PRISM RESEARCH: YESTERDAY, TODAY, AND TOMORROW

Margaret F. Fels, Clifford M. Hurvich and Cathy L. Reynolds
Center for Energy and Environmental Studies
Princeton University

ABSTRACT

PRISM, the Princeton Scorekeeping Method, is a statistical procedure which uses available data to monitor energy conservation in housing. The PRISM software has been used for the measurement of energy savings in a wide variety of energy conservation programs, involving use of all major fuels for heating, in multifamily as well as single-family buildings, over a wide range of heating-dominated climates in the U.S., and for aggregate as well as individual-building consumption. Applications to date, by Princeton and by other scorekeeping groups, are summarized. In addition, current and future directions for PRISM research are identified in the context of anticipated applications.

PRISM RESEARCH: YESTERDAY, TODAY, AND TOMORROW

Margaret F. Fels, Clifford M. Hurvich and Cathy L. Reynolds
Center for Energy and Environmental Studies
Princeton University

KEEPING SCORE

As evidenced by the range of conservation approaches being reported at the ACEEE 1986 Summer Study on Energy-Efficient Buildings, the need for keeping accurate score on the actual amount of energy saved in buildings is increasing. Furthermore, standardized scorekeeping is crucial to the ultimate determination of "What works?" and "What doesn't work?" in energy conservation. Much progress has been seen since the first ACEEE Summer Study in 1982: the discussion of scorekeeping has shifted from "whether" to "how" to use real data, and the importance of real data has repeatedly been proved in the often-found shortfall of actual savings relative to the engineering estimates used in the planning of conservation programs.

The PRInceton Scorekeeping Method, or PRISM, is a statistical procedure whose primary objective is standardized measurement of energy savings in buildings. Based on actual, whole-house meter readings, PRISM tries to create an accurate picture of how much energy people have consumed, and how much they have saved over time. (We define the word "scorekeeping" to mean the measurement of actual energy savings.) Perhaps surprisingly, reliable scorekeeping is not difficult: the required data for PRISM (meter readings from utility bills and average daily temperatures from a nearby weather station for an approximately one-year period) are readily available, and the software is easy to use. As depicted in Fig. 1a, the method produces a weather-adjusted index of consumption, Normalized Annual Consumption, or NAC, for each house and year of analysis, as a measure of what energy consumption would have been under typical weather conditions. Total energy savings are derived as the difference between NAC in the pre- and post-periods. A conservation effect is thus neither masked by a cold winter nor exaggerated by a warm one, nor is it obscured if the time covered by billing periods in one "year" is longer or shorter than in another.

The origins of PRISM date back to Princeton University's earliest energy analyses of buildings, in the 1970's (Schrader, 1978; Socolow, 1978). In fact, the simple relationship between a house's energy consumption for space heating and outside temperature was recognized, in the published literature, at least 80 years ago (Macon, 1906; Bolton, 1911). In its current form, PRISM differs from other approaches in several important ways: in its physical foundation, which allows a physically meaningful interpretation of the results; in its emphasis on reliability, particularly of the NAC index, which in general is extremely well determined; in its standardized output, which facilitates comparisons across programs, and its accurate error diagnostics attached to all the estimates it produces; in its availability, to a wide variety of potential scorekeepers; and, finally, in its objective of generality, to all fuel types and to a wide range of building types and climates.

PRISM is currently the method of choice for more than 30 scorekeeping groups, including municipal and state government researchers, national laboratories, private entrepreneurs, and utilities, both gas and electric; see Fig. 2. Until recently, access to a mainframe computer with a Fortran 77 compiler was required; now a version compiled for a personal computer is expanding the range of users. Through an informal users network, each application of PRISM is increasing the collective understanding of the method's strengths and limitations.

