INSTRUMENTED BUILDINGS: EXPERIENCES IN OBTAINING ACCURATE DATA

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ABSTRACT

In our field studies of large buildings, a great deal of effort has been required to assure data of sufficient quality for scientific investigations of energy consumption. In this paper we discuss some of the pitfalls which we have encountered in the course of monitoring buildings. We then describe the methods we have developed to climb out of them and avoid them in the future. The problems have included: electrical storm damage to a hardwired, distributed-intelligence data acquisistion system; thermal instability and limited resolution of solid-state temperature measurement electronics; troubles with pulse counters for gas and electric meters; difficulties in placement and calibration of flow meters. Our ways of dealing with such problems are: criteria for selection, redundancy, and placement of sensors; calibration procedures; data cross-checking; quick-look plotting and tabulation of data. Many of our quality assurance techniques have been embodied in software we developed for acquisition, archival, extraction, and preliminary analysis of the data from our buildings. This paper highlights our experiences in monitoring buildings so that we might allow others to benefit from what we've learned as well as from suggestions and related experiences from our colleagues in buildings energy conservation research.

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INTRODUCTION

As we prepared to write up our respective results on energy conservation research in buildings, we realized just how much of our time was spent working on the process of acquiring the data on which we base our results. Where did that time go and what were we doing? We made trips to the buildings for installing and calibrating instruments (and reinstallation and recalibration!), fixing sensors, debugging the data logging software. Back at the office, we'd download the data, convert it, inspect it, cross-check it as best we could, and finding problems, back we would go to the building. This iterative process is certainly familiar to anyone doing fieldwork. When we step back and scrutinize our experience, and then improve, refine, and systematize it, the result can be improved methods for research. It is such issues of instrumentation methodology which form the subject of this paper.

This is a collaborative effort; we wrote different sections based on our individual experiences during several projects. However, we interacted while the work was in progress--getting a monitoring system to work correctly is an instance when many heads are better than one. (Often enough, it took more than one pair of hands to do the job, whether or not we thought another head was needed!) This is not an exhaustive tale of our trials and tribulations in data acquisition. Rather, we report on particular areas of instrumentation work where we found unexpected problems that were interesting and challenging. We highlight some measurement tasks which were particularly troublesome and on which we really had to learn by trying and develop new approaches.

We also want to communicate the processes by which we arrived at the solutions to our monitoring pitfalls. For this reason, the paper is written in an anecdotal style. Each section is devoted to one of the areas we want to highlight, presenting the problem encountered, the process by which we addressed it, and the solutions we found. We hope that this collected hindsight can become the basis of foresight for the future work of ourselves and others.

The discussions here are drawn from our data acquisition system (DAS) experience in three buildings. Two are power line carrier (PLC) systems installed in apartment buildings (Beechwood Gardens and Lumley Homes). A PLC system uses remote transponders to transmit data as high frequency signals over existing power lines to a central receiver/transmitter unit. The third is a hardwired system with remote transponder boards transmitting information to a receiver/transmitter via a single twisted pair. It is installed at Enerplex, a pair of commercial office buildings. Both types of systems are controlled by a microcomputer. (See Harrje et al. (1984) for more detail.)

PULSE COUNTING MEASUREMENTS

For an analyst who wishes to diagnose energy use in a building, perhaps the most important "vital signs" are fuel flows into and throughout the building. So, the most direct way of determining how energy is used in a building is to literally "take its pulse." Most utility meters used to measure fuel flows may be monitored by counting pulses--voltage signals which correspond to a unit of delivered energy. Many water meters provide pulse outputs to measure flows needed to compute energy delivery in domestic hot water systems and water-based space conditioning systems. Counting pulses accurately is a crucial requirement for a building instrumentation system.

All of our systems use pulse generating meters. The PLC systems monitor two gas and one electric meter each, and a total of three water meters. The Enerplex system monitors 26 electric meters and one pulse generating water meter. For our meters, pulses are generated by a switch closure, which requires an external voltage to generate the signal. We use digital electronic recording devices consisting of a counter chip (a binary register) and circuitry which detects the pulse signal, filters switch bounces and increments the counter. We have two types of interfaces between the meter and the counting device, one for each type of data acquisition system. These are illustrated in Figure 1.

