

A TALE OF TWO METHODS: ANALYSIS OF ENERGY USE DATA FROM MULTIFAMILY RETROFIT TESTS

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INTRODUCTION

Over the past few years our organization has tested a number of energy conservation retrofits for multifamily dwellings, including steam cycle control systems and hot water outdoor reset and cutoff controls (Peterson, 1986), furnace vent dampers (Hewett et al, 1986a), conversions of two-pipe steam systems to hot water (Lobenstein et al, 1986), and installation of tenant metering systems (Hewett et al, 1986b). In order to determine the savings and cost-effectiveness of these retrofits it was critical for us to find or develop analytical methods that would give accurate and reliable savings estimates regardless of changes in weather between test periods. We believe it will be useful for other researchers in the multifamily sector to learn of our subsequent experiences with two quite different methods, the Princeton University PRISM program run on a mainframe computer and our own system of a spreadsheet and two auxiliary programs that run in-house on a personal computer.

THE PRISM PROGRAM

The PRISM program represents the current (and steadily evolving) state of the art in the automated analysis of residential energy use data (Fels, 1983). It fits a set of dated energy use observations to a file of local weather data using a three parameter model of constant non-heating base use, a heating threshold temperature, and a heating response rate. This model is individually fit to each dataset, then its parameter values are used with a long-term average weather data file to calculate a Normalized Annual Consumption Index (NAC) representing use over one "typical" year. It is computationally well-behaved and gives a robust NAC estimate allowing direct comparisons of use based on original datasets that could differ greatly in length and weather.

Since PRISM was initially developed and applied for single family home data (usually, though not exclusively, gas or electric utility readings), there was some question whether multifamily dwelling data would be usable for analysis or whether the buildings themselves would appear consistent with the underlying PRISM model of a substantial summer period of nearly constant non-heating use plus heating use that increases linearly with degree days. We have now accumulated enough experience with PRISM both in single family (over 450 buildings in 4 projects) and multifamily (about 120 buildings in 7 projects) datasets to contribute to the resolution of these questions.

The principal difficulties we encounter in analyzing single family data stem from time constraints (tenancy changes too close to the retrofit date, or attempting to do a post-retrofit analysis before enough readings and/or months

of data are available), from real but atypical observations in the datasets (due to system malfunctions, or to short-term changes in the number of occupants or heated space, for example), or from the meter reading performance of the local utilities (errors causing high-low pairs of readings, or estimated billings occurring too frequently or at unfortunate times). Cases that do not have these problems or that can be salvaged by dataset additions or changes typically give very good PRISM results both in statistical terms and in terms of matching the underlying physical model of the program.

For the most part multifamily data shows all the same characteristics, plus a few unique ones. One practical problem is the occasional difficulty of getting the required whole-building data for large apartments that have several submeters and/or separate accounts that must all be acquired and combined (sometimes in the face of differing meter reading schedules that exacerbate the problem of estimated billings). Other buildings have had a change in heating fuels at the time of the retrofit of interest, or they may have intermittently switched fuels throughout the test period. These factors give multifamily analyses a different flavor, but they don't substantially change the rough rule that about 60% of cases with nominally adequate data will run cleanly on the first attempt, 25-30% of cases can be salvaged by dataset manipulations, and 10-15% of cases will never run well due to insufficient or hopelessly inconsistent data (Dunsworth and Hewett, 1985).

A thornier difference between single family and multifamily data is the appreciable occurrence of model non-linearity in the latter. This can take the form of a stepped discontinuity rather than a point transition from heating to non-heating use, due to intervention by building maintenance people or by an automated boiler cutoff system. It can also take the form of an apparently curved heating line, whether due to a fundamentally non-linear relationship (caused by the mild weather effects of an outdoor reset control, for example) or to smoothing of a discontinuous relationship by use of readings on a monthly scale. Some curving cases could even be due to different factors at the cold (eg. inadequate radiation capacity) and mild (eg. smoothed control discontinuity) ends of the heating line. Any of these cases can give adequate PRISM results as-is (albeit usually with "unrealistic" parameter values), or else a "nicer" model can be derived by deleting some of the most non-linear data points. It is debatable which result is physically more meaningful or numerically more representative of the actual use of the building. We tend to massage our datasets, partly because the unaltered sets do not as often give acceptably well-defined PRISM results and partly because our analyses sometimes make use of the individual parameter values and we want them to reflect the true heating slope and baseload use in the data. This non-linearity problem is a special case of the general problem of whether (or when) any dataset changes are justifiable and whether an altered model is as representative of overall use in that specific period as an unaltered model would be, issues that are a perennial concern to all PRISM users.

