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END-USE LOAD AND CONSERVATION ASSESSMENT PROGRAM
THE RESIDENTIAL PILOT STUDY

By
G.B. Parker
E.W. Pearson
W.F. Sandusky

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Pacific Northwest Laboratory
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SUMMARY

This report documents a residential pilot study designed to test procedures for conducting the full-scale Residential Base Case Study for the End-Use Load and Conservation Assessment Program (ELCAP). This program, which is sponsored by the Bonneville Power Administration (BPA), will provide electrical energy use data on a variety of buildings and residences within the BPA's service area.

The residential studies will meter approximately 600 residences throughout the Pacific Northwest. Four specific tasks were tested in the pilot study: recruitment of residences, installation of the metering equipment, acquisition of data from the metering equipment, and data management. Each of these tasks will be part of the full-scale study that will be completed for BPA's service region. The pilot study was designed to simulate, within reason, the actual conditions that would be encountered during the full-scale study.

Results of the pilot effort were instrumental in planning and implementing procedures to be used for the full-scale study. For example, during the recruitment phase, we learned that the homeowners' decision to participate in the study could generally be determined by our initial contact call; that is, if an interview could be scheduled, the homeowners generally agreed to having metering equipment installed in their homes.

Although installation of the metering equipment was not, in itself, a major obstacle, the pilot study indicated that most electrical contractors were not familiar with the metering technology or with the use of current transformers to make electrical load measurements. Therefore, an additional procedure was developed to catch obvious errors while the contractor was still at the installation site. This procedure, known as a standard load test, was tested in a post-pilot study and will be used in the full-scale study.

Acquisition of the data from the metering equipment depended almost entirely on the quality of the telephone service to the site. Several of the regions within the BPA's service area are serviced by phone companies with substandard equipment. The poor quality of the telephone service made additional error checking routines necessary. Determining the optimum time for interrogating the data logger was one useful strategy.

Data management activities were greatly revised as a result of the pilot study. Because of the variety of possible installation-related problems, a substantial effort went into designing procedures to verify the data. Fortunately, it was possible to design verification procedures so as to be effective as ongoing verification tools once routine data collection began.
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The End-Use Load and Conservation Assessment Program (ELCAP) is designed to improve understanding of the energy performance and conservation potential of buildings in the Pacific Northwest. This program, which is sponsored by the Bonneville Power Administration (BPA), comprises a number of different studies which require similar data and which take advantage of a single, common metering technology. Seven of these studies rely on metering end-use electrical consumption in residences which currently exist, are being built to current construction practice, or are being built to standards proposed by the Northwest Power Planning Council. In total, approximately 600 residences will be metered.

To prepare for these large energy metering studies, Pacific Northwest Laboratory (PNL), who is conducting the program, first undertook a pilot study to test various program elements (i.e., recruitment, installation, data acquisition, and data analysis) before beginning the full-scale study. The pilot involved recruiting residences and installing metering equipment in 18 residences throughout the region. Two of these residences were in Montana, six were in Oregon, and 10 were in Washington. The pilot study began in the spring of 1984 and was completed in the late fall of 1984. Since the residences are also part of the full-scale study, electrical end use data continue to be acquired from these sites on a routine basis.

The actual data collected during the residential pilot were not the principal objective of the effort. Rather, the goal of the pilot study was to test the initial procedures prepared for completing the various program elements, allow PNL staff to become more familiar with the effort required to meter residences, test the metering equipment under field conditions, and provide training for, and evaluation of, prospective installation contractors for the full-scale study.

Each of the respective task areas had specific objectives to be completed during the pilot. For example, the primary objectives of the recruitment effort were to determine the most effective method to contact the homeowners, secure an appointment, and explain the program and the Cooperative Agreement. The main objective of the installation task was to determine if the initial installation procedures prepared by PNL could be understood and used by the installation contractors. The secondary objective was to provide the contractors sufficient experience with the data acquisition equipment and installation practices to bid installation of the equipment for the full study.

For the data acquisition task, the pilot study was designed to acquire experience with telecommunications between the central data acquisition equipment and the units in the field, to test parameter entry software and protocols used to initialize data collection activities at the field unit, and to determine what irregularities related to data acquisition may occur. The objectives of the data management task were to exercise data management protocols, specifically for data transfer from the central data acquisition unit to the minicomputer on which verification activities would be completed, and to develop data verification techniques.

This report describes the various program elements tested in the pilot study, the experience gained during the study, and resultant changes in procedures that will be implemented for the full-scale residential studies. The report is organized
according to the sequence of events followed in the metering program. It begins by describing how the pilot residences were initially selected and recruited. Next, the various installation activities are described. Finally, the performance of the data acquisition and analysis systems is described, along with the quality control activities used to ensure that the collected data were accurate.
2.0 RECRUITMENT ACTIVITIES

The goal of the residential pilot recruitment was to field test recruitment procedures and to train staff for the eventual recruitment of the full sample. Specifically, the pilot recruitment was designed to evaluate the following:

- effectiveness of the initial contact letter
- effectiveness of the initial phone contact
- process of making appointments for interview
- occupant's understanding of program during the interview
- occupant's understanding of the Cooperative Agreement and difficulty of getting Agreement signed by occupant
- adequacy of information obtained from the structure survey and breaker circuit panel survey
- adequacy and usefulness of the forms filled out by the recruiter
- contingency plans in the event of refusal or rejection by the occupant
- coordination of phone installation activities
- access payment schedule, negotiation, and amount.

2.1 INITIAL PROCEDURES AND OVERVIEW OF PILOT RECRUITMENT

Before beginning the recruitment activities, a document was written outlining all necessary plans, procedures and forms to be used to recruit residences. Procedures were also established for a filing/tracking system and for the transfer of information to other tasks within the project (e.g., installation and data base management). These initial procedures were designed to address the various elements envisioned for the recruitment process. Those elements are listed below and displayed in Figure 1.

1. Identify residences.
2. Divide BPA service territory into recruitment regions.
3. Mail introductory letters and phone residences to assess interest.
4. Schedule and conduct interview and sign Cooperative Agreement.
5. Select sites, notify resident/owner, and schedule phone installation.

Eighteen residences were chosen for pilot recruitment, which was designed to recruit at least two residences for each pilot installation contractor. The residences were 'primary' residences selected from a list of 1000 (500 primary and 500 replacement) residences from the 1983 Pacific Northwest Residential Electrical Survey (PNWRES), which was supplied by BPA.

The recruitment was conducted by seven PNL staff members and ran from April 5 through July 7, 1984. The recruiters were assigned to make the initial telephone contact to determine interest in the program, set up an interview at the residence, and recruit the houses. In most cases, occupant interviews were conducted with all adult members of each household, and were conducted during all hours of the day up to about 8 p.m. Generally, only retired or self-employed residents could be interviewed during daytime working hours (8 to 5 p.m). The amount of time required to complete the recruitment activities at the residence was about 1.5 hours.

As part of the recruitment process, an INWATS telephone line was established for the use of recruiters when in the field and for residents to use should they have
questions or problems with the program. This line made it possible for the recruiters to call into the PNL offices at any hour to pick up or leave messages; this was particularly useful since some of the field work took place in different time zones. No residents used the INWATS service during the pilot program.

The pilot recruitment also included the tasks of arranging for phone line installation, developing procedures for making 'nuisance' payments, and actually getting the payments to the occupants. The payments ranged from $50 to $150 depending upon the amount of equipment installed and inconvenience to the resident.