Currently, we use "off the shelf" pulse output meters to obtain pulses from a utility meter. One exception was earlier in Lumley Homes, when our instrumentation contractor modified one of the gas meters with a magnetic switch for pulse generation because a pulse generating register for the meter could not be found. We were unable to get reliable data from the meter. After some persistence, a manufactured register was located for the meter and arrangements were made with the utility company for its installation. Once installed, we had no further problems with the meter. In this case, it was better to hunt down and install "off the shelf" manufactured devices than to struggle with designing and building them from scratch.

In the PLC system, both the counter/transponder and computer interface were supplied by the DAS vendor. The vendor of the Enerplex system supplied only the digital transponder board and the computer interface. We used an off-the-shelf isolation relay, but we had to construct counter boards from the vendor's schematic. The DAS vendor claimed the ability to handle pulse-counting, which is true, but we did not realize that we needed to build our own counter boards. This added delays and extra work to the monitoring project. We would not go this route again--it is much better to select a system that includes all the necessary hardware.

Our homemade counter boards have a 16-bit counter (two 8-bit counters in series). The off-the-shelf counter used in the PLC system has but an 8-bit counter, thus it can only count from 0 to 255. Because of this limited range, one must carefully consider the sampling rate as compared to the maximum expected pulse rate from the meter. One must also include robust logic for handling counter overflow (which just starts the counter from zero again) in the data logging software. We discuss these two consideration below.

The critical overflow time for the counter, or time to reach the maximum number of counts, is the one that occurs at maximum pulse rate. It is given by $T_c = M / (N P)$, where M is the counter capacity, N is the pulse factor for the meter, and P the peak flow through the meter. To avoid missing a full register of counts, one must have a sampling time $T_s < T_c$. For the electric meter at Lumley Homes, where M=255 pulses, N=20 pulses/kWh, and P=120 kW, the overflow time is T_c=6.4 minutes. We must sample that counter more frequently than every 6.4 minutes and furthermore, if the computer is down for any longer than that (and that's just so unlikely, right?) there may be missed counts. The sampling rate at Lumley Homes is about once every 90 seconds, so there is no problem when everything is fine. Our other meters have larger overflow times. The short overflow time for the Lumley electric meter causes us to miss counts when the computer is down, or when data logging is suspended for data transfer or setup operations--we could work more comfortably with a bigger register or a smaller pulse factor for the meter. While on the subject, we must mention that the pulse factor can be difficult to track down--the meter makers stamp lots of numbers on meter nameplates, but none quite so straightforward to interpret as something like "N pulses/kWh." After reading the cryptic nameplate data, it sometimes took a few phone calls to utility people before we found out the pulse factor.

Proper handling of counter overflow was an area of difficulty in our original PLC data acquisition software. The software must recognize when a counter overflow has occurred. The program determines a meter reading by computing successive differences between values of the counter. No more than one overflow should occur between readings, and an overflow is detected when the the difference between the current reading and the previous reading is negative. The logic should then add (for an 8-bit counter) 256 to the difference, yielding a positive number less than 256 which is the correct number of meter pulses between readings. But the software supplied by the PLC system vendor sometimes added 256 when it shouldn't have, causing the DAS records to be too high. The PLC software was further complicated by a consistency checking algorithm and we were unable to successfully debug this problem. We ultimately avoided it by using the software we wrote ourselves for data logging, but in the meantime we had accumulated a lot of data which were suspected of having bogus 256's added. Quick-look plotting revealed the error as random spikes in the graph. Initially, quite a few man hours were spent checking such data and we did the correcting manually (using a text editor and hand calculator). We subsequently automated the process by creating an option for it in our data archival software.

