TAKING PRISM ONE STEP FURTHER: THE REFRACTION METHOD TO DECOMPOSE ENERGY SAVINGS

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ABSTRACT

A simple "refraction" method is developed to extract energy conservation trends from energy billing data. With this methodology, energy savings estimated by the Princeton Scorekeeping Method (PRISM) are decomposed into physically meaningful components. In addition, indoor temperature changes are inferred, and the effect of such changes on energy savings is quantified.

The method is demonstrated in two test applications. The first, to individual-house billing data for a large number of gas-heated houses in Wisconsin, suggests the dominant role of structural retrofitting in the energy savings achieved by a low-income weatherization program. The second application, to utility aggregate data for nearly one million gas-heated houses in New Jersey, points to the importance of lower thermostat settings in the years immediately following the oil embargo, and, since 1980, to a substantial decline in consumption by appliances including water heaters. More recently, the role of structural retrofitting seems to be increasing, but a "takeback" effect due to a concomitant increase in indoor temperatures may be eroding the resulting savings.

While the refraction results must be interpreted with care, their physical reasonableness in these test cases reinforces the potential of energy billing data to enhance the understanding of energy conservation.

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INTRODUCTION

The Princeton Scorekeeping Method (PRISM) has been applied to heating-fuel billing data to evaluate energy conservation programs in a wide variety of contexts (Fels, 1986ab). Most of these studies have emphasized the usefulness of Normalized Annual Consumption (NAC), whose stability makes it a particularly useful monitoring index. The other PRISM parameters, base level α, heating slope β, and reference temperature τ, are comparatively poorly determined, rendering inferences based on these parameters somewhat uncertain (Rachlin et al., 1986).

It turns out that, when results for large numbers of houses are averaged in some way, the individual parameters, α, β and τ, can offer valuable insight into the nature of conservation activities. In this paper, we describe how physical sources of energy savings can be identified, and how indoor temperature changes can be inferred, from changes in the individual parameters of the PRISM model. The resulting estimates of savings components must be interpreted with care, with attention to measures of the accuracy of the estimates and to the validity of assumptions required for the savings decomposition.

Extending the "PRISM" metaphor, we use the term "refraction" for the decomposition of NAC savings estimates into components attributable to different physical changes in the house. The refraction method is tested here on two data bases of gas-heated houses. The first, from a low-income weatherization program in Wisconsin, consists of individual-house billing data for 243 houses; the second, representing average natural gas consumption for all gas-heated households in New Jersey, consists of aggregate utility sales data. The analyses summarized here are described in more detail in an earlier paper (Goldberg and Fels, 1986).

REFRACTION OF PRISM RESULTS

The NAC index for estimation period k is given by:

$$NAC_k = 365\ \alpha_k + \beta_k\ H_o(\tau_k) \tag{1}$$

where $H_o(\tau_k)$ is the long-run heating degree-days computed to base τ_k.

Taking the difference of Equation 1 between k=1 and k=2 gives the energy savings, $NAC_1 - NAC_2$, between periods 1 and 2 in terms of changes in the individual parameters α, β, and τ, as follows:

$$NAC_1 - NAC_2 = 365\ (\alpha_1-\alpha_2) \quad + \quad (\beta_1-\beta_2)\ \overline{H}_o \quad + \quad \overline{\beta}\ [H_o(\tau_1)-H_o(\tau_2)] \qquad (2)$$

$$\equiv \quad A \quad + \quad B \quad + \quad T$$

where

$$\overline{H}_o = [H_o(\tau_1) + H_o(\tau_2)]/2 \qquad (3a)$$

and

$$\overline{\beta} = (\beta_1 + \beta_2)/2 \quad . \qquad (3b)$$

For later use, we also define

$$\overline{\alpha} = (\alpha_1 + \alpha_2)/2 \quad . \qquad (3c)$$

We use Equation 2 for the components analysis. If, indeed, there is a drop in NAC, then the decomposition indicates the sources of observed energy savings, in terms of three physical components. The base-level component (A) represents savings due to reduced temperature-independent consumption, and is simply the difference in the base-level estimate; the heating-rate component* (B), the difference in heating slope multiplied by average long-term annual degree-days, attempts to isolate savings due to a decrease in heating slope; and the temperature component (T), the difference in long-term annual degree-days multipled by the average heating slope, represents savings resulting from a decline in reference temperature. Formulae for computing the standard errors of these components are given in our earlier paper.