2.2 DESCRIPTION OF THE PILOT RECRUITMENT

The first set (14) of residences were initially chosen from the Tri-Cities, Washington area (where PNL is located) in order that we might more closely control field procedures and more easily oversee installation activities. Once the 14 residences in the Tri-Cities area were selected for recruitment, initial contact letters were sent. The recruiters followed up with phone calls about a week later. Of the residents contacted, none returned the stamped postcard supplied with each letter, which requested an expression of interest and resident telephone numbers; however, two residents called us directly (on our office phones) to indicate their interest. The recruiters were able to schedule interviews with 12 of the 14 residents sent letters; these appointments were scheduled within 2 weeks of the phone calls. Of the two residences for which we were unable to set up interviews, one was a tenant-occupied house with the tenant temporarily unavailable and later recruited; the other residence was found to be unoccupied.
All 12 residents interviewed agreed to participate in the metering study and signed Cooperative Agreements. This high percentage of signups (12/14) was expected in the local area as the population was familiar with PNL and they had no doubts about the legitimacy of the study. We anticipated a lower success rate in other parts of the region where PNL was not well-known. These first pilot interviews were also used to train two additional recruiters to be used in the full-scale study.

Residences were also recruited in Oregon for the pilot study because of the Washington State requirements regarding general and electrical contractors. A contractor licensed in Oregon was not allowed to work in Washington; he had to obtain a general contractor's license in Washington before obtaining services of an electrician in Washington. (This is described more fully in Section 3.2.) Since the pilot study was also being used to train a number of different contractors from all over the region, it would not have achieved our purpose to use only Washington contractors. Additional candidate pilot residences, in Central Oregon and Portland, were supplied by BPA in order to accommodate two additional installation contractors. Although we needed only four residences in central Oregon and two in Portland, we sent contact letters to eight in central Oregon and four in Portland because we anticipated a lower success rate for these areas, and additional candidate residences would need to be available for the recruiter in the field.

Of the eight residents sent letters in Central Oregon, none returned the postcard indicating interest, one refused on initial phone contact, and only three were contacted from the office before leaving for the field. Either people were not home when we called or the phone number was unlisted. Phone numbers were not supplied by BPA as part of the resident's information and needed to be identified through directory assistance. Once in the field, the recruiter was able to contact two additional residents. One resident contacted by phone was leaving for vacation and declined an interview. This resident was placed on hold for the full study. The recruiter was unable to telephone or locate one residence (very rural area and the occupant apparently left town with his residence—a mobile home), and the other resident declined an interview (because of family problems). An attempt to make "cold" contacts (no initial contact letter) with two replacement residences proved unsuccessful—they refused over the phone. Of the original eight letters sent, interviews were successfully conducted with three residents, all of whom signed Cooperative Agreements.

All of these residences were from the case studies samples (either mobile homes, renters, attached residences or gas/oil heated residences), which was not expected. We had anticipated that all pilot residences would be from the Base Case sample (owner-occupied, single-family, detached units), which were considered easier to recruit.

Of the four residences sent letters in the Portland area, none returned the postcard indicating interest in the program. Before leaving for the field, we were able to contact two residents by phone. One resident agreed to an interview; the other was too busy to meet with a recruiter at that time. This resident was put on hold for the full recruitment. The third residence was not listed in the phone book and was thus not contacted from the office. The fourth residence could not be contacted after several phone calls.
The field recruitment resulted in a successful interview with the one resident contacted before leaving for the field. After visiting the residence with no listed phone number, the recruiter learned that the original occupant had moved and that the house was being leased to new occupants who had no authority to sign an agreement without the owner's approval. Information was left with the current resident to pass on to the owner (who had moved outside of the region). This house was left to be considered as part of the full study.

Since we were still short one house in Portland, we sent letters to two additional residences. We were able to contact occupants of both residences by phone, and both were successfully recruited in a second trip. The two Portland residents we were unable to contact in the first recruiting trip were eventually contacted and successfully recruited, making a total of four residences in the Portland area for the pilot. The Portland recruitment effort was successful on only 50% of the residences sent letters, and it took two recruiting trips from Richland to recruit the two residences. However, as with the recruited residences in Central Oregon, which had an even lower rate of success (3/8), the recruited Portland residences were all part of the case study sample (in this case, the gas/oil study), a more difficult sample to recruit.

Because two of the nine installation contractors were based in Seattle, we decided it would be cost-effective to recruit four residences in the Seattle/Tacoma area for them rather than having them travel to the Tri-Cities for installations. Letters were sent to ten residences—three in Tacoma, two in Seattle, and two north of Seattle. Phone contact was made with five of the residents, four of whom were interested in talking to a recruiter. The one resident refused over the phone. Contact was later made with one of the owners (a rental case study), who informed us that the residence was currently vacant. This residence was put on hold for the full study. Of the four we were unable to contact, one resident had an unlisted phone number, one had no phone, and the other two were simply never at home.

The recruiter conducted successful interviews with three residents whom we had previously contacted and was able to make an appointment with the resident with an unlisted phone number by knocking on the door. This resident was also successfully recruited. One resident who had agreed to an interview later became ill and was put on hold for the full study.

A recruiter later contacted the other two residents by phone. One resident was successfully recruited. The other resident had sold the house since the survey, but was kind enough to give us the name of the new owners. He also offered to call the new owners and tell them about the study before we sent out the initial contact letter. The new owner was later contacted by phone, interviewed, and recruited. A total of six out of ten residences were recruited in the Seattle/Tacoma pilot study. Of those recruited, two were gas/oil case studies and the remaining four were from the base case.

2.3 PILOT EXPERIENCE

The recruiters were generally trained in the field, which proved a quick and effective method of learning interview techniques and what to note for the structure and circuit breaker surveys. The Recruitment Manual developed for the interview also proved to be an effective tool for explaining the study and the details of the
monitoring. Many of the technical questions anticipated to be asked by residents were discussed with recruiters. If, during the interview, the recruiters were asked questions for which they had no answer, they would simply tell the occupants that they did not know the answer but would have the correction information transmitted to them at a later time.

Because recruiting in the field depended heavily on personal style, success depended quite a bit on the manner and presentation of the material (e.g., the personal approach of the recruiter) as well as on the content of the presentation. Choosing recruiters who were somewhat aggressive, on the phone and in the residence, and who could deal with hostile or uneasy residents was as important as choosing recruiters who could answer technical questions related to residential structures, circuit breaker panels, and the electronic instrumentation. For example, it was important to be able to gain the confidence of a hostile or uneasy occupant and reassure them that the study was important, legitimate, and would not be a great disturbance to them. All recruiters had a good mix of these qualities, which probably accounted for the recruitment's success rate once an interview was conducted: in every home in which an interview was conducted, the residents decided to participate in the study and signed the Cooperative Agreement.

The skill of the person making the initial phone contacts proved to be just as important as that of the field recruiters. She had a good knowledge of residential structures, telephone techniques, data base management, and sources for finding information about owners and occupants of residences. Her initial telephone calls effectively screened those residents who had no interest in the study—an invaluable time-saver. If residents refused upon this initial contact, letters could be sent to replacement residences before recruiters left for the field. In this first phone contact, the residents were asked to specify the best time to reach them at home, information which helped the recruiters to begin organizing their time and schedule.