Another potential problem on which we spent a fair amount of time turned out to be a non-problem--the real problem was lack of information. The issue was switch bounce, which we suspected in debugging the high count difficulties with some of our PLC system meters. The DAS vendor who installed some of the equipment earlier in the project had in fact put a resistor and capacitor (RC) circuit between the counter/transponder and the pulse meter, corroborating our suspicion that bounce might be a problem. After toting out our oscilloscope, we did indeed find bouncy switches on gas meters and one water meter. We spent time trying RC circuits and building more sophisticated debouncing devices--experiencing once again the difficulties of having to develop our own hardware--until the vendor produced a piece of literature from the PLC manufacturer which stated that the counter electronics were fully debounced! The moral here is be sure of the problem before you try to fix it.

A few problems fall under the heading of improper installation. At Enerplex, the electrical contractor misconnected some of the electric meters to the starter relay boxes for the chillers. Measured consumption was too low, when checked against both a portable power meter and ammeter, yielding astoundingly high COP's. The meter connections were checked and corrected. Wrong installation resulted in burned-out isolation relays for a few of the electric meters. A typical electrical contractor is not familiar with the proper hook-up procedures for monitoring equipment. Unless closely supervised or provided with carefully detailed specs, the electricians tend to "wing it" when they encounter an unfamiliar situation, so that they can get on with the job, rather than pause and ask how to make the proper meter connections.

Given these difficulties with "pulse taking" in buildings, why use this method? Why not install relatively inexpensive watt-transducers, for example? For submetering, a long-term continuous record of energy use is crucial for disaggregation. And again, there is the value of redundancy. By insisting on installation of meters that have human-readable output (that means eyeball readable dials!) as well as computer-readable pulse output, and by eyeball-reading the meters frequently, we always have a record of the crucial energy flows. We cannot count on the computer staying up; there will be software glitches and interruptions to update the system.

The bottom line in "pulse taking" for buildings is that the consumption computed by the DAS should match the consumption recorded on the meter dial. The meter dial is usually right. (We did find an exception. When a gas meter dial was stuck for six weeks, the utility company didn't fix it right away, and so we are missing data for this period.) We have learned to make it a practice to read the meters, sometimes every few minutes, during critical measurement periods such as times when we experimentally control the HVAC equipment in a building. Energy flows are too important to trust the DAS data alone. Over a four-month period early in the Lumley project, when we had various DAS start-up problems, the extra 256 counts problem, and extended data gaps due to outages or computer crashes, we were able to rehabilitate the gas meter data and get some results because we had eyeball-readings with which to compare it. In fact, comparison of the computer recorded data with the manual readings helped us identify some of the aforementioned problems. The process was labor-intensive, but better than losing data from four months of a heating season. When the DAS is working properly, checking the data against manual readings gives aggreement within 1-2%, which is often the resolution limit of the meter dials. Such cross-checking should be compulsory for all meter data to be used for analysis, and as the saying goes, "Anyone who isn't finding many errors in his data isn't checking very well!" (Pollack and Joiner, 1981).

LIGHTNING PROTECTION

The Enerplex DAS is vulnerable to damage from electrical storms. When the system was designed, we were concerned about the weather station sensors on the roof of one building; each is connected to a transponder board by a pair of wires. Because the board is expensive (about $500) and serves other sensors as well, we installed a device to protect it from electrical-storm damage coming in from the sensor wires. The device limits current, via fuses, and voltage, via a gas tube and zener diodes.

A strong storm in July 1985 showed us that further protection was needed. The microcomputer which controls the entire system was untouched even though it did not at that time have a filtered power supply. Extensive damage to the system occurred in the following areas:

1. The receiver/transmitter board which bridges the transponder boards and the computer was seriously damaged.
2. All 16 transponder boards were damaged on the signal end, where they connect to a pair of wires which links all the boards to the receiver/transmitter. The fuse on the signal line of each board needed replacement, a simple job; on several boards components downstream of the fuses were zapped. Either the fuses didn't blow fast enough or component damage was due to excessive voltage and not current. Some boards were damaged from transients coming in from the power supply circuitry which takes 110 VAC and converts it to low DC voltage. The fuse on the AC section of the board, like the signal lines fuse, wasn't able to protect the boards in all cases.
3. The temperature sensors connected to one board were burned out.