In this study, we assume α, β and τ are derived from PRISM applied to the heating fuel. Obviously, the interaction between fuels should not be ignored when more than one fuel (e.g., gas and electricity) is used in a house by its furnace and its appliances. We hope in future work to include this interaction explicitly; for the time being, we will consider qualitatively the effects of possible changes in electricity consumption on the refraction results we obtain for gas-heated houses.

Returning to Equation 2, it is tempting in a simplified physical model of the heating fuel to associate the T-component with lowered thermostat settings, the B-component with structural retrofits or furnace efficiency

* In previous work, B was termed the "shell component". Since this term actually reflects changes in heating system efficiency as well as in shell tightness, we have adopted the more general term "heating-rate component".

improvements, and the A-component with decreased appliance usage or increased appliance efficiency for appliances fueled by the heating fuel. To examine the extent to which these associations are valid, we take a closer look at the physical effects likely to induce changes in α, β and, especially, τ.

THE TEMPERATURE COMPONENT

Changes in the reference temperature τ are likely to reflect changes in the indoor temperature T_{in}. However, T_{in} is not the only factor which affects τ. In the PRISM model, τ is interpreted as the maximum average daily outdoor temperature at which the furnace is required. This temperature is lower than the indoor temperature because some of the house's heating requirement is met by intrinsic gains Q, from occupants, appliances, and the sun. The difference between T_{in} and τ depends also on the house's "lossiness" L, which is the product of the heating rate β and the furnace efficiency, i.e.,

$$\tau = T_{in} - Q/L. \tag{4}$$

Differentiating Equation 4, then substituting $T_{in}-\tau$ for Q/L in the resulting expression, we obtain the following first-order approximation:

$$\Delta\tau = \Delta T_{in} + (T_{in}-\tau)\ \Delta L/L - (T_{in}-\tau)\ \Delta Q/Q\ . \tag{5}$$

Defining $\Delta\tau = \tau_1-\tau_2$, a positive change indicates a drop in τ, and thus a change in the direction of conservation. The first term, ΔT_{in}, indicates how a thermostat setback might translate directly into a reduction in τ. The terms in ΔL and ΔQ, respectively, indicate how interventions such as house tightening and more efficient appliances might affect τ.

Conversely, Equation 5 allows us to see what a drop in τ implies about a drop in T_{in}, depending on how lossiness L and intrinsic gains Q have changed. To estimate ΔT_{in} from PRISM estimates therefore requires not only $\Delta\tau$ but also information about L and Q. The needed information can be inferred from the parameters α and β, provided some additional assumptions are made.

First, assuming no change in the furnace efficiency, the relative change in lossiness, $\Delta L/L$, is well approximated by $\Delta\beta/\beta$. Furnace efficiency improvements and decreased lossiness would both lower β, so that $|\Delta\beta/\beta|$ becomes an overestimate of $|\Delta L/L|$ if furnace efficiency has increased.

Second, assuming that appliances represent the main source of intrinsic gains, and that the change in the energy consumed by appliances is essentially uniform across fuels (e.g., for gas and electric appliances in a gas-heated house), the relative change in intrinsic gains, $\Delta Q/Q$, may be approximated by $\Delta\alpha/\alpha$. If, instead, appliances fueled by the heating fuel contribute only a small fraction of Q, with the dominant sources of Q being sun, people, and unchanged appliances, this approximation overstates $\Delta Q/Q$.

With the above assumptions about $\Delta L/L$ and $\Delta Q/Q$, Equation 5 gives:

$$\Delta T_{in} \simeq (\tau_1 - \tau_2) - \delta\ [(\beta_1 - \beta_2)/\bar{\beta}] + \delta\ [(\alpha_1 - \alpha_2)/\bar{\alpha}] \tag{6}$$

where δ, the temperature offset, is defined as:

$$\delta = T_{in} - \tau \tag{7}$$

and $\bar{\beta}$ and $\bar{\alpha}$ are defined in Equation 3. As a starting point, we use $\delta = 3.9^{o}C$ ($7^{o}F$). However, the dependence of the temperature offset δ on L and on Q suggests the importance of exploring the effects of different assumptions about δ by applying Equation 6 over a range of δ-values. The validity of the approximations, $\Delta L/L \simeq \Delta\beta/\beta$ and $\Delta Q/Q \simeq \Delta\alpha/\alpha$, and the effect of varying these assumptions, should also be considered.

