of the living room adjacent to the party wall. Remember that the party wall partition is uninsulated and depends on the external seal to keep air from moving behind the sheetrock interior walls. The external seal has not really worked out too well. If we look at the same corner in infrared, the outside wall is at a relatively uniform temperature even though it is facing the weather, but the party wall and the corner is quite cool, some five or more degrees centigrade cooler than the outer wall temperature. We can see that following along the party wall there are low temperature regions between each pair of studs, and the pattern in some cases may feed back along that party wall across the entire living room indicating a possibility for significant heat losses. This is a feature that one really has to take into consideration in designing the many future replicas of this building design.

The infrared technique can also be used to look at the exteriors of buildings. Scanning a number of townhouse units at a distance, we can see the effects of the sun that has recently been heating the wall surfaces of the townhouses; even though the sun has set, there are still some residual effects. We can also see clearly where the window areas are located in this building. Care must be taken with glass surfaces and metal frames because of emissivity differences in infrared viewing. The scanning technique might prove quite useful externally to give a broad brush view, searching where major problems in construction might be manifested in a building. This technique allows one to critically probe already constructed buildings, a feature characteristic as well of the air infiltration technique just mentioned. These new techniques are being perfected. We are only in the early stages of benefitting from infrared scanning and the monitoring of air infiltration. Data from heavily instrumented homes is just becoming available and computerized so that we can obtain maximum benefits from the data.

Questions and Answers Following Socolow and Harrje Presentations

Question: Was there any effort to correlate the mechanical design of heat losses with the infrared performance of the building, the recorded performance of the buildings?

Harrje: I would say that this is in the very preliminary stage. Actually the on-site usage, beyond the work that is being done at NBS under more controlled conditions, has been only in the last few weeks. We are just getting to the quantitative stage to evaluate that kind of question.

Q: Would you translate the windward penalty. You said one third of a wall; I'm not quite sure I understand that.

Socolow: I said about one half an outside wall. The penalty for being an end unit is about 10% of the total winter heat load and it corresponds pretty closely to the fraction of the typical heat loss calculation which is due to an extra end wall. The penalty for being on the windward side in this town was roughly half that size.

Q: Does being in the windward side have some benefits during the summer when you might get some cooling effect by having an increased airflow through the house?

Socolow: It might, but I am not certain of that.

Q: Does the wind being in the winter from the northwest and in the summer southwest mean that you do not get this effect?

Socolow: Seeing this in the summer time is very difficult because air conditioning has much more behavioral noise in it than the gas consumption in the winter, so we have to have a much more controlled system, which we do not have yet.

We began with heating largely because it is so much more straightforward. The behavioral patterns are graphically different for summer air conditioning. But it may make sense to study behavioral patterns primarily in the summer just because things are more dramatic. For the analysis of the quantitative methods like heat loss calculations, it has so far been much more productive to look at winter energy consumption.

Harrje: The hour-by-hour data from either the townhouses or the individual houses is still awaiting a cooling season, so that we really do not have the detailed information as to air conditioner usage and weather effects.

Socolow: The performance of the individual units, with the data acquisition system which has been in place only since the winter, will tell us a great deal as to how the air conditioning works.

Q: Could you comment on why you think changes in the consumer's attitudes are so important?

Socolow: I am not sure I am the best person to do that but it does seem that if the builder is correctly assessing his market and the customer still does want a low first cost, then if customers change and builders stay keen, there will be a new ball game. I am suspecting and predicting that an increase in sophistication on the part of the customer will change the rules.

Q: This study has been going on during a period in which personal energy uses become somewhat a social matter and I wonder how you take any steps to avoid the possible problem of the fact that people know that you are measuring what they do, consciously or unconsciously.

Socolow: Of course this interests us and does concern us. I think that we have several forms of protection against this. One is that we are looking over long periods of time. It is not very easy to stay self-conscious for very long in this area. Second, we have kept primarily a low profile. A lot of people know we are there, and they like it that we are studying them but we have not made a great attempt to teach or to try to modify what they do; in no sense have we tried to carry out that type of intervention. And third, we have data on a number of units before this recent period and would detect various substantial changes in behavioral patterns. I do not think that we see them. I might add that the town has gas consumption for heating, in which the supply question is far more indirect than in the fuel oil situation. There is no chance for gas running out, and that may mean that people are far more relaxed in this regard.

Q: Do you see enough variation in the construction practice to be able to identify any substantial change?

Socolow: This is a research goal that we are presently dealing with. We do not at this time. These units that were constructed and monitored during the summer have just been occupied during the last couple of months. And we are carrying out two types of research to address your question. One is to look at the aggregate gas consumption for the remainder of this winter to see if it correlates with some of the indices of construction quality which Professor Fraker developed. The second is to go into particular units, such as where infrared pictures were taken, and ask: Do we see the consequences of the faults that we have detected during the summer? I think the answer to that is Yes.

Harrje: Yes, it is clearly evident that we did see the faults. The problem in working out some kind of a rating system is assigning proper weighting factors. Can you rate a dwelling in the construction phase predicting what it is going to use in energy later on, without knowing accurate breakdowns between conductivity and air infiltration heat losses?

Q: What do you know about people's heating patterns at night?

Socolow: A major gap so far in the research is that we have not known the thermostat settings in the homes we have been looking at with the exception of the three units that have been instrumented in detail. One of the critical lines of questioning in the questionnaire that has been developed is: What are your thermostat patterns and how come you do what you do? Of course, we are going to try to check that to see if people are really about to describe this. That will be an area of research for our program next year.

Q: Can you say a few words about how the data back up the conclusion that psychological variables rather than socio-economic variables seem crucial?