THE PC-BASED METHOD

Because some of our retrofit test programs use the alternating mode (or flip-flop) experimental design, which generates shorter observations than PRISM usually uses, and because these tests are generally completed within one heating season and therefore lack any of the non-heating use observations that PRISM requires for best results, we developed a second analytical method specifically for such cases. This method uses spreadsheet equations to convert furnace run-time meter readings into use in therms/hour and then to regress use on standard degree days (ie. using a 65°F reference temperature for all cases) that have been calculated for each reading period by an auxiliary program. A second auxiliary program then applies long-term temperature bin data to calculate space heating use over a "standard" heating season from mid-October to the end of April (a period chosen from experience with a number of building managers that happens to correspond to the dates when the average daily maximum temperature goes below the average multifamily reference temperature of about 63°F). Seasonal use is the sum of the use at all temperatures for which the regression model predicts a positive heating demand. Plots of the data can readily be generated using spreadsheet program functions, and enough intermediate statistical results are printed out to permit exact tests of possible outlier points and of differences in normalized use between test modes.

Since exact reading times are recorded, this method should avoid the potential distortions of using a whole-day approximation (as PRISM does), which become more of a problem as observations are taken over shorter periods and which can lead to degraded model results or to the unnecessary loss of from one to 20% more cases that fail standards of model fit solely due to the introduced noise of weekly reading period variability. Degree day values should be similarly more precise, though still limited by our use of daily midpoint temperatures rather than detailed hourly data. While using a fixed reference temperature is a possible source of bias (Lee et al, 1983), we feel this risk is minimized by the fact that local multifamily buildings analyzed with PRISM have reference temperatures clustering near the chosen 65°F value ($63.6 \pm 3.8^\circ\text{F}$ for 57 cases), by the fact that our protocol does not generate any data points near enough to a 65°F mean temperature to be significantly distorted by reference temperature mis-specification, and by the fact that our regressions are not forced through the zero-zero point but are instead free to take on other intercept values (which we believe correspond in part to deviations of true reference temperatures from 65°F and in part to various levels of distribution system losses).

In practice this method seems to have worked very well, with regression R^2 values over 95% in most cases suggesting that the use of weekly or biweekly readings is quite satisfactory. It has become an easy method as more steps became computerized and as our technical staff became more familiar and adept with it. Though we are generally satisfied with it, there are a few questions we hope to investigate further as we continue to use it. One of these is the issue of the best reading period length to use, and our preliminary results suggest that one week is long enough if the heating system in question can be expected to equilibrate rapidly after a change of retrofit modes. A second

issue is whether our standard mid-October to late April season is better overall than either our alternate early October to late May season or some other heating season specification. Another question is raised by the occasional case with a high Y-intercept value (concern over missing some important mild weather behavior has contributed to our decision to take year-round readings for one recent project) or a negative Y-intercept (so that some readings could be close enough to the true reference temperature to be biased by our method).

COMPARISON AND DISCUSSION OF THE TWO METHODS

Our experience has convinced us that both of these methods can give useful results in multifamily retrofit tests and that to a large degree they complement each other by dealing with different sorts of cases. Thus PRISM is most appropriate for analyzing a year or more of main meter data before and after an essentially irreversible retrofit (such as total boiler replacement). It is the method of choice if a retrofit may affect not only the heating response rate but also the reference temperature and base use (which we find to be maddeningly true even in some cases where our a priori expectation is the opposite). It is also preferable if it is known or suspected that the reference temperature may be very different from 65°F.

In contrast, the PC method is best suited to retrofits that can be easily turned on and off (such as outdoor resets or electric vent dampers) and that are expected not to have any impact on non-heating use. It works well with submetered space heating data that PRISM could not deal with, and it works in alternating mode tests that are completed in nine months or less rather than the two years or so that PRISM prefers. It can also be fairly easily modified to deal explicitly with curvilinear models if that is an issue in a particular case, and with the right choice of reference temperature and season length (?) the problem of stepped discontinuities will be finessed.

There are some cases to which either method may be applied, and it is instructive to review our results from a vent damper test that fell into this category because we collected year-round hour meter and regular gas meter data. We found that the two methods gave similar model fits and that points appearing as an outlier on one would also show up on the other (though the PC method lends itself more readily to doing exact outlier tests). Savings results were qualitatively similar in sign and relative magnitude, and adjusting PRISM NAC values for non-heating use outside our standard season gave use results essentially equal to those of the PC method, though it suggested that a season midway between the two we have used might be best on average. PRISM took significantly more manual data preparation and massaging (large numbers of weekly observations had to be coded, artificial base use was added to submeter data to get the best performance from PRISM, and manipulated reruns were required for several non-linear cases), but in return it erased our concerns about season length and using a fixed reference temperature and it provided information about the behavior of several buildings around their reference temperatures.

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