Equation 6 indicates the extent to which energy savings have been either augmented or diminished by indoor-temperature changes. To carry the analysis one step further, the temperature shift ΔT_{in} can be translated into a quantifiable energy savings or loss. This translation is accomplished by comparing the observed NAC for the second period, NAC_2, with the NAC that would have been realized if the indoor temperature had not changed. The latter, hypothetical NAC_2' is determined by replacing τ_2 with $\tau_2 + \Delta T_{in}$ in Equation 1 (with k=2). Thus, the energy impact of a shift in indoor temperature is given by:

$$TB = NAC_2' - NAC_2 = \beta_2[H_o(\tau_2 + \Delta T_{in}) - H_o(\tau_2)] \ . \tag{8}$$

Unlike the temperature component T in Equation 2, which incorporates changes in all the factors affecting the reference temperature τ, the quantity TB given by Equation 8 isolates the effect of changing indoor temperature T_{in}.

It is well known that a temperature benefit, or positive savings TB, can be obtained simply by turning down the thermostat, even in the absence of any improvement in the house structure or appliances. On the other hand, economists have conjectured that a takeback (negative TB) might occur after a house has been made more energy efficient, analogous to choosing to drive more after buying a more fuel-efficient car. Equation 8 gives a basis for assessing the extent to which such takeback behavior may be occurring.

The refraction approach, in summary, involves three steps:

1) separate the estimated savings for a group of houses into three physically meaningful components, A, B, and T;

2) estimate the concomitant change in indoor temperature, using Equation 6, and convert this temperature change into energy savings (temperature benefit) or loss (takeback), i.e., TB, using Equation 8;

3) interpret each estimate (A,B,T, and TB) in light of possible conservation actions, including changes affecting the house's appliances, building shell, furnace, and thermostat.

For all components, the estimation errors, and the sensitivity to a range of possible assumptions, need to be considered.

APPLICATION TO INDIVIDUAL HOUSES

The refraction method was applied to each house in a group of 243 "Good Houses" resulting from the PRISM analysis of Wisconsin's low-income weatherization program (Goldberg, 1986).* These houses were weatherized in 1982 under a program administered by the Wisconsin Department of Health and Social Services. While the work done varied considerably across houses, the emphasis was on sealing windows and doors, and installing insulation. The median savings for these houses were 10% of the pre-retrofit NAC, as compared with 2% for a set of "Good-House" control houses. Only the treated (weatherized) houses are analyzed here; since the savings in the control group were small, we felt that a decomposition of those savings would not be very meaningful. The refraction results thus represent a decomposition of the total savings, without regard to whether the savings are attributable to the program or to external events.

The median results of computing the base-level (A), shell (B), and temperature (T) components for this set of 243 houses are summarized in Table Ia. Comparing each median to its standard error indicates which changes, averaged over the entire group, are significantly different from zero. The interquartile ranges (IQR) show clearly the broad distribution of each component's estimates across these 243 houses, as well as the relative contribution of each component to the total savings. The median estimate of total savings is 13.1 GJ_{th}/year (124 therms/year), which, as mentioned earlier, represents about 10% of the pre-weatherization

* The Good-House restrictions, that the pre- and post-weatherization periods each have at least ten actual meter readings and R^2 values from PRISM fits of the data which are greater than 0.90, ensure that the refraction method is applied only to houses for which the individual parameters are likely to be physically meaningful.

consumption level. The heating-rate component, with a median of 9.8 GJ_{th}/year, is by far the dominant contributor to these savings; since virtually no heating system work was performed in this group of houses, this component can reasonably be regarded as a shell effect. Changes in base level, with a median of 2.7 GJ_{th}/year, are small but still significant, and temperature effects, with a standard error larger than the median of 0.8 GJ_{th}/year, are not significant. The dominance of the shell effect is reasonable, since most of the weatherization work done in these houses had to do with shell tightening.