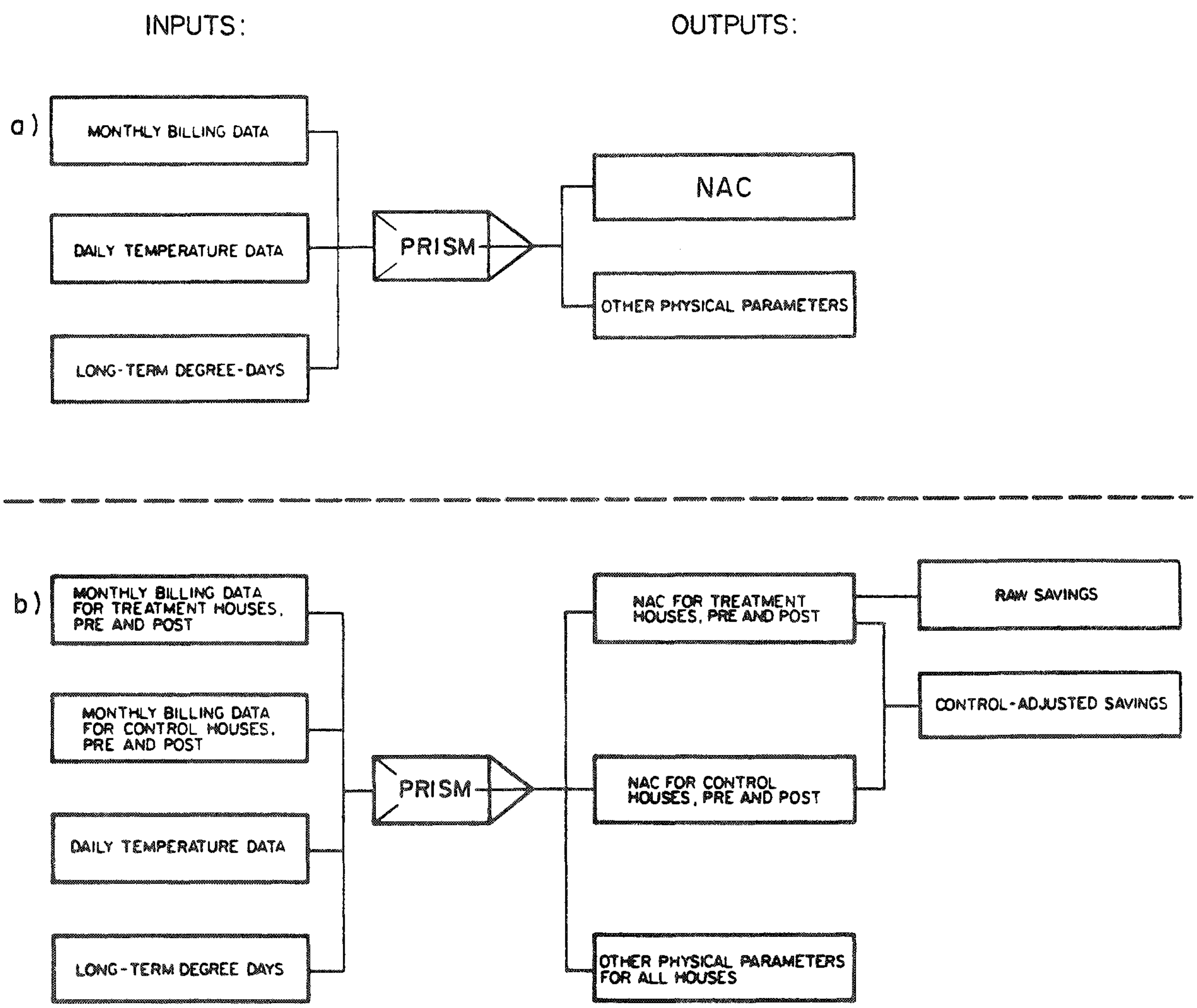

Figure 1. Schematic diagram showing the data requirements for PRISM and the estimates that result from it: a) for one house; and b) calculating control-adjusted savings for a group of treated houses.