We were able to repair some of the boards ourselves and we also replaced the temperature sensors. The manufacturer repaired or replaced the other boards, a time-consuming and expensive process. Replacing an individual temperature sensor requires that the new one be calibrated. Replacing a temperature-sensor transponder board, with its offset and scaling resistors, requires that all of the sensors, a maximum of 16, be recalibrated, a most unpleasant job when a building is occupied and it is inconvenient to remove and reinstall the sensors.

We now have the lightning protection system shown in Figure 2. The weak points in the DAS revealed by the storm have been shored up and the computer has been protected at its electrical access/egress points: AC power and the telephone line. A recent storm did nothing more than blow four plug-in fuses in the protectors installed at either end of the line connecting the two buildings. The primary lesson is one of redundancy: the fuses on our transponder boards were inadequate.

Lightning protection for our two PLC systems consists of surge limiters for the computers and, for outdoor temperature and solar sensors, the same kind of device as is used at Enerplex. The PLC transponders are fused on the 110 VAC input.

TEMPERATURE SENSORS

Over half of the channels installed in our projects are temperature sensors that monitor HVAC equipment performance and temperature in air ducts, occupied spaces, and outdoors. We use two types of temperature sensors: an integrated circuit type whose current output varies linearly with temperature; and nonlinear resistance temperature devices (RTD's) that can be linearized through circuitry or postprocessing of data. To obtain accurate information from these sensors, we have found that it is important to understand not only the limitations and advantages of each type of sensor, but also the circuitry that drive them. Data sheets and catalogues give some idea of the former, but if paired with poor circuitry, even the best sensors give questionable data. Accuracy of calibration, thermal stability, and sensor location are also of concern in obtaining reliable data.

The integrated circuit temperature sensors used in Enerplex and Lumley Homes provide a nominal current of 1 uA/C and are marketed in several grades, reflecting the deviation of the sensor from the nominal current and sensor nonlinearity. The lowest grade costs about $5 per sensor, and the highest about $50 per sensor. We have found that the lowest grade sensor performs as well as the highest grade, if appropriate circuitry is used, if the sensor is calibrated correctly, and if temperature swings are small compared to the sensor's full range. The expected temperature swing for our sensors is no larger than 60 C. The full range given by the manufacturer is -55 to 150 C.

The circuitry usually converts the sensor's current output to a voltage through a resistor and allows the user two potentiometer adjustments which together determine the "offset," or temperature corresponding to 0 volts, and correct for "slope," or current output deviation. The adjustment procedure is not necessarily straightforward. One potentiometer does not always control the offset and the other the slope; in such cases they must be set iteratively to produce the correct offset at the correct slope. A two point calibration is the only way to ensure accurate calibration. The manufacturer of such circuitry rarely gives the equation relating potentiometer adjustments to slope and offset. Such was the case with the Lumley Homes PLC system; we had to derive the equations from the circuit diagram. The Lumley Homes temperature sensors are eached housed with its circuitry in a small plastic box. A PLC transponder supplies DC power to the circuitry via a short cable which also returns the voltage output from the circuit back to the transponder. There the signal is digitized by a 7 bit analog-to-digital (A/D) converter yielding an integer between 0 and 127. As purchased, the A/D output corresponded to a temperature between 0 and 127 F; no post-processing of data was required. But the circuit resolution was poor, only 1 F, and calibration errors were as large as 5 F.

We do not need a 0 - 127 F range for most of our PLC sensors (they measure apartment temperatures), and we wanted to increase the resolution by changing the settings of the potentiometers that control the slope and offset voltage. But these were low quality 3/4 turn potentiometers; precise settings were impossible. Even if perfect settings were possible, we needed another resistor in the circuit to achieve to desired resolution.