The apparent lack of temperature effects can be explored further using Equations 6 and 8. The resulting estimates of indoor temperature changes (ΔT_{in}) and takeback effects (TB) are summarized in Table Ib. The median ΔT_{in} estimate is $-0.2^{o}C$, indicating a slight temperature increase. This change is small in absolute terms, and also small compared to the standard error of the median, $0.3^{o}C$. Overall, then, for this group of 243 houses, no significant change in indoor temperature appears to have occurred, even though individual households may have raised or lowered their indoor temperatures appreciably, as indicated by the large range (IQR). When the temperature changes are converted house by house to energy savings, i.e., to TB via Equation 8, the resulting median takeback effect appears to be not significant.

These qualitative results were corroborated by re-estimating TB, the takeback effect, using different assumed temperature offsets δ, and by varying assumptions about $\Delta Q/Q$ and $\Delta L/L$ in Equation 6 for ΔT_{in} (see Goldberg, 1986). None of the resulting median estimates of takeback effect was nominally significant. Thus, even though the largest median takeback estimate (2.4 GJ_{th}/year) is 18% of the total median savings of 13.1 GJ_{th}/year, attention to the uncertainties of the estimate shows the evidence for a takeback effect to be weak. The overall conclusion from this refraction analysis of the set of Wisconsin houses is the dominance of shell tightening in the total savings achieved, with very little, if any, of the savings being taken back by an increase in indoor temperatures.

Another study, at Oak Ridge National Laboratory, found similar results in a data set of "clean" electrically heated houses analyzed by PRISM as part of an evaluation of a Bonneville Power Administration (BPA) program (Hirst and White, 1985). The estimated mean increase in indoor temperature was $0.2^{o}C$ for 97 houses receiving retrofits in 1982 and $0.6^{o}C$ for 113 houses receiving retrofits in 1983. (A value of $\delta = 4^{o}C$ was assumed.) Only the latter change was statistically significant; the associated takeback effect amounted to 25% of the total energy saved in the 1983 participant group. The reason for the different results in the two sets of houses, which received similar retrofits in two successive years, is not evident, particularly since no significant takeback effect was found in either year in the 32-house nonparticipant group.

Returning to our Wisconsin data base, the large IQR's in Table I show the great variability of estimated components and indoor temperature effects across the group of houses studied. Much of this variability across houses comes from uncertainty in the original parameter estimates α,

β and τ. Because these parameters and their associated components are inherently less well determined than the total NAC savings, applying the refraction method to individual houses is likely to give some erratic results. Therefore, the method is considerably more suitable for analysis of large groups of houses than for analysis of a single house or a small number of houses.

While an increase in indoor temperatures is tantalizing in view of its possible impact on energy conservation, the evidence for the small temperature changes discussed thus far is inconclusive, even with a group of nearly 250 houses. With a more dramatic change, or with a substantially larger data set, particularly one that spans more time, a clearer picture of trends in temperature settings might emerge. To this end, we turn to a PRISM refraction of a very large set of houses, consisting of all gas-heated houses in the state of New Jersey.

APPLICATION TO AGGREGATE CONSUMPTION

For the refraction analysis of aggregate gas consumption in New Jersey, we start with four-year estimates of NAC and of the model's three individual parameters, for 1970-73 through 1982-85 (see Fels and Goldberg, 1986). Table IIa shows the absolute and percentage change in NAC between successive periods. Over the entire period, consumption has declined by a total of 47 GJ_{th} (440 therms) per customer-year, or by 25% when compared with the pre-embargo (1970-73) level.

The three components of the energy savings (A, B and T in Equation 2), together with their standard errors, are summarized in Fig. 1. From 1970-73 to 1975-78 (Fig. 1a), the temperature component (T) accounts for about two-thirds of the 13% decline in NAC. From 1975-78 to 1979-82 (Fig. 1b), the base-level component (A) dominates the 8% decline in NAC. For both periods, the shell component (B) contributes only about a quarter of the change in NAC. Over the entire decade, from 1970-73 to 1979-82, about 50% of the total energy savings is thus attributed to the temperature component (T), and about 25% each to the base-level (A) and shell (B) components.