2.3.1 Documentation/Coordination

The pilot study provided a good test of the documentation and filing/tracking system as well as of the recruiting procedures. Individual folders were assembled for each resident to be recruited and contained all the forms for filling out during the interview, along with a copy of the initial contact letter. Once a house was recruited, the folders became part of a permanent file in a central location, where the information was now available to other tasks. It soon became apparent that there were many uses for the information on the forms, which were, therefore, made on multipart forms so that the information could be distributed.

Polaroid cameras were used to record the structure (outside), circuit breaker panel, woodstove, and the selected location of the data logger, temperature sensor, and phone jack. These photos were used in making installation decisions and especially in determining sites for weather stations.

Because the pilot study was conducted in several phases, it did not require a lot of coordination between the recruiters in the field and the laboratory. Thus, the pilot study did not sufficiently test the coordination that would be required in the full study. During the full-scale study, it would become necessary to coordinate several recruiters in the field at one time, sending dozens of letters a week, phoning dozens
of people a week, arranging for phone installation and payments, and transmitting information to other elements of the project, such as the group responsible for installing the equipment.

However, it became evident that continuous communication between recruiters and the laboratory was necessary. The person making the initial contacts needed to know which of the residences that had not been contacted from the office had also not been contacted in the field. The pilot recruitment was not large enough to test the procedure for mailing letters and contacting replacements for the primary residences. More than enough primary residences had been chosen for the staff to recruit more than enough residences to satisfy the need for the pilot study in any given area. Therefore, replacements were not needed while the recruiter was in the field. The replacement procedures would be tested more thoroughly during the full study.

Scheduling phone service required little coordination since we were dealing with only a few residences and only a few phone companies. However, the pilot experience gave a good indication of the lead times necessary for scheduling the service, the documentation requirements (internal and for the phone company), and the necessary information to be transmitted to the phone company to initiate service. Also, these early experiences with phone companies made clear what information would be necessary for data communications and billing information; this was important in the full study when dealing with several phone companies and residents simultaneously.

2.3.2 Time

The amount of time expected to be spent recruiting each home was established during the pilot recruitment. This included the time spent mailing letters, making phone contacts, conducting the interview, travelling between residences, filling out the necessary paperwork, and arranging for phone service. Our estimates of time needed in the field were fairly accurate. We estimated recruiting an average of two houses a day, counting travel time, days for which people were unavailable due to vacations and summer activities, and arranging for interviews.

However, the amount of time needed to carry out the various activities from the Laboratory was underestimated. The time spent sending contact letters, making initial phone contact, and tracking the recruiting progress was significantly more than what we had anticipated. The addition of a computerized data base tracking system only slightly reduced the amount of time necessary for tracking the recruiting effort. The amount of time necessary for arranging for phone installations was also more than expected (about twice); we, therefore, hired a person whose primary responsibility was to arrange for phone installations and to answer the INWATS phones.

The initial phone contacts were valuable but time-consuming, and proved to be a real nuisance for the recruiting effort. Phone numbers were not included with the resident sample list. A number of residences had unlisted phone numbers, or no phone at all. A lot of time was consumed tracking down phone numbers from directory assistance and locating residents who could not be reached by phone. The task of making initial phone contact with residents turned out to take about twice the amount of time allotted for this task; also, because so many households have both adults employed outside the home, it was often impossible to contact the residents during daytime working hours.
2.3.3 Cost

The total cost to recruit the 30 residences was $21,500, $19,600 in labor and $1,900 in travel/living costs. Labor costs consisted of the cost of setting up the mechanism and procedures for recruiting, which included both the task manager's and project secretary's time, the time to recruit the residences, and train the recruiters. This cost equates to $717 per recruited residence and $524 per contacted residence (those we sent letters to). This was about twice the initial estimate for the full recruitment effort of about $350 per residence, but was within expected costs since we were training recruiters as we recruited residences. There were often two staff members involved in recruiting a single residence, thus doubling the cost of recruiting that residence.

2.4 CONCLUSIONS

The pilot study exercised to some degree most of the tasks associated with recruitment and provided valuable experience that would prove useful for the full study recruitment. On the basis of the conclusions derived from the pilot study, a number of modifications were instituted for the recruitment of the full sample.

For example, we initially thought that all of the information on the residence, from the initial contact letter through the access payment, could be contained on a master file form placed in the resident's file. However, after sending letters to only 41 residents and trying to recruit these residences, it became apparent that some kind of data base was necessary to keep track of the recruiting effort and all the data to be collected on the residence as well as the information on phone service installation and access payment. This would make it possible to generate recruiting reports and resident information and to sort them according to any informational needs. Also, more information could be stored in a data base than what could be put on a master paper file. As the full study proceeded and the number of replacement residences increased, the data base would become the focus of the recruiting effort, especially its capability to track replacements.

The pilot study also verified the usefulness of the various forms and pointed up the need for certain modifications. The Call Record was changed to include directions to the residence so that the installation (phone and monitoring equipment) people could easily find the house (especially in rural areas). Similarly, a DO NOT FORWARD was typed on the envelope of the initial letters mailed to the residents. While a seemingly trivial change, it saved us a good deal of time; for if the resident had moved, the letter was returned, thus indicating that a new occupant was in the residence. This kept us from telephoning residents who had moved and from assuming that they were in the same house as the sample indicated.

The clarity and completeness of the Cooperative Agreement were well tested during the pilot recruitment. The residents seemed to understand the contents of the Agreement and accept the language and intent. Only minor changes in wording were made to eliminate unclear terms and redundancy.

Our experience with the interviews led us to conclude that we needed to candidly state that the metered data could not be available to the occupant until after the study was completed. This was more straightforward than merely mentioning this fact in passing or in response to residents' questions during the interview. We carefully
explained that if data were provided earlier in the program, the sample could become "contaminated"; that is, the occupants may change their energy use based on our data, which would bias the sample and thus dilute the usefulness of the data. Most residents accepted this explanation. The importance of receiving some tangible product was also illustrated early in the recruitment when it was clear that initial recruitment efforts would have been somewhat easier had the residents received some of the PNWRES data.

The pilot effort indicated the success we could anticipate in recruiting the full sample. Success was measured by the number of residences recruited compared to the number of primary residences contacted. Because recruitment was conducted in several areas of the region, the pilot also gave a good indication of the success outside of the Tri-Cities area. The Tri-Cities experience would have indicated an 85% success rate. Experience in the other areas where PNL is not well known and where residents were more difficult to contact (by phone and by letter) yielded a much lower success rate (70-75%) and a more realistic idea of the success to be expected in the full study.
3.0 INSTALLATION ACTIVITIES

Installation activities in the residential pilot study comprised selecting installation contractors, preparing initial procedures for installation contractors and PNL staff, conducting training sessions, installing the metering equipment, and performing initial verification checks of completed installations. Information gained from these activities was used to formulate revised procedures for installations in the full sample study. In the course of the study, the need to develop a new procedure to confirm proper installation and sizing of current transformers (CT) became apparent; activities related to this procedure included identification and handling of installation-related problems through the formation of a Problem Identification Team (PIT). These activities, along with installation cost data for the pilot installations, are discussed in this section.