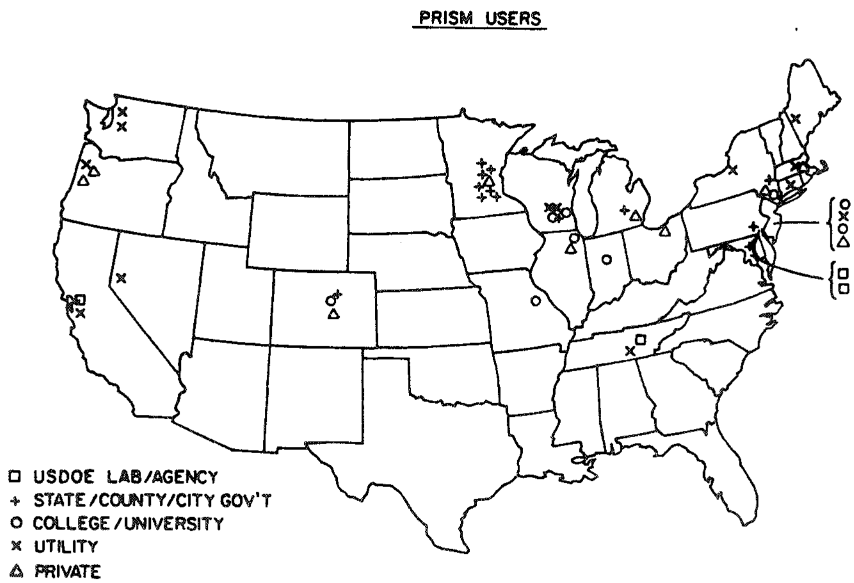

Figure 2. Map showing PRISM users in the U.S. as of June 1986.

SCOREKEEPING TO DATE

PRISM has been widely applied to groups of single-family houses. A number of applications are reported in the special PRISM issue of Energy and Buildings (Fels, 1986), including an evaluation of Wisconsin's low-income weatherization program (Goldberg, 1986), an evaluation of Bonneville Power Administration's residential conservation programs (Hirst, 1986), the decomposition of aggregate consumption trends (Goldberg and Fels, 1986), and analyses of the effectiveness of house doctoring (Dutt et al., 1986; Rodberg, 1986). The method is being used extensively in Minnesota to monitor the success of a variety of city and state programs (e.g., Hewett et al., 1986; Robinson, 1986). Other applications of PRISM include evaluations of furnace retrofits, in two independent studies in Colorado (Warner and Claridge, 1986; Salmon, 1986), and a measurement of the effectiveness of increasing the solar component for space and hot water heating (Cautley, 1986). In addition, the U.S. Energy Information Administration is investigating potential applications of PRISM for analyses of the national Residential Energy Consumption Survey (RECS) data base (Carlson, 1986).

Recently, the almost untapped resource of energy savings in multifamily buildings has received increasing attention. PRISM is being used to identify and understand that resource, in a 60-unit gas-heated apartment building in New Jersey which is being instrumented and analyzed by Princeton University (DeCicco et al., 1986), in San Francisco Housing Authority apartment complexes being analyzed by Lawrence Berkeley Laboratory (Goldman and Ritschard, 1986), and in a number of oil-heated buildings being monitored by Princeton (Englander and Dutt, 1986). In the latter, careful combination of dipstick readings with oil delivery data can provide sufficient information for reliable PRISM analysis. PRISM's applicability to commercial buildings is also being explored, with a surprising level of success in some cases and with evidence in other cases of the temperature dependence of consumption being swamped by other effects (Rabl et al., 1986).

Whereas the methodology development initially emphasized gas-heated houses, special problems relating to other fuels have been recently addressed: electric cooling, which at best confounds the analysis of electric heating (Fels et al., 1985); the sparseness of data for oil-heated houses (Fels et al., 1986); the interference of supplemental heating by wood on the analysis of the main heating fuel (Fels and Stram, 1986). Although not <u>all</u> houses, and certainly not all people occupying them, can be expected to obey the simple principles embodied by PRISM, the success of the studies thus far confirms that PRISM is a particularly useful way of extracting as-it-is physical information from billing data.

NEXT STEPS FOR PRISM RESEARCH

The primary objective of our scorekeeping research is to realize the full potential of billing data for monitoring consumption in all climates and building types. Several new directions are currently being explored:

- a more robust statistical procedure, to reduce the sensitivity of the estimates to anomalous consumption data
- monitoring heating and cooling consumption in cooling-dominated climates
- allowance for the interaction between heating and non-heating fuels ("total energy scorekeeping")
- a better understanding of the limitations of the method in multifamily and commercial buildings
- enhancement of the method when frequent consumption data (e.g., daily) are available, particularly in large buildings
- shortening of time after retrofit for preliminary scorekeeping results (PRISM requires one year of post-retrofit data)
- development of an energy rating system based on actual consumption data

- adjustment of the methodology for houses with a large solar contribution, and, ultimately, development of an index for rating the design of energy-efficient housing

- PRISM as stage one in two-stage evaluation approaches.