The more recent results indicate a persistence in the decline of base-level consumption but a shift in the other trends. Figure 1c shows a dramatic increase in the role of the shell component (B), reflecting an accelerated drop in heating slope from 1979-82 to 1983-85. On the other hand, the temperature component (T) in the most recent period has changed sign due to a slight increase in reference temperature (by 0.3^{o}C). Between different adjacent periods since the embargo, different components have dominated: first T, then A, and now B, as we progress across Figs. 1a, 1b, and 1c. Over the entire period since the embargo, from 1970-73 to 1983-85 (Fig. 1d), the division of the savings among the three components has become fairly even.

The standard errors shown in Fig. 1 allow a rough assessment of the significance of the components. Although the standard errors of the total savings are small ($\simeq$ 2 GJ_{th} for ΔNAC from one four-year period to another), the standard errors of the individual components are much larger (≃ 6 GJ_{th} for T, and ≃ 4 GJ_{th} each for B and A). On a relative scale, the standard error of ΔNAC between any two periods is in all cases less than 20% of the estimate of ΔNAC, whereas the relative standard error for an individual component is occasionally larger than the estimate itself. In Figs. 1abc, only the largest component of the total change between two adjacent periods appears significant by itself: T for period 1 to 2, A for period 2 to 3, and B for period 3 to 4. For the longer interval Fig. 1d, all components are sufficiently large to be reasonably well determined. Therefore, while neither the individual parameters α, β, and τ nor the individual components A, B, and T are estimated with great precision, it seems possible to identify, with some degree of certainty, the dominant sources of energy savings from one period to another.

Perhaps the most interesting trend is in the temperature component T.* Table IIb summarizes the resulting aggregate estimates for the change in indoor temperature (ΔT_{in}) and its effect on energy savings (TB), between the main multi-year periods.

In the earlier period from 1970-73 to 1975-78, the aggregate drop in T_{in} of 1.5^{o}C is well estimated by the PRISM estimate, $\Delta\tau$ = 1.6^{o}C. The associated temperature benefit (positive TB) is 15 GJ_{th}/year, suggesting that the drop in indoor temperature was responsible for over 60% of the total savings achieved by the aggregate in that period. Not surprisingly, this estimate for TB is similar in magnitude to the temperature component T, since $\Delta T_{in} \simeq \Delta\tau$. In the next period, from 1975-78 to 1979-82, the decrease in T_{in} of 0.7^{o}C is underestimated by $\Delta\tau$ (= 0.2^{o}C); i.e., due to the concomitant decline in α, T_{in} drops by more than just $\Delta\tau$ would imply. The associated value of TB is 7 GJ_{th}/year, again giving a temperature benefit of about 60% of the aggregate savings. Note that in this period TB is much larger than T, which was only 16% of the total savings. Therefore, over the entire decade from 1970-73 to 1979-82, a persistent decline in indoor temperature is indicated, with about 60% of the overall savings attributable to this decline.

In Table IIb, the only increase in indoor temperature, or negative ΔT_{in}, is for the most recent period, from 1979-82 to 1983-85. The associated negative estimate for TB indicates a takeback effect of 2.1 GJ_{th}/year, and thus that the savings in this period would have been about 20% larger in the absence of the temperature increase. When the entire post-embargo period is considered, from 1970-73 to 1983-85, this reversal has little effect on the overall drop in indoor temperature: the estimates for ΔT_{in} and TB are very similar to what they were for the post-embargo decade (1970-73 to 1975-78).

The results in Table IIb assume δ = 3.9^{o}C in Equation 6. We have also repeated the calculations with values of δ from 2.2 to 7.8 ^{o}C (4 to 14 ^{o}F), and, where warranted, without the $\Delta\alpha/\alpha$ term in Equation 8 (in order to vary

* Candidate reasons for the large recent base-level component (A) are explored in Goldberg and Fels (1986).

the $\Delta Q/Q$ assumption). The resulting sensitivity analysis confirms the tentative conclusions drawn from Table IIb (see Goldberg and Fels, 1986).

We are led to an intriguing hypothesis, that structural and furnace retrofitting (through a large positive shell component B) is beginning to take hold in New Jersey, but that its potential is being eroded slightly by a takeback effect (through negative TB) resulting from a return to higher indoor temperatures. The overall trend since the embargo may be a gradual shifting of the dominating conservation source from a decline in indoor temperatures to shell tightening. This hypothesis makes sense in view of the longer lead times needed for structural retrofitting than for thermostat setbacks.

Albeit with large uncertainties, this decomposition of total consumption trends has intriguing policy implications for New Jersey. The possible strong role of lower thermostat settings in post-embargo conservation, and the relatively minor, though growing, role of structural retrofitting, translates into optimism that much greater energy benefits from retrofitting are yet to be achieved. Very recent results, through the summer of 1985, urge caution, in that some of those benefits already achieved are possibly being reversed by a return to higher indoor temperatures. Continued analysis of New Jersey data and similar analyses of data bases in other states are needed to test the validity of these inferences.

CONCLUSION

As long as the uncertainties of the estimates are carefully assessed, the PRISM refraction approach seems useful for refining the characterization of conservation in large groups of houses. Two test applications, one to individual-house billing data and one to utility aggregate sales data, demonstrate the added insight available from this closer look at PRISM savings estimates. In both cases, a dominant role for a single component is suggested, namely, shell tightening in the former and declining indoor temperatures in the latter.

Particularly in view of the far-reaching policy implications that may result, more testing is needed. This should be done with the aid of supplemental survey data, with which the assumptions required for the refraction method, and the resulting conclusions, can be validated. In addition, the effect of a non-heating fuel on the results needs to be investigated. If other test applications are successful, the refraction approach will allow the scorekeeper to take the information extractable from energy billing data one step further than was hitherto believed possible.

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Table I. Summary of median refraction results for Wisconsin study*

Median measures:**	median	IQR	se(median)
a) Major components (GJ_{th}/year)			
Temperature (T)	0.8	21.1	1.4
Heating rate (B)	9.8	23.6	1.5
Base level (A)	2.7	10.4	0.7
ΔNAC (total)	13.1	20.9	1.3
b) Indoor temp. effects			
Change in indoor temp:† ΔT_{in} (^{o}C)	-0.16	4.02	0.26
Energy impact:†† TB (GJ_{th}/year)	-0.8	23.7	1.5

* Based on 243 Good Houses, from [5]. T, B, and A are determined from Equation 2. For this set of houses, the pre-retrofit NAC had a median of 132 GJ_{th}/year.

** IQR = interquartile range; se(median) = IQR/$\sqrt{N}$ where N is the number of houses.

† ΔT_{in} is determined from Equation 6 with $\delta = 3.9^{o}$C. A negative value indicates an increase in T_{in}.

†† TB is determined from Equation 8. A negative value suggests a takeback effect. To compare with total savings, see ΔNAC in Table 1a. Equation 8 was not estimated for two extreme outliers, i.e., houses which had $\tau_2 + \Delta T_{in}$ outside the range (-17.7, 37.8)^{o}C [(0, 100)^{o}F].

Table II. Estimated total energy savings, indoor temperature changes and resulting energy impact for New Jersey aggregate study

End points of analysis*:	1970-73 to 1975-78	1975-78 to 1979-82	1979-82 to 1983-85	1970-73 to 1979-82	1970-73 to 1983-85
a) Change in NAC					
ΔNAC (GJ_{th}/cust-yr)	24.9	12.4	9.6	37.2	46.9
% of NAC_1	13%	8%	7%	20%	25%
b) Change in ref. temp:** $\Delta\tau$ (^oC)	1.55	0.21	-0.30	1.76	1.46
Change in indoor temp:† ΔT_{in} (^oC)	1.52	0.73	-0.24	2.25	2.01
Energy impact:†† TB (GJ_{th}/cust-yr)	15.3	7.0	-2.1	22.3	18.5
% of total savings: (TB/ΔNAC) * 100	62%	57%	-22%	60%	39%

* Four multi-year periods are chosen: 1970-73 as the pre-embargo base period; 1975-78 and 1979-82; and 1983-85 as the most recent non-overlapping (three-year) period. The periods are based on August-to-July heating years; 1983-85 ends with July 1985.

** A positive $\Delta\tau$ indicates a drop in τ.

† ΔT_{in} is determined from Equation 6 with $\delta = 3.9^oC$. A positive value indicates a decrease in T_{in}.

†† TB is determined from Equation 8. A positive (negative) value suggests a temperature benefit (takeback) effect.