3.1 TASK GOALS AND OBJECTIVES

The pilot study was designed to determine if the initial installation procedures prepared by PNL could be understood and implemented by the installation contractors. To assure that representative information on contractor abilities and costs was obtained, nine installation contractors were selected to participate in the pilot study. Some of these contractors had previous experience installing metering equipment. Others were electrical contractors with experience installing normal electrical distribution systems in new homes or remodeling systems in existing residences.

A secondary objective of the installation task was to provide the contractors sufficient experience with the data acquisition equipment and installation practices to bid on solicitations for installing the equipment for the full sample, and the other residential studies. By carefully explaining this objective to the contractors, we tried to encourage competitive bids for the larger scale work and assist the contractors in understanding that they all had an equal chance for future work.

3.2 DESCRIPTION OF PILOT INSTALLATION EFFORT

Selection of installation contractors followed the standard government procurement path of advertising the expected work in the Commerce Business Daily, major newspapers around the Pacific Northwest, and a major newsletter for the construction trade. Letters were also sent to electrical engineering/consulting firms listed in the Seattle and Portland phone directories. These advertisements resulted in approximately 55 firms responding to the request for proposal (RFP) package. To ensure that firms would clearly understand the scope of work required and give them the opportunity to ask specific questions on the RFP after they had been able to study it, bidders meetings were held in Richland and Seattle, Washington and Portland, Oregon. Attendance at these meetings was small, with the largest gathering in Richland.

Eleven proposals were received in response to the RFP. Of these, nine were northwest firms located in Washington, Oregon, or Montana. Two of the proposals were from firms outside the region (Tennessee and Washington, DC). Most of the proposals (9 out of 11) were from firms that had submitted proposals for the commercial pilot study. Of the 11 proposals submitted, all were considered responsive to the RFP.
The proposals from the firms outside the region were not considered competitive because of their high travel costs to complete the installations in Pacific Northwest residences.

Negotiations with the nine successful bidders were completed and agreements were signed during the early part of March 1984. Each contractor was to install metering equipment in two residences. All residences were in the Tri-Cities, Washington area so that the training session could be held at the first residences to be metered with the least inconvenience and travel cost for PNL staff conducting the training, and so that members of the project team could more easily observe the installation process.

The first contractor, in preparing for the installation, filed for an electrical permit with Washington State's electrical inspector's office. The inspector indicated that unless both the current transformers (CTs) and the data logger were listed by an agency recognized by the State of Washington, permits would not be approved. He cited articles in the National Electrical Code (NEC) and Washington state laws that require these items to be listed by agencies such as Underwriters Laboratories (UL).

Project staff members met with the Washington State electrical inspector, who agreed that a variance process could be followed so that installations could proceed in Washington. However, as noted earlier, the Washington State electrical inspector required all electrical work to be done by a licensed Washington electrician working for an electrical contractor with an administrator's license. If the electrical contractor was being paid by a consulting firm, then that firm must have a Washington general contractor's license. The state required that PNL certify that these rules were followed and that each installation be inspected.

The other states in the region had similar requirements for electricians working within their states and also required inspection of each installation. Idaho has no state law pertaining to listed equipment; Oregon considers the installations to be temporary and therefore does not require the equipment to be listed. The electrical inspectors in each state requested a list of the residences that would have equipment installed.

Because several of the contractors did not have a Washington general or electrical contractor's license, we had to locate suitable pilot residences in areas where they could perform the work. Four pilot residences were chosen in Oregon and two in Montana for this purpose. The six in Oregon were recruited from the full sample study. The two in Montana are super-insulated, prefabricated homes, obtained by the Montana-based contractor, so they provide a unique data set.

The RFP package included a written procedure for installation of the data acquisition equipment. This procedure covered installing CTs in the breaker panel, mounting the field data acquisition system (FDAS), connecting the CTs to the FDAS, and verifying that the FDAS was operational. The procedure was based on the limited field experience with the FDAS unit and techniques used in similar data acquisition programs. The procedure did not provide information for installing and operating the modem, or initial data verification.

Other procedures were developed to supplement the procedure included in the RFP. These were procedures used to train the installation contractors and to prepare
initial measurement plans before beginning installation activities. The latter procedure included two forms, a panel documentation and a channel assignment form; these would be completed by the installation contractor as part of the measurement plan.

The pilot installation process was completed with the usual number of problems encountered in a pilot study. However, most of the electricians were comfortable installing metering equipment. Most of the sources of errors were related to incorrectly developed measurement plans, misidentified phases of each breaker, and incorrectly chosen scaling resistors for each FDAS channel. At the completion of the pilot study, all of the firms expressed an interest in participating in the full sample study.

In an attempt to better understand the effort required to complete the installation and help PNL become familiar with construction practices for the Residential Standards Demonstration Program (a subset of the residential studies), one of the residential pilot contractors was also asked to install metering equipment in an RSDP matched pair of residences. Since an enclosure for the FDAS unit and conduit to the panel had been installed during the construction of the residence, the time required to complete the installation was reduced. Both installations were completed in a day. The installation contractor noted that the process was also aided by correctly labeled circuit breakers.

3.3 MEASUREMENT PLANS AND INSTALLATION PROCEDURES

Preparation of a measurement plan is a vital part of the installation process. This plan identifies the various circuits in the breaker panel, notes the location of the FDAS unit with respect to the panel, and provides information on the logger's data channels. It also provides relevant contact information (i.e., phone numbers of the residents and FDAS and date of equipment installation). It serves to document the installation process and provides a mechanism to establish data files for acquisition of the end-use data. Thus, completion of a proper measurement plan is fundamental to obtaining realistic and representative end-use data.

For the pilot installations the contractors were first trained to complete a panel documentation form. This form, as illustrated in Figure 2, requires information on the load for each breaker, the size of the breaker, and the phase of the service to which the breaker is connected. The form also serves as a worksheet to determine how CTs are to be placed in the panel to monitor the loads. The contractors had little difficulty completing information on breaker size, breaker phase, and breaker loads. However, they sometimes merely assumed that the labeling on the panel was correct or that the phases changed down the panel in an alternating fashion. These assumptions were sometimes incorrect and thus delayed completion of the installation. Most of the contractors did not know how to correctly assign CTs within the panel to monitor all of the end-use loads. For the contractor's first installation, this assignment was completed by the PNL staff conducting the on-site training. The contractors were able to assign the CTs for their second installation with some assistance from the on-site PNL staff.
## Panel Documentation Form

Panel Name _____________________________

<table>
<thead>
<tr>
<th>CT# (If Any)</th>
<th>φ</th>
<th>(Name)</th>
<th>(Amps)</th>
<th>CT# (If Any)</th>
<th>φ</th>
<th>(Name)</th>
<th>(Amps)</th>
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Figure 2

Panel Documentation Form
Once the panel documentation form was completed, the next step in the installation process is to install the CTs in the panel and mount the FDAS. All the contractors were able to perform these tasks with minimal instruction, and in all cases, these tasks were handled by electricians.

After connecting the CTs to the FDAS, the contractors were required to complete a channel assignment form (Figure 3) that identified CTs with each individual FDAS channel, indicated the phase of current monitored by the CT, and provided the size of the scaling resistor installed for each channel. This latter item posed the most difficulty for the contractors. They were not familiar with the concept of scaling the output of the CT to closely match the maximum amperage of the breaker(s) being monitored. After observing the installation of scaling resistors at the first assigned residence by PNL staff, they felt more comfortable with the concept and task.

Another problem associated with assigning CTs within the panel and installing scaling resistors was the inadequate combination of CT and scaling resistor to handle the maximum load. For example, there were several occurrences of contractors combining the loads from 20 and 15-A breakers through a 30-A CT scaled to 30-A maximum output. Although the actual load in these two circuits may rarely exceed 30-A, this was considered an installation problem. In this case the contractor should have called for a 100-A CT with an appropriate scaling resistor to produce a maximum output of 35 A. After these types of installation errors were pointed out to the contractor, they occurred with only minimal frequency.

Initial verification of the installation process consisted only of the on-site contractor calling the appropriate PNL personnel and asking them to attempt communications with the site. This procedure was used only to determine that the site was operational. In some cases, the installation contractor was reached via the resident's phone and asked to turn on various appliances. PNL personnel, using the real-time communication link, checked whether a load increase was observed for the proper channel. Direct communication was not possible with the pilot sites in Oregon because of the inability to communicate with the FDAS units over shared phone lines. Technical specialists from PNL later visited the site after the equipment was installed to perform a quality control check. This check consisted of a physical inspection of the CTs in the panel to check proper CT orientation, determination that all loads were being monitored, verification of the panel documentation form and breaker size, verification of scaling resistor size, and assurance that CTs were properly connected to the FDAS.

The quality control checks revealed many installation and hardware problems. Although most were minor, most required some modification of the metering configuration and/or equipment so that the FDAS would acquire accurate and representative end-use data. Later in the pilot study a procedure was tested by the PNL staff that appeared helpful in eliminating most installation problems. This procedure, known as a Standard Load Test, was further developed for use in the full sample study. This test would be applied to each CT to detect improper CT orientation, improper manufacture of CTs, and improper connection of the CT to the FDAS unit. The test can also be used to determine if the phase of the reference voltage has been correctly determined. The application of this test is discussed in Section 3.5.
<table>
<thead>
<tr>
<th>End Use Assignment</th>
<th>Electrical Load Data</th>
<th>K.W.H. Config.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH #</td>
<td>End Use Code</td>
<td>WMB Ser #</td>
<td>Panel Name</td>
</tr>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>Bldg. Name</th>
<th>Date</th>
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Figure 3

Channel Assignment Form
3.4 COST

Agreements between PNL and the contractors were on a labor hour basis. Under this type of agreement the contractor is paid a fixed rate for each hour worked on the installation plus actual travel and living cost. Each agreement had a ceiling limit to protect PNL. This type of contract was used because of the uncertainty regarding the actual effort required. Under this type of agreement contractors recover all their costs unless they choose not to for some reason.

The average contractor’s installation cost per house for the group of 18 residences in the pilot study was less than $1000 ($977) with a standard deviation of $346 per residence. The actual contractor cost for two residences ranged from $1460 to $357 per residence. These costs are only comparable if actual labor hours, labor rates, material costs, and travel costs are reviewed.

The largest average installation cost resulted from extensive travel time to the pilot residence and higher labor rates. In this particular contractor’s agreement, normal hourly labor rates were allowed during travel, along with fixed costs for every mile traveled. Higher labor rates resulted from having both an electrician and an electrical engineer install the equipment. The lowest average installation cost occurred when only an electrician performed the installation. The lowest average cost required approximately 12 hours per residence at a rate of $21.00 per hour with no labor cost for travel included. The highest average installation cost required an average of 10 hours per residence, including travel time, at $34.32 per hour. If travel time were not included, the average time for the electrician to complete the work would have been 4.5 hours.

The above noted cost figures do not include labor costs associated with the on-site PNL staff support effort. In most cases, only one PNL person worked directly with the contractor’s installation team and performed the quality control checks after the work was completed. This effort would add approximately $400 to $500 to the cost range from about $900 to $2000.

Based on the contractor cost reported for the pilot installations, $1400 was budgeted for installation of metering equipment in the full-scale residential study. This initial budget was based on the requirement of a fixed price contract for the full-scale study installation contractor. We also expect that the successful bidder for the installation activity will employ an electrician on a full-time basis to assist in the installation of the equipment. The budgeted amount is to include all travel, per diem, and miscellaneous equipment costs associated with the installation activities required in the full-scale installation.

3.5 CONCLUSIONS

A review of the Residential Pilot Study indicated a clear need for some changes in various installation tasks if the full sample study were to be completed efficiently and effectively. In some cases, the changes involved improved or expanded procedures used by PNL staff and contractors. Some problems encountered under the pilot study required the generation of new procedures or significant revisions in how the full study would proceed.
The pilot study was a learning experience for both the contractors and PNL staff. The contractors having completed two installations had a good understanding of preparing measurement plans, installing metering equipment, and coordinating with the project staff. Both the PNL staff and the contractors gained an appreciation for the amount of time required to complete the various activities. The pilot study resulted in PNL project staff better understanding the coordination effort required to schedule installations and having a clearer understanding of the capabilities of the contractors and electricians.

The optimum installation team appears to be a technical specialist and an electrician. The technical specialist would be responsible for developing the measurement plan, directing the electrician, and completing the system verification. The electrician would be responsible for installing the CT in the breaker panel, mounting the FDAS, and running CT leads through conduit and connecting them to the FDAS. This type of arrangement is particularly useful for those situations in which a variety of electricians will be used by a contractor. If only one electrician is used, sufficient training must be provided and the same electrician should be used for each installation, as their efficiency and competence increased significantly when performing the same task repeatedly.

Since the pilot study indicated a high probability of incorrectly placing and connecting CTs and potential hardware problems, an additional installation procedure, a Standard Load Test, would be implemented for the full sample study. In this test the installation contractor applies a known current to each and every CT while the PNL staff is in communication with the FDAS on a real-time basis. By observing the increase in counts for the channel being observed, we are able to compute the load for the channel. If the value is similar to the standard load applied, then it is reasonably clear that the CT has been installed with the proper orientation and connected properly to the FDAS. This technique was tested by electrical contractors in selected residences (from the full sample) in the Tri-Cities, Washington and found to be an effective way to detect most installation and hardware errors. However, the test is not fool-proof. Under certain conditions, a CT may be improperly installed and the load test computed in such a manner to indicate proper installation. To ensure the proper operation of each CT, a connected load test would be required. However, the time required to complete a connected load test and the inconvenience to the occupants convinced us to not include the test as part of the installation procedures for the full sample study. The Standard Load Test will not determine if all loads for a particular end-use group are being monitored; that can only be determined by review of the measurement plans.

Other procedures used by the installation contractors were also expanded and reorganized into a more usable format. For example, installation of separate items (e.g., CTs, FDAS, temperature sensors, woodstove sensors, and humidity sensors) were reorganized into separate procedures. The Installation Handbook provides an overview of the installation process and identifies the appropriate detailed procedure depending on the type of installation and specific metering requirements.

Problems found during the quality control check of the installation also led to the implementation of a procedure to generate a Problem Identification Form (PIF). This form contained information on site identification, observed problem, and possible corrective action. The form allows the project team to monitor overall performance and thus keep track of any installation problems, identify any patterns to the
problems, and schedule maintenance visits to the sites. Issuance of these forms also led to the creation of a Problem Identification Team (PIT), which consists of representatives of the hardware, installation, data acquisition, and data analysis tasks who review PIFs and agree on corrective actions to eliminate the problem(s).
4.0 DATA ACQUISITION

The data acquisition task comprised developing software for the FDAS, installing a dedicated central data acquisition system (DAS) for interrogation of the field units and preliminary data processing, developing a software package for the interrogation and data processing tasks and, finally, routinely interrogating the network and processing the data. The formal residential pilot program was coincident with much of the code development work, and exercised all of these tasks on a modest scale. The pilot study yielded practical experience with the challenges of operating the central DAS with a network of field units of the type planned for the full sample study. As a result of these experiences, modifications to procedures and software were planned and implemented. This section describes the experiences garnered by the data acquisition task from the residential pilot study and some additional experimental installations that coincided with the pilot study.