Our calibration efforts proved difficult as well. We tried calibrating at several points between 10 C and 40 C. Since the sensors are housed in the same box as the circuitry, electronic components change temperature with the sensor during calibration. The resistance used to produce a voltage output from the sensor significantly varied with temperature. Much effort was spent replacing temperature sensitive, low quality resistors with 1% precision resistors. We also found that the input voltage to the temperature sensor was not constant, but changed when the transponder was plugged into a new wall outlet. Our final solution was to calibrate the sensors in place, in individual apartments. Since we could not set potentiometers accurately, we simply read the voltages at several places in the circuit and computed constants used to post-process the data and produce the correct temperature. We were unable to calibrate at two points, since we could not carry controlled temperature boxes around to the apartments, and we were forced to calibrate in air. Admittedly, our calibration procedure was less than perfect, but the only other solution was to invest in new equipment at a cost of about $6000 for 20 sensors.

At Enerplex, the sensor circuitry is on the transponder boards and not in a box with the sensors. Multiturn potentiometers make precise settings easy. A 12 bit A/D converter gives a 0.048 C temperature resolution. By adjusting one offset potentiometer on each temperature transponder board, the correct reference voltage is provided for all 16 sensors sensors on the board. So, one voltage must be set very precisely, and then every sensor on the board is calibrated by one slope adjustment each. No iteration is required. We can use a water environment for calibration, since the sensors are packaged with the electronics. (With air sensors, we put both the sensor and the calibration standard in a waterproof tube.) We adjust the slope potentiometer at room temperature and check the sensor temperature against the standard at a much higher temperature. If the offset is set correctly, any sensor error is due to nonlinearity. With this type of circuitry, even the lowest grade sensors can be calibrated to ± 0.1 C over their working temperature range. We have rechecked sensors after calibration with good results. For this type of calibration, the sensor must be removed from its monitoring location and connected near the computer so that a person can watch the computer while turning a potentiometer. But the result of this effort is accurate data.

Earlier in the Enerplex project, calibration efforts were feeble. An outside contractor responsible for installation and calibration thought that using the highest grade sensors implied that no calibration was needed. When we asked them to demonstrate accuracy, they complied by checking each sensor at one point, in situ, in still air. This method was not only inaccurate, but it involved five people, because the sensor, potentiometers and computer are at different locations unaccessible by telephone and too distant for one set of walkie-talkies. On top of this ludicrous calibration effort, the contractors did not set the offset potentiometer, so that even if the one point calibration was perfect, the sensor would deviate at other temperatures.

We have used RTD's in our second PLC project with much success. The PLC temperature transponders convert the nonlinear RTD output voltage to a temperature without additional sensor circuitry. As before, a 7 bit A/D gives a 1 F resolution, but we carefully checked these sensors over their entire range and found no sensor error. The only problem with RTD's is that no external adjustment is provided to change the range or resolution. We needed to measure temperatures above 127 F, on hot water pipes, for example. To do this, we added a resistor in parallel with the RTD and calibrated the sensor over the new temperature range to produce software correction constants. With the resistor, the temperature range decreased slightly, and the temperature output was slightly nonlinear, yet acceptable. In some sense, we were lucky that the changes we needed were small. If we needed to increase the range, nonlinearities and resolution may not have been acceptable.

The final enemy of good temperature data is thermal stability and sensor location. Apartment sensors must be placed away from televisions, lights, and sunlit walls, and we are sometimes hard-pressed to find a good location. Locating sensors is further complicated by aesthetics. Residents do not perceive wires and boxes stuck to the wall as stylish decor. They sometimes insist that we keep the sensor low--behind furniture for example. And more than once, we have found our transponder unplugged and sitting in a drawer. Integrated circuit type sensors respond very quickly to temperature changes, and a person walking by or sitting near a sensor can influence it. In office buildings, we have better choices of sensor location, but have found accessibility to be a problem. We can obtain accurate readings by burying sensors inside double walls, over drop ceilings, inside fan ducts, where they may not be disturbed by people or lights, but finding and pulling these sensors for recalibration or "check-ups" is very time consuming.

FLOW METERS

Both air and water flow meters have caused problems at Enerplex due to poor sensor location, calibration problems and faulty meter electronics. Redundancy has been our chief weapon and, at times, a false friend.

One of our water flow meters is a turbine meter similar to the kind used by the local water company. We initially compared the readings with flow measurements we made by recording pressure drops across pumps and using pump curves. The pressure gauges supplied with the pumps were woefully inaccurate and we calibrated them with a deadweight tester. Using flows across the pumps was risky because we were usually on the portion of the pump curve where a small difference in pressure makes a large difference in flow and because the pressure gauges have some jitter; nevertheless, we took flows through two pumps as an indication that the turbine meter was about 30% percent low and we computed chiller COP's on the basis of pump flows. We eventually calibrated the turbine meter and found it to be only 3% low, but calibration was a non-trivial task. The meter had to be removed for us by a contractor equipped with the blank flanges needed to seal off the pipe after the meter was removed (the isolation valves leak). Because we could not provide a calibrated flow of 200 gpm, where the meter operates, we took it to the water company, who graciously calibrated it free of charge. We have learned the hard way to trust a turbine meter above pressure measurements across pumps.

Another turbine meter is installed in piping which carries cold water from a seasonal thermal storage facility to a heat exchanger in the north building. This meter has been in excellent agreement with a visual flowmeter in the same pipe, thus we have not felt the need to recalibrate it. On the other side of the heat exchanger we have a vortex-shedding water flow meter which records flow to the building's cooling coils. We insisted on this meter when working with our instrumentation contractor even though the flow is supposed to remain fixed, because the flow is needed to compute cooling delivered to the building and the COP of the chillers used in series with thermal storage. The meter is about one pipe diameter downstream from an elbow; there is no good place to put a single meter. In retrospect, two meters should have been installed after the piping splits and goes through long, straight runs. By performing an energy balance across the heat exchanger (only possible when the storage facility is in use) we found that the vortex meter only records about 50% of the flow, which can be as low as 70% of its specified value. Redundancy, in this case checking the vortex-meter reading against the flow estimated from an energy balance, was once again crucial.

Our airflow measurements are in large ducts, with 24-33 ft^2 cross-sectional areas. We don't place much faith in a single point measurement in the middle of the duct because we don't know the flow pattern across the duct; such measurements tell us when there is airflow but only give a rough indication of the magnitude. To get accurate readings, we added instruments which measure the flow at points on a 1 foot grid and integrate the readings. These instruments work on the heated-wire principle and require an electronic control panel which feeds a voltage proportional to air speed to one of our transponder boards. The improved accuracy has come with a price: the fancy but faulty electronics, which have caused spurious readings and short circuits, put us at the mercy of a small company which has had difficulties staying in business. We have used the point measurements to tell us whether the integrated readings make sense; if so, we then rely on them for quantitative analysis.

We use paddle-wheel flow meters for measuring water flow rates in the domestic hot water loop of both apartment buildings and in the heating water circulation loop at Beechwood Apartments. The paddle wheel is inserted at a slight depth into the flow stream. Its rotation produces a low-level voltage wave with a frequency proportional to the flow rate. A signal conditioner converts the waveform to an analog signal that is proportional to the flow rate. We feed the analog voltage into a PLC transponder which transmits the digitized equivalent over the power lines.

Paddle-wheel meters are not new in the field of flow measurement. Recent advances in digital electronics have aided the development of such low cost flow meters. But our experience suggests that the calibration procedures of manufacturers may not be adequate for precise measurements. Additional calibration is needed for each individual transducer and pipe run installed in the field, especially for flow meters in small (1" or less) diameter pipes. A constant derived from meter calibration is only valid over the upper 90% of the meter range. The paddle wheel stops spinning at a flow between 0 and 10% of full scale. Thus very low flows can produce a zero reading.

We performed our own calibration of small-diameter pipe meters using pipe sections identical to those that would be used in the field. Our calibration constants were significantly lower than those reported by the manufacturer. We did not have the capability to calibrate a 3" pipe meter and sent it back to the manufacturer for calibration. The manufacturer does not calibrate individual meters. Rather, a single transducer for each size is calibrated under the assumption that all units of the same size are identical. Indeed, the constant for this meter was also lower than originally specified. In this case, the lesson was not to accept the manufacturer's calibration. If, as with the larger meter, one cannot perform an in-house calibration, it is important to find out if the manufacturer's calibration procedure is valid (in this case it wasn't) and to have the meter recalibrated.

ON A HAPPIER NOTE

Not all of our efforts to collect data have been plagued. Recently we added instrumentation at Beechwood apartments to monitor air conditioning use. We decided to monitor compressor runtime in apartments where we were already monitoring temperature. Our temperature transponders had one free input bit. This was perfect (although unplanned), because we only needed one bit of information--on or off. We found and purchased an off-the-shelf relay to provide the signal. We packaged the relay in a black box into which we plug the air conditioner. The box mounts just beneath the air conditioner and almost looks like an integral part of it. The assembly was designed and built in-house at a parts-cost of $35 per box. Construction and installation of 11 units required about 45 hours of labor. The data acquisition software we developed was flexible enough to handle the new channels with less than one hour's worth of programming.

Another success story has been our use from early on of "quick-look plots" to examine incoming data on a weekly basis. This has proved helpful in flushing out problems with sensor locations and sensor failures which might have otherwise remained unnoticed. At Enerplex, we measure interior temperature at five locations. By comparing these data on plots, we identified a bad sensor that was reading low. The temperature seemed reasonable by itself, but not when compared to the four other interior temperatures. We also discovered that the vendor software was not reporting negative outdoor temperatures (it took the absolute value). The visual aid provided by plots was key in discovering each of these problems. Quick-look plots were intended to be an analysis tool--pinpointing interesting data and faults in building operation--yet this secondary benefit of debugging the instrumentation has been most welcome.

We also have tackled the need for consistent data by developing our own software packages for both data collection and data archival. We use these in house, and they are general enough for export to other building energy analysts. The new data collection software replaces the purchased software used in both the Enerplex system and the PLC system. The new software, written in Pascal, corrects bugs such as the 256 glitch, and checks consistency as the data are collected. The software polls each channel 200-400 times per hour, and the consistency checking allows us to throw away bad readings which might otherwise spoil an entire hour's worth of data. The archive program checks consistency over a longer time span and produces a log of errors so the user can identify problems causing inconsistency. Although they took time to develop, these programs eliminate the need to debug vendor software (written in BASIC and poorly constructed), instill more confidence in the data collected, and eliminate the time consuming task of developing individual programs for consistency checking.

CONCLUSION

Part of our hindsight in looking back on the pitfalls is simply that instrumenting buildings for energy studies isn't as easy as one might expect--call it further empirical confirmation of Murphy's Law, if you will. The recurring solutions presented here have been the most valuable weapons. There will always be unavoidable problems, but on looking back on ours, most were solved by using three rules of thumb: include redundancy in the measurements, as confirmed by many problems; know when to take the problem into your own hands, as with in-house flow meter calibrations and software overhauls; and know when to leave the problem to someone else, as when using off-the-shelf products. The perceived difficulty of a task is related to one's expectations of ease, and so, even if the tips we offer here don't really make buildings instrumentation work easier in the future, they'll make it seem less difficult because you know what kinds of experiences to expect.