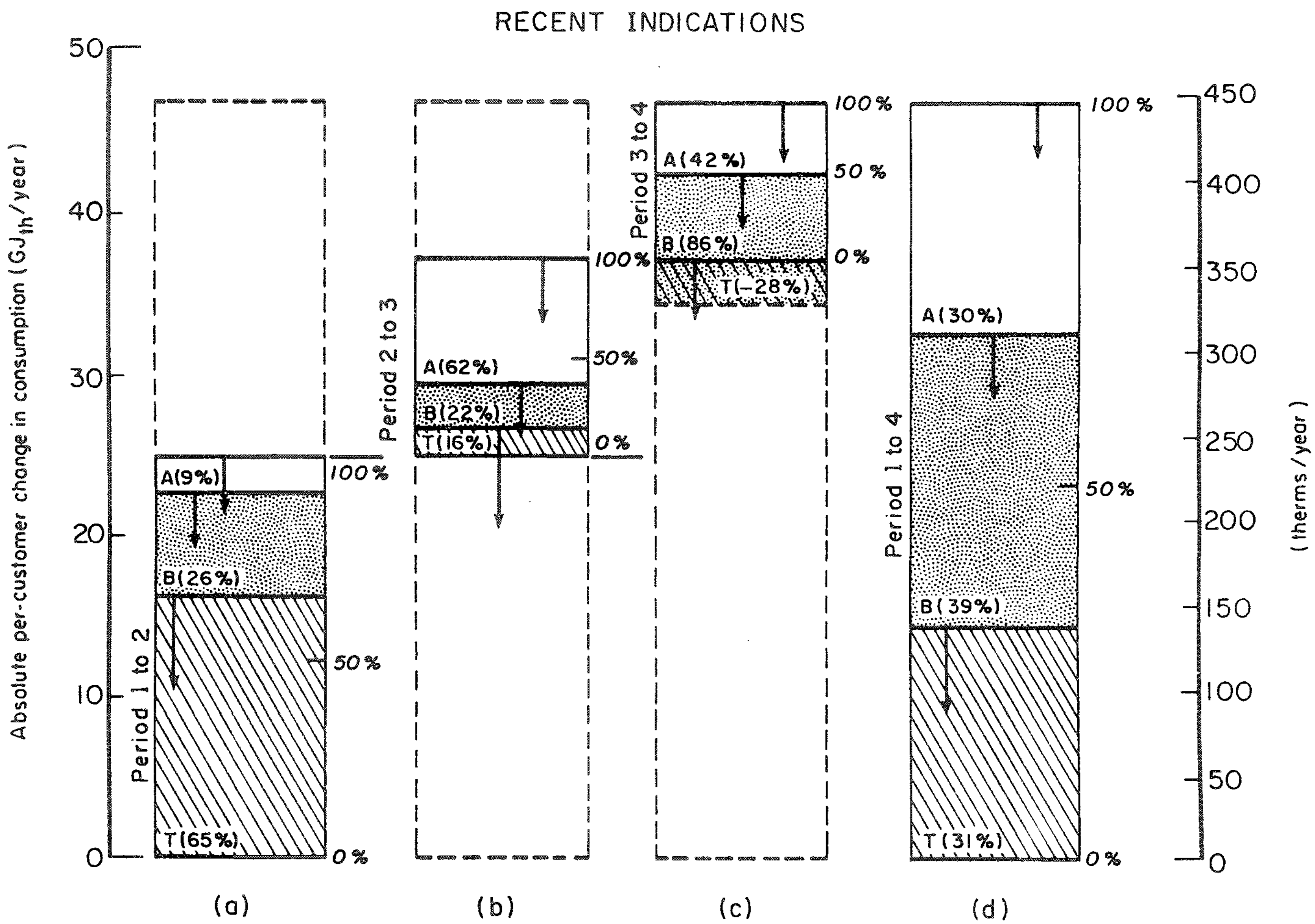

Figure 1. Summary of refraction results for New Jersey aggregate study. For each change between periods (1 = 1970-73, 2 = 1975-78, 3 = 1979-82, and 4 = 1983-85), the base-level (A), heating-rate (B) and temperature (T) components are shown: a) for period 1 to 2, b) for period 2 to 3, c) for period 3 to 4, and d) the overall change from period 1 to 4. Both percentage and absolute changes are shown. The number in parentheses is the percentage contribution to the total change in NAC. Arrow from the top of each rectangle represents the standard error for that component.