4.1 DATA ACQUISITION TASK GOALS

The data acquisition task had several goals during the residential pilot study. We planned to:

1. Exercise and test the FDAS software.
2. Exercise and test the DAS hardware and software.
3. Acquire experience with telecommunications conditions between the DAS and the network of FDAS units, and modify procedures and communications software to accommodate the conditions.
4. Catalog data irregularities occurring in practice, and modify data acquisition, communications and data processing procedures and software to deal with these irregularities.
5. Test parameter entry software and protocols, and modify this software and these protocols as necessary.

The first two of these goals may be described as working the 'bugs' out of the FDAS and DAS. As the FDAS and DAS are the subject of independent documents, activities related to these goals are discussed only briefly here. The remaining three differ from the first two in that they represent tests of procedures under project conditions; it is to these that most of Section 4 is devoted.

4.2 SYSTEM OVERVIEW AND INITIAL PROCEDURES

The major functions of the microprocessor-controlled FDAS are indicated in Figure 4. Each unit has a number of analog and digital input channels, to which are connected the power meter circuits and sensors. Signals from the energy and sensor channels are accumulated over some period of time, termed the integration period, and then stored in memory. Each record in memory consists of a time stamp and values for the engineering and sensor data. Logger memory is organized in circular fashion, each record following its temporal predecessor until the data memory is full. The next record is then written to the first memory location, overwriting earlier data.

To avoid data loss, the logger must be polled at an interval shorter than the time required to cycle completely through logger memory. The length of individual data
records is determined by the number of channels actually in use at a given site; this and the temporal resolution of the collected data determine the frequency with which the field units must be polled to avoid loss of data.

Operation of the FDAS units is dependent on a number of parameters, which may be set remotely from the DAS. Two of these parameters determine the mode of data collection—the time resolution or integration period, set at either 5 or 60 minutes during the pilot experiment, and the number of bytes of data retained for each field in the data records. This last parameter, in combination with the integration period, determines the power resolution of the data. For the residential pilot installations, data were collected at single byte resolution. Some data in the experimental installations were collected at two-byte resolution.

The network of field units is controlled by the DAS, the principal component of which is a Hewlett-Packard microcomputer. The DAS has several functions. First, it carries out the network polling. This involves scheduling the polling, initiating communications with the sites and transferring data. Communications statistics are maintained as part of this process. Next, the data collection parameters regulated by the field units are set remotely from the DAS. Third, parameters required for communications and conversion of data to engineering units are maintained on the DAS. Fourth, several data processing steps are carried out on the DAS. The data are placed in temporal order (a step made necessary by the circular memory in the logger), checks for certain error conditions are made, and the data are converted to engineering units. Finally, data are transferred, both to archive and to the VAX computer on which the ELCAP data base is maintained. Each of these functions is performed by a custom Pascal language software system developed for ELCAP. The DAS hardware configuration is indicated in Figure 5 and a flow chart of the system operation is provided by Figure 6.

Three sets of data acquisition procedures were tested during the residential pilot and coincident experimental installation studies. These include data acquisition protocols in the field units, procedures for interrogating the field units from the central DAS, and procedures for preliminary data processing. The next few paragraphs discuss each of these procedures as they stood, or, if incomplete, were planned, at the beginning of the residential pilot study.
It was initially planned to acquire data at hourly temporal resolution, although some 5-minute resolution data were collected. Single byte data were acquired for all channels in the pilot sample. The significance of this is that only the eight most significant bits of data collected on each channel during an integration period are retained. During the pilot, two byte data resolution was used (retaining the 16 most significant bits) at the experimental installations. Such collection has the potential to improve the precision of the data at some increased cost in storage capacity. It also permitted the testing of the stability of the offset calibration of the analog-digital converters in the FDAS under field conditions.

The initial intent, which led to the procedures employed during the pilot project, was to use the federal telecommunications system (FTS) for data interrogation. All interrogations were to be conducted at 1200 baud. During the course of pilot work, we experimented with using that system to reach those portions of the region that were participating in ELCAP. We also investigated the use of commercial lines to
reach portions of the region with which we experienced data transmission difficulties over the FTS lines or for which direct dial FTS capabilities (Idaho and Montana) do not exist.

According to the initial plans, each FDAS unit was to be interrogated when its memory was roughly half full. We estimated that this would provide, at a minimum, several days of grace for each installation, within which time communications problems could be resolved without loss of data. Scheduling was intended to be fully automatic, with the computer selecting those loggers in need of interrogation. Interrogation of the network was intended to take place at night, to avoid tying up the DAS during working hours. Reports of the interrogation were to be made to the operator each day, with the operator then able to manually resolve any problems.

The initial data processing procedures take the data from the form in which it is provided by the field units and convert it to time series engineering data. These procedures were also intended to operate automatically, with much of the processing taking place during non-working hours. A flow chart of the data processing steps is given in Figure 7. A related set of procedures, involving parameter entry and verification, was also developed and tested during the pilot work. These procedures are shown as a flow chart in Figure 8.

4.3 PILOT EXPERIENCES

Communications difficulties encountered during the course of the pilot fell into four categories. First, telephone line quality often affected data transmission. In the worst cases, telephone line noise was sufficiently severe to prohibit communications with a site or set of sites. Second, some of the installations are in noisy electrical environments; consequent telephone line noise can disrupt communications. Third, numerous problems were encountered with the performance of the modems incorporated in
the FDAS units. Fourth, although the communications protocol includes error checking for data transmission from the field units to the DAS, no error checking is carried out for transactions that involve transmission of information from the DAS to the FDAS units, such as parameter setting. Communications conditions which readily admitted data transmission sometimes did not permit transfer of information from the DAS to FDAS.

The quality of data transmission over telephone lines is of great concern. If reliable data transmission was to prove impossible with a large fraction of the ELCAP installations, the scope of the project would require substantial revision. During the pilot studies, a good deal of experience was accumulated with data transmission. This experience indicates that the reliability of data transmission from a given FDAS is a function of several variables: the region in which the installation is located; whether polling is carried out over FTS or commercial lines; the speed of transmission; and the rate of transmission. All affect the probability of successful interrogation. Because of transmission difficulties in some regions of Oregon, a protocol was adopted whereby interrogation was attempted over commercial phone lines if interrogation over FTS lines failed.

Phone line quality was not the only factor affecting data transmission. Modem problems were endemic during the course of the pilot study. Among other things, it was discovered that the modems acquired for the study had a number of different configurations and did not, in general, operate according to specification. In particular, the reset circuits on these devices behaved erratically. In consequence, a 100% testing protocol of modems was initiated, which reduced the incidence of communications problems associated with modem failures.
The time of day at which interrogation takes place can also be important. Automated nighttime interrogation of the network was instituted towards the end of the pilot study with fairly satisfactory results. Most of the interrogations proceeded smoothly, and the system operator was properly notified of all failures in good time to take corrective action. The pilot version of the interrogation system, which permits interrogation of only a single unit at a time, is capable of supporting roughly half to two thirds of the total network contemplated. A version of the software which permits simultaneous interrogation of multiple field units is under development for the main study.