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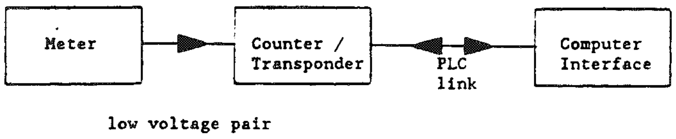
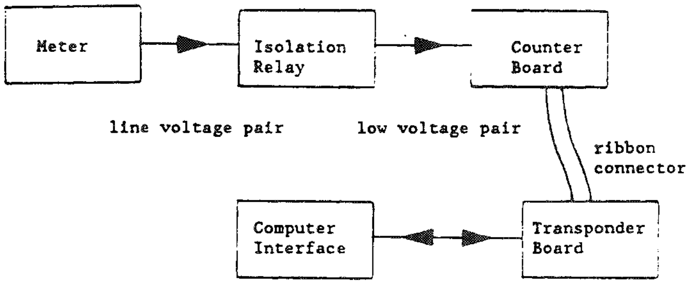
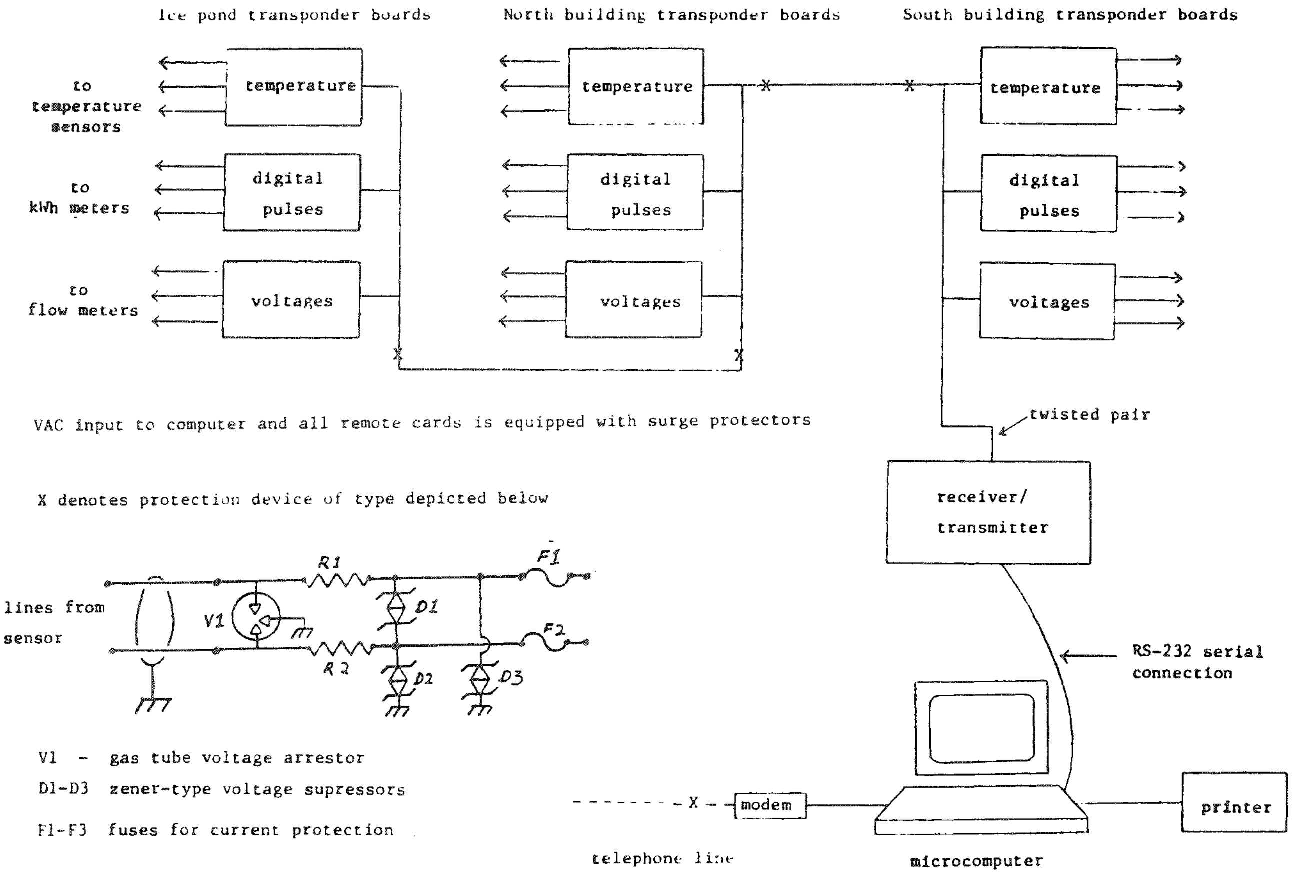


(a) as used at Beechwood and Lumley projects



(b) as used for electric meters at Enerplex project

Figure 1. Pulse counting meter interface arrangements



VAC input to computer and all remote cards is equipped with surge protectors

X denotes protection device of type depicted below

V1 - gas tube voltage arrestor
D1-D3 zener-type voltage supressors
F1-F3 fuses for current protection

Figure 2. Lightning protection for Enerplex system