These are ambitious research goals, and some are farther along than others. Robust PRISM, for example, is fairly well advanced; with it, physically reasonable and accurate results are often obtainable from "problem" data sets containing a small fraction of anomalous consumption values.

We do not expect to be able to carry out the necessary research in all these areas by ourselves, but, rather, we will rely on the growing network of PRISM users and the variety of challenges they present to PRISM as they meet the needs of their individual scorekeeping projects. Our role will be to synthesize the new findings of the scorekeeping community, in order to understand the extent to which PRISM, and, more generally, simple scorekeeping tools, can be used to measure the effects of conservation.

Most of the research items mentioned above concern the development of weather-normalized consumption indices from which savings can be reliably extracted. The last item on the list places PRISM in its broader context of evaluation and thus deserves more discussion.

PRISM AS THE FIRST STAGE

Invariably, an evaluation of a conservation program ought to go beyond a PRISM analysis of the treated houses. First, adjustment for the performance of a group of untreated, "control" houses is often desirable, in order to decouple the savings induced by the measures of interest from the savings that would otherwise have occurred due to external events (such as increased energy prices). This involves application of PRISM to control houses, and a comparison of distributions of savings in the control and treatment groups; see Fig. 1b. Selection of the control group is an important issue and should build on statistical and subject-matter (energy-related) knowledge. The analysis can then be updated for succeeding years, to track the durability of the savings.

Second, it is often necessary to go outside PRISM and invoke the use of additional information, in order to determine the cost-effectiveness of various tried approaches to conservation or to clarify the reasons why some households saved more than others. PRISM provides reliable estimates of weather-adjusted savings for each house as dependent variables which can be regressed against socioeconomic variables such as house area, household size and income, energy price, and program participation. Thus the PRISM analysis depicted in Fig. 1 may be thought of as standardized scorekeeping, representing stage one of the evaluation, while subsequent analyses, limited by available data and shaped by the specific needs of the project being evaluated, constitute stage two. Hirst at Oak Ridge National Laboratory has explored the use of different variables in a variety of stage-two models which use stage-one PRISM estimates as input (Hirst, 1986, and references therein).

We believe that a careful two-stage evaluation offers advantages not obtainable in a single cross-sectional model. Stage one -- PRISM -- is a physical model, describing a specific relationship between consumption and outdoor temperature which is expected from physical principles: PRISM explores the extent to which the relationship holds in each house. In the second stage, no such pre-conceived relationship between consumption and the other variables can be derived; use of different combinations of variables in the regression explores what the relationships might be. Thus, stage one compensates for month-to-month variability in each individual house, by adjusting for weather which is the same for all houses in the same region. In contrast, stage two compensates for house-to-house variability in the weather-adjusted consumption and savings.

With PRISM as stage one, the evaluator knows how well the physical model worked on each house, and, most important, how accurate the weather adjustment (i.e., NAC) was. In a sense, three-parameter PRISM provides some discipline about how many variables to include in the first stage, and some guidance as to what data (e.g., subsets of "good-fit" houses), and what variables, to include in the second stage. This physically meaningful information is virtually lost in an all-in-one approach in which the variation of consumption across houses will mask the individualized relationship of consumption to weather (degree-days) which is evident in each house.

We hope that the availability of a well-tried scorekeeping method will allow the discussion concerning evaluation at this meeting to shift from boring details of how to weather normalize, to broader, more challenging issues: how to choose a control group, how to use the savings estimates to evaluate a program's cost-effectiveness, and what conservation lessons can ultimately be learned from comparisons across programs.

ACKNOWLEDGEMENTS

Credits for the development of PRISM are numerous. Funding has been from multiple sources: the Office of Buildings and Community Systems of USDOE (Contract No. DE-AC02-77CS20062); the Electric Power Research Institute (Project RP2034-4); and, most recently, the New Jersey Department of Energy and all seven of the New Jersey gas and electric utilities, through the establishment of the New Jersey Energy Conservation Laboratory at the Center for Energy and Environmental Studies, Princeton University. Among the many individuals who contributed are Miriam Goldberg, Michael Lavine, James Rachlin, Robert Socolow, Daniel Stram, and Thomas Woteki.