Occasionally, trouble was experienced with spurious commands being received by the field units when in communication with the DAS. Because of the simple form of the logger commands, phone line noise can easily be interpreted as command transmission. Although these events were infrequent, software modifications to protect the FDAS from spurious commands are under consideration.

The most important aspect of the pilot experience with data processing was learning what irregularities could be expected in the collected data. Irregularities can be detected either on a check of FDAS operating parameters against the record maintained by the central DAS or by examination of the retrieval data records. Data related errors that have been noted during interrogation and the conversion processes include:

1. Mismatch between integration period reported in raw record (or, equivalently, the number of channels collecting data) and as recorded in processing parameters
2. Mismatch between record length in raw record and as stored in processing parameters
3. A flag in the raw record set by the interrogation process indicating that logger parameters are not valid
4. Repeated blocks of records (several consecutive records repeated as a block in the data file as obtained from the logger)
5. Mismatch between the number of raw records available for conversion to engineering units and the number supposedly obtained from the logger
6. A power outage, indicated by the presence of several of these conditions.

These error conditions fall into three groups. First, there are parameter errors (conditions 1-4). These conditions can occur if parameters have been incorrectly output to the FDAS from the DAS, if FDAS parameters have been corrupted, or if one of the parameter files on the DAS has been corrupted. In addition, an errant logger clock can occasionally result in condition 4. Second, there are errors in data transmission, or logger memory (condition 5). Finally, a power outage (condition 6) results in loss of the logger time; records collected after power is restored start at zero time.

To date, experience indicates that none of the conditions were sufficiently frequent to cause major troubles in the data acquisition effort, although the parameter entry procedures were improved to reduce the occurrence of parameter errors. A simple algorithm has been developed to compute proper time stamps for records collected after a power outage, although this algorithm cannot handle multiple power outages.
4.4 CONCLUSIONS

The pilot study has demonstrated that the DAS software is reasonably reliable and fairly robust. Procedures related to logger scheduling, data processing, and parameter entry have sustained only modest modification as a result of the pilot experiences; in general, they seem to work reasonably well. Communications problems are the most likely to cause data loss during the full study, with FDAS units in certain regions being almost impossible to interrogate over the FTS. Consequently, certain portions of the network will be polled over commercial lines during the full study. Power outages will also result in a certain amount of lost data. It appears that these outages may be fairly common in rural areas of the region.
5.0 DATA MANAGEMENT

Pilot activities for the data management task focused on exercising data management protocols and developing data verification techniques. This section will describe the tasks involved in data management and verification, treat pilot experiences in each of these areas, and conclude with a brief statement regarding the capability of post-pilot procedures to meet the demands of the large data rates associated with the full ELCAP sample.

5.1 OVERVIEW OF DATA MANAGEMENT AND VERIFICATION

The task of data management begins once engineering data have been provided from the DAS. Once placed on the data management computer, currently a VAX 11-780 system, the data must be formatted for entry into the engineering data base, subjected to verification procedures, and then placed in the engineering data base. During the pilot study, the data were also routinely aggregated to the end-use level.

The DAS provides data in the form of files containing records, the individual fields of which represent power consumption or non-energy sensor readings on individual channels of the FDAS. These files are in a convenient format for data processing and transmission to the VAX. The first step of the VAX data processing is the conversion of the data's format to that of the engineering data base. During the conversion process, a number of error conditions, such as missing data records, are detected and corrective action taken. (At this time, too, a number of data quality flags may be added to the records; this portion of the procedure was not operative during the pilot project.)

As noted above, the data arrive on the VAX at the channel level. That is, the individual fields represent energy consumption on circuits monitored by a single channel of the FDAS. These later may be aggregated to the end-use level according to a set of equations specific to each installation. For instance, an office building may be so instrumented that the lighting end use in a particular zone is given as a sum of the power drawn on a number of channels; in this case the aggregation equation would look something like

\[ L = C_{26} + C_{27} + C_{28} \]

where \( L \) represents the power devoted to the lighting end-use, and \( C_{26}, C_{27} \) and \( C_{28} \) are the power measurements obtained from channels 26, 27 and 28 of the FDAS.

After processing, the data are entered into the data base. This step involves breaking the data into files of a determined temporal length, ensuring that the records to be added to the data base are not redundant, and then actually placing the new records in the data base. Throughout the course of the pilot, both the channel and end-use aggregated data were held in the data base. This was primarily to simplify debugging efforts. It was intended that eventually only channel data would be held on-line, with aggregation to end-use taking place as the first step in analysis efforts.

One of the keys to any experiment is assuring the production of data of known and reasonable quality. Prior to the residential pilot data, verification had been
considered and it was concluded that, although some sensible procedures could be identified in advance, practical experience would be necessary to identify the major error conditions which would be present in the data. Thus, an important goal for the pilot study was determining what error conditions would be observed in practice and devising procedures for handling those conditions.

It was recognized, even prior to the pilot study, that data verification procedures would have to be automated to a substantial degree. In view of the large size of the ELCAP sample (1000 structures) and the detail in which each site was to be studied, it was clearly impractical to attempt manual verification on a routine basis. Preliminary planning centered on techniques for identifying field unit failure during the course of the study. However, the pilot study clearly demonstrated that diagnosis of initial installation problems is a far more pressing concern.

5.2. DATA PROCESSING EXPERIENCE

As indicated above, determining which problems might affect data processing procedures was one of the objectives of the residential pilot. These problems were discovered to take any of several forms. Irregularities in the data, as supplied from the DAS, can cause difficulties with data handling and can affect the quality of the data base. There are a large number of parameters which control the data processing; any difficulty in ascertaining these parameters or entering them correctly into appropriate tables will also affect data processing. Finally, there are a number of logistical considerations. ELCAP is a large project, and large quantities of data will require routine processing during the full study. Data handling procedures must be capable of meeting the consequent demands.

5.2.1 Data Irregularities

Data irregularities result from the various error conditions enumerated in Section 4.3. The pilot study revealed the following data irregularities:

- doubled records in the data as transferred from the DAS
- repeated blocks of records in the data as transferred from the DAS
- missing records or blocks of records in the data as transferred from the DAS
- missing or incorrect time stamps in single records or blocks of records as transmitted from the DAS
- records not in temporal order in data files transmitted from the DAS
- bad first data records in data files transmitted from the DAS.

It is relatively simple to handle data files in which multiple records or blocks of records occur without either great increase in the complexity of data handling software or damage to the final data base.

Missing records or blocks of records represent a more complicated problem. Missing records can arise as a consequence of a variety of error conditions on the DAS or in the field units, including communication problems such as noisy phone lines, a bad memory location in a field unit, and power outages at the sites. Fortunately, some improvements to DAS communications protocols significantly decreased the frequency of all error conditions except power outages. Other than creating null records with a
flag to indicate missing data, no action is taken during data processing when a missing record or block of records is encountered.

Power outages also cause incorrect time stamps on records because the internal data logger clocks are reset when power is restored. Pilot experiences indicated that power outages would be an endemic problem, albeit of modest frequency. In most cases, it is possible to restore the correct time stamps based on knowledge of the time of logger interrogation, the time stamp on the last unaffected record, and the number of missing records. (As noted in Section 4, multiple power outages between serial acquisitions cannot be handled in this fashion.) A procedure of this type will be implemented for the full study, and records to which it is applied will be marked with an appropriate flag.

The preliminary data processing on the DAS fails to place records in temporal order when more than one 'wrap' point is discovered. Data logger memory is polled from lowest to highest location. Due to the circular design of the memory, this usually results in a wrap point, across which the time stamps are not contiguous. A power outage, in which the data logger clock is reset, results in a second wrap point. Unwrapping of data for which multiple wrap points exist can readily be handled during the VAX data processing procedures in concert with the restoration of time stamps discussed above.

The pilot experience suggested that the first data records obtained after a modification of logger parameters are often corrupted; evidently they represent power consumption for a partial interrogation period. This corruption showed up as systematically low values for energy consumption in the first record following the modification. As changing of parameters in a logger should be a relatively rare event, it seems sensible to simply discard the corrupted records and treat the data as missing.

5.2.2 Parameter Problems and Logistics

Parameter problems did indeed occur during the pilot study, usually because of incorrect measurement plans but sometimes because of data transcription errors. Based on the pilot study, it was clear that verification procedures needed to include tests designed to detect parameter problems. In addition, we decided to maintain all parameters within the framework of a single data base using flexible commercial data management software. This will permit maintenance of multiple parameter generations for each site, as may, for instance, be required if an installation is modified by the addition of meteorological sensors; it will also ensure consistency in parameter handling.

Logistical considerations have proved to be the principal driving force in designing modifications to data handling procedures and software. Pilot experience showed that the size of the full ELCAP sample clearly requires that data handling be as automated as possible. Consequently, work is under way to modify the data handling software so that all data handling steps, including reformatting, introduction of data quality flags, aggregation to the end-use level, verification, and introduction of new data to the engineering data base, can take place without operator intervention during off-hours.
5.3 Verification

The pilot test of the data acquisition and management system has had the greatest impact in the area of data verification. We originally believed that the continued monitoring of data quality, with the goal of detecting FDAS or sensor failure, was the major verification issue. The pilot study quickly demonstrated that initial installation verification must also be considered. Under initial installation protocols almost none of the FDAS installations proceeded without some error (see Section 3.5). Because of the difficulty of diagnosing all potential installation and equipment problems without examination of the data, it became necessary to create a set of data-based verification procedures. The procedures designed to meet this need also meet the ongoing data verification requirements.

5.3.1 Installation and Equipment Problems

In this section the types of installation and equipment problems encountered during the pilot study are discussed, together with the classes of verification procedures which are to be implemented for the full study to provide the capability of diagnosing these problems.

In order to develop sensible, data-based installation verification procedures for the residential study, it was necessary to develop a list of installation problems along with their effects on the data. By then examining the data for evidence of these effects, the associated installation and equipment problems can be diagnosed. During the course of the pilot study a large number of reasonably frequent installation and equipment errors were identified, together with their associated effects. The most important of these are given in the following list.

Calibration: Each channel is calibrated in the laboratory so that zero power yields a small positive signal; this offset signal is then subtracted from observed signals to yield the actual power consumed on a channel. This calibration may be affected by such installation details as the length of wire connecting a CT to the data logger. If the lab measured offset signal is different from that obtained in the field, then, under zero power conditions, a small positive or negative signal will result.

Unmonitored Load: A channel which is actually drawing power may have been left unmetered. This condition will result in the power drawn on the breakers appearing to be less than the total power drawn whenever the unmetered channel is active.

Incorrect CT or Scaling Resistor Installed: The interpretation of data from a channel on the FDAS requires that one know the size of the CT and scaling resistor used in the power metering. If an incorrect component is installed, the derived power consumption values will be incorrect by a constant factor. (Errors in listing various components in the measurement plan or data entry errors can be detected and resolved in the same fashion.)

Incorrectly Installed Resistor: If a resistor is not properly installed, the data for all channels on a particular power meter board can be driven to high values.
Reversed CT: One of the most common installation errors is reversing the leads on a CT. When power is drawn on the mismetered circuit, the affected channel, and perhaps other channels on the same power meter board, give negative readings. The same error can occur if a wire is passed through the CT in the wrong direction, or if the CT is mislabeled by the manufacturer.

Voltage Reference of Incorrect Phase: Each power metering channel is associated with a voltage reference. If the voltage reference is of the wrong phase, the power measurement will be in error. Such an error will result in low readings on a particular channel, which should result in failures of the sum check.

Measurement plan in error by misassignment of channels, an incorrect connected load survey, or an erroneous list of equipment used to monitor a given circuit: Incorrect assignment of channels or connected load survey lead to implausible data being collected (e.g., a circuit on which a hot water heater is operated but which is labeled as a lights and convenience outlet on a measurement plan will yield incongruous results). Usually, an error in the equipment list will lead to erroneous conversion of field data to engineering data; most often the errors will be in the form of a multiplicative factor.

Parameter errors as a consequence of the measurement plan errors (given above) or failures in data transcription: These errors can result in effects of the sort described in the preceding paragraph, and in incorrect end-use aggregation equations.

5.3.2 Verification Procedures

During work with the pilot data, we learned that most of the installation and equipment problems were associated with clear data signals. In particular, by comparing redundant measurements (independent measurements of comparable quantities such as power drawn by an entire circuit panel and the sum of the power drawn on the component circuits) and by checking the data for reasonableness in dynamic range and diurnal pattern, it proved possible to diagnose these problems with good accuracy. Indeed, one of the major consequences of the pilot study was the acquisition of experience necessary to design effective initial installation and data verification procedures.

Because of the frequency of installation errors and equipment problems in the pilot study, the time-consuming nature of the verification protocols devised based on the pilot experience, and the evident need to provide an ongoing check of the data throughout the course of the project, a suite of semi-automated data verification procedures has been designed. Testing of initial versions took place during the extended portions of the pilot study. These procedures, in large part based on the redundant measurement installation protocol adopted as a consequence of pilot experiences, will be described in detail in an independent document.

5.4. CONCLUSIONS

The residential pilot study had an enormous impact on the data management task. The pilot experiences made clear the potential for installation errors and the importance of providing automated data verification to identify and correct such errors. Consequently, we diverted substantial effort to data verification. As a result of the
pilot, a list of potential installation problems was created and two sets of verification procedures developed to diagnose these problems. Fortunately, it was possible to design these procedures so as to be effective as ongoing verification tools as well.

As constituted at the conclusion of the pilot, the verification procedures require roughly four hours per residential installation. Using the tools and procedures developed during the pilot, an analyst is able to identify errors not found during the initial FDAS installation, and to provide useful diagnostic information in all cases. This is, of course, an enormous savings when compared to the costs involved in dispatch of a repair team to a remote site without benefit of information as to what needs to be repaired. Nonetheless, considering the large number of installations, verification is clearly going to be a costly activity, and attempts to reduce the man hours required to verify a single installation are continuing.

As a final note, it is impossible to overstate the importance of the redundant metering. Although it does add to the cost of each installation by requiring use of a few additional CTs, it has proved to be, by far, the most powerful tool for detecting problems, without which, it would be practically impossible to assure the validity of ELCAP data.
STUDY DESIGN AND IMPLEMENTATION