Socolow: I would say that two types of data explain this. First, data on the community as a whole. Broadly speaking, this is not a community with a very wide range of income. It does not have either the very rich or the very poor. It is also an increasingly homogeneous community; most residents are coming from New York City and moving to their first home. The original part of the town was much more diverse, coming from a wider area geographically. The variation we see is first of all substantial and secondly not particularly smaller in the later parts of the town than in the first one. Now that does not say the variation is due to psychological factors, but that might be a good place to look. Second, data from a statistical analysis we performed. In a statistical test we had the income, the number of children in the family, and the place of origin, and we did some tests as to whether any of these factors correlated with gas or electric consumption. And under this type of sample the answer was no. The number of children did not correlate with the electric consumption.

Q: Are these houses equipped with sufficient equipment to allow enough heating in the worst weather?

Harrje: I would say if anything the houses have furnaces that are oversized. We can tell that from looking at the detailed information on how long it takes to make a temperature adjustment after a thermostat setting. One of the things we might like to do is to reduce the gas furnace orifices to cut the heating capacity down to where it more properly fits the given unit and see what happens.

Q: How about the air conditioning?

Harrje: The air conditioning equipment seems to run rather steadily in the summer period. Where there seems to be inadequacies is that in certain of the townhouses the builder changed the ducting, moving the furnace and the central distribution system somewhat off the center of the house. Immediately, the air conditioning deficiences were evident. In the Quad 3 area certain individuals have added bedroom air conditioners just to boost the system. I would have to say that even in other units the air conditioning is marginal on the hottest days.

Q: Do you have any idea of attitudes toward comfort?

Harrje: Well, this is one of the topics that we are trying to get more information on using the questionnaire, for example, to find out something about the clothing habits without asking the question, "do you take off your clothes when it gets hot?"

Q: Another question, out of all the data that you have collected, have you begun to establish or make available information on the significance of the lack of insulation or other structural details vs. some living habits and other patterns?

Socolow: This is the goal of the current stage of the research. As we pull this together, we have as an integrating tool, the National Bureau of Standards NBSLD Program which we will be both checking and using to integrate our data. We do not now have what we are after, which is the quantitative partition of the energy: A quantitative energy balance that checks and then partitions the energy into what goes into the various sectors. We can say that the rule-of-thumb heat load calculations are not far wrong in predicting average consumption. But we do not have what you are asking for yet and of course that is where we want to get.

Q: As a corollary to that if I can ask one other question. In most buildings that are covered by a code, the air infiltration or air introduction is something that has to be done mechanically after the air infiltration has been eliminated. Has anything been done to establish the desirability of a certain amount of natural respiration or infiltration in the building as a physiological trade-off against having to introduce fresh air mechanically?

Harrje: The combustion air comes in through cracks between the basement and the rest of the house. I should also mention that we really noticed in our townhouses an unexpected source of heat loss; the basement was directly connected to the attic through about a one-foot square opening that surrounded the transite pipe that carried flue gasses, so that heated air in the basement moves to the attic and out through open vents in the attic. Hence, there is this other air circulation set of events that takes place simultaneously with what goes on in the living space.

Q: Are any of the builders using this information in the area in their design or construction such as this one particularly?

Harrje: I would say not yet. We have talked to several builders groups and to comfort engineers, and so on, to try to get them to spread the information that we have to others, but I have not seen that we have much evidence that this is being incorporated in changes so far.

Q: Is there any change in the financial incentives, either to the builder or the purchaser of the homes that might reflect investment since the project has started?

Harrje: Well some of the financial arrangements the builder has been allowed to make have changed. Earlier, one might for instance have an electric water heater put in because the electric company was offering subsidies to get it in, and then the consumer would be paying through the rest of his home ownership, higher energy bills to have that appliance. Now, that kind of thing has stopped. So there is no longer an influence to put something in there that is a long-term detriment to the homeowner. But in other areas as far as inducements or making it very well known to the buyer of the home exactly what the heating and cooling bills might be, we have not any evidence of this. But I see, for instance, in the appliance project that I am directing, there is one of the new appliances, a refrigerator, marketed so that the shopper sees clearly stated on the front of the refrigerator that it will pay for itself in ten years by saving on electrical consumption. What we see in the lab is it will do just that.

Socolow: I will follow up on that question if I may. Our own results, for example the results on savings on double glass, are used today by the salesman who is attempting to help the people make the decision as to whether to go for the double glass option or not. Second, midway through the construction of this town, the FHA property standards were constrained with stricter rules on insulation. Interestingly enough, when the builder went back to look at his design to see if it was already within the new rule, he found that he did not have to modify his construction. I must say that my impression is that those new rules, as far as New Jersey is concerned, brought the FHA standards up to the prevalent practices of the times.

There is in identical units, a shift between the second quad and the third at Twin Rivers from electrical water heater, dryer and range to gas. Now, we have made a quantitative comparison of the electric and gas consumption through the winter, and of course the gas consumption in Quad 3 is larger and electric consumption is lower. By subtraction separately for gas and electricity, we can make an energy comparison and a cost comparison. In the energy comparison the energy consumed for the gas appliances is about two thirds of the fossil fuel energy required to produce the electricity for the corresponding electric appliances. We are averaging over several hundred units so that we're probably canceling out the usage pattern differences that would be important in smaller samples. It is certainly energy conservation to make this change to gas appliances. The shift was brought about, as Dave Harrje mentioned, because the electric utility was no longer allowed to make certain financial arrangements with the developers to have these electric appliances put in.

In terms of cost, the cost for gas appliances was cheaper also, compared at present prices. In the shift from electricity to gas appliances, the developer had to give up about $100 per unit in credits from the electric utility. But the customer is paying $50 more in extra costs for utilities if he has the electric appliances. He would have gladly paid the developer the same $100 if he had been at all conscious of what was happening.