REFERENCES

Bolton, R. P. (1911) "Heating requirements in New York weather", The Heating and Ventilating Magazine, VIII (March), pp. 1-10.

Carlson, L. (1986) private communication, Energy End Use Division, U. S. Energy Information Administration, Washington, DC.

Cautley, D. (1986) private communication, Wisconsin Division of State Energy, Madison, WI.

DeCicco, J. M., G. S. Dutt, D. T. Harrje and R. H. Socolow (1986) "PRISM applied to a multifamily building: the Lumley Homes case study", Energy and Buildings, 9, #1, pp. 77-88.

Dutt, G. S., M. L. Lavine, B. G. Levi and R. H. Socolow (1986) "The Modular Retrofit Experiment: design, scorekeeping and evaluation", Energy and Buildings, 9, #1, pp. 21-33.

Englander, S. L. and G. S. Dutt (1986) "DHW energy savings in multifamily buildings", in Proceedings, ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA.

Fels, M. F., ed. (1986) Measuring Energy Savings: the Scorekeeping Approach (a special double issue of Energy and Buildings, 9, #1-2), Elsevier Sequoia, Lausanne, Switzerland, 180 pp.

Fels, M. F., M. L. Goldberg and M. L. Lavine (1986) "Exploratory scorekeeping for oil-heated houses", Energy and Buildings, 9, #2, pp. 127-136.

Fels, M. F., R. H. Socolow, J. Rachlin and D. O. Stram (1985) "PRISM: A conservation scorekeeping method applied to electrically heated houses", Electric Power Research Institute Report No. EM-4358, Palo Alto, CA.

Fels, M. F. and D. O. Stram (1986) "The effect of burning wood on saving electricity", Energy and Buildings, 9, #2, pp. 119-126.

Goldberg, M. L. (1986) "A Midwest low-income weatherization program seen through PRISM", Energy and Buildings, 9, #1, pp. 37-44.

Goldberg, M. L. and M. F. Fels (1986) "Taking PRISM one step further: the refraction method to decompose energy savings", in Proceedings, ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA.

Goldman, C. A. and R. L. Ritschard (1986) "Energy conservation in public housing: a case study of the San Francisco Housing Authority", Energy and Buildings, 9, #1, pp. 89-98.

REFERENCES (cont'd)

Hewett, M. J., T. S. Dunsworth, T. A. Miller and M. J. Koehler (1986) "Measured vs. predicted savings from single retrofits: a sample study", Energy and Buildings, 9, #1, pp. 65-73.

Hirst, E. (1986) "Electricity savings one, two, and three years after participation in the BPA Residential Weatherization Pilot Program", Energy and Buildings, 9, #1, pp. 45-53.

Macon, W. W. (1906) "Highest economy in furnace heating: proper temperatures, ventilation and coal consumption for different outside temperatures", The Metal Worker, Plumber and Steam Fitter, 66 (November 10), pp. 47-49.

Rabl, A., L. Norford and J. Spadero (1986) "Steady state models for analysis of commercial building energy data", in Proceedings, ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA.

Robinson, D. A. (1986) "Definition and calculation of a normalized building thermal load", in Proceedings, ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA.

Rodberg, L. S. (1986) "Energy conservation in low-income homes in New York City: the effectiveness of house doctoring", Energy and Buildings, 9, # 1, pp. 55-64.

Salmon, L. (1986) private communication, Energy Resource Center, Colorado Springs, CO.

Schrader, T. F. (1978) "A two-parameter model for assessing the determinants of residential space heating", MS Thesis for Dept. of Mech. and Aer. Engineering, Princeton University, PU/CEES Report No. 69, Princeton, NJ.

Socolow, R. H., ed. (1978) Saving Energy in the Home, Ballinger Publishing Co., Cambridge, MA, 249 pp.

Warner, J. L. and D. E. Claridge (1986) "Use of the Princeton Scorekeeping Method to evaluate gas furnace retrofits in the Denver area: results and limitations", in Proceedings, ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA.