MASTER

THE EFFECTS OF ATMOSPHERIC VARIABILITY ON ENERGY UTILIZATION AND CONSERVATION

by
Elmar R. Reiter, Principal Investigator
C.C. Burns, H. Cochrane, G.R. Johnson,
H. Leong, J. McKean, J.D. Sheaffer,
A.M. Starr and J. Webber

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Final Report of Research Conducted Between
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Under Contract DE-AS02-76EV01340
The U.S. Department of Energy

by

Elmar R. Reiter, Principal Investigator
C.C. Burns, H. Cochrane, G.R. Johnson, H. Leong,
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ABSTRACT

An interdisciplinary approach towards a detailed assessment of energy consumption in urban space-heating and cooling is presented in terms of measurement and modelling results. Modelling efforts concentrated on the city of Minneapolis, Minnesota, using data from the winter seasons 1977/78 and 1978/79. Further developments of a reference model also fall back on data from Cheyenne, Wyoming, and Greeley, Colorado. Mean absolute daily errors of gas consumption estimated by the physical model applied to Minneapolis are 6.26% when compared to actual energy usage for the period 12/1/77 to 2/28/78. The mean daily absolute errors for the statistical reference model for the same time period were 5.54%.

Modelling of the energy consumption required a detailed input of meteorological parameters from a special network of stations. As a spin-off we obtained an assessment of the effects of anthropogenic heat on urban heat-island generation under various synoptic conditions. A detailed building census, comprised of 105,722 heated structures, was obtained by augmenting the information contained in the computerized assessor's files with data extracted from the Yellow Pages telephone directory.

A field survey in Greeley, Colorado, indicated that investment returns from insulating houses might not be as high as hoped for. Possibly a considerable amount of insulating material is applied wastefully. Misinformation seems to be the primary cause of misguided energy conservation. Progress in conservation could be achieved if utility costs were considered in mortgage loan applications, together with principal, interests, taxes and insurance. Detailed energy consumption modelling would be a premise for such fiscal management approaches.

Another extensive field survey yielded data for a local input-output model applied to the city of Greeley. Economic multipliers for dollars of output, space-heating, energy use and employment were developed and used for growth projections to the year 2003 under varying scenarios. Combination of these different multiplyers yielded sector-by-sector assessments of the vulnerability to temperature variations and to energy curtailments.

For a more detailed summary see Chapter 6.

1. SCOPE OF WORK ACCORDING TO RESEARCH PROPOSAL

Our research proposal, submitted on July 10, 1978 established research goals to be met over a three-year period, starting on January 1, 1979. The following task statements are taken from that proposal.

"Over the next three-year period our research efforts will be concentrated in the following areas:

1.1 CAUSES OF THE INTERANNUAL ATMOSPHERIC VARIABILITY

A major target of our research into the weather-caused variability of community-wide energy demands remains in the forcing functions that govern atmospheric variability itself. We have been successful in identifying sea surface temeprature (SST) anomalies, mainly in the North Pacific, as important correlants with severe winter weather anomalies over the midwestern and eastern United States. Some of the physical mechanisms that may cause SST anomaly formation have been discussed in our "Triennial Report". During the forthcoming contract period we intend to pursue our current line of research, focussing our attention on (a) the long-term (20 month) memory involved between the tropical trade-wind systems and the warm-water transport in the Kuroshio current, (b) the short-term (1-2 months) feedback between the storminess of the North Pacific and surges in cold water anomalies appearing there, and (c) the role of water-transport anomalies in the cold Qyashio current system.

1.2 EFFECTS OF SST ANOMALIES ON PLANETARY WAVE PATTERNS

More detailed correlations will be sought between the latent and sensible heat transfers from the ocean to the atmosphere and the forcing of atmospheric planetary wave patterns. It is hoped that this line of research will provide clues about the physical mechanisms involved in the statistically observed correlation between SST anomalies in the North Pacific and U.S. Weather anomalies.

1.3 PLANETARY WAVE PATTERNS AND REGIONAL WEATHER ANOMALIES

Our present studies of regional weather (mainly temperature) anomalies over the eastern United States and their forcing by planetary wave patterns will be extended to cover longer seasonal periods. By involving results from items (1) and (2) above we will attempt to devise and test regional temperature forecast schemes that can be combined with our energy demand model to arrive at monthly or seasonal energy requirement projections.

1.4 ENERGY DEMAND BY A LARGE METROPOLITAN AREA

We will continue the adaptation of our energy demand model to the data base from a large midwestern metropolis. Eventually some 107,000 heated and/or air conditioned structures will be handled by our model in context with this task.

1.5 PARAMETERIZED MODELLING APPROACHES

Expansion of our model applications to large metropolitan areas and, eventually, to large geographic regions will entail the development of parameterization techniques that rely, at least in part, on economic indicators obtainable from Bureau of Census data. Such parameterizations will have to replace gradually the strict model input requirements of a detailed building census. Preliminary work, some of it detailed in our "Triennial Report", has yielded encouraging results especially in the city of Cheyenne, Wyoming, but more detailed data will have to be scrutinized extensively before the complex interaction of environmental weather and climate factors, social and behavioral factors, and economic factors can be gauged with sufficient reliance to be incorporated into our numerical model. To achieve this end, we have again, after a hiatus of two years, invited a small team of economic experts to help us formulate an objective modelling approach. We feel that the mismatch between national energy consumption and the availability of unthreatened reserves has deteriorated to the point that weather- and climate-caused perturbations could have major effects on economic stability, much more so than was the case at the start of our research efforts three years ago.

1.6 NONSTATIONARY MODELLING ASPECTS

We have commenced to incorporate heat-load computation schemes for the air conditioning (cooling) season into our model. For such calculations we can no longer assume stationary conditions to prevail over two-hour time periods, as we have done successfully in the past. Nonstationary aspects also will have to be considered when buildings with large internal heat-storage capacity (through the use of "exotic" building materials with or without active and/or passive solar systems) are to be modelled and validated against actual energy consumption data. Our current efforts in modelling new building types of increasing complexity for both, heating and cooling requirements, will continue during the forthcoming contract periods.

1.7 MODELLING APPLICATIONS TO USER PROBLEMS

Through seminars and lecture tours by the research personnel involved in this project, our energy-demand modelling capabilities have recently received strong feedbacks from potential users. Among those to be mentioned are the Colorado Energy Research Institute in Golden, Colo., and the Energy Conservation Committee of the American Institute of Architects. From prelimianry discussions it appears that our model will have to be adapted to provide guidance in regional energy-use projections and planning, and in the optimization of building design criteria. We will use these contacts with the user community to sharpen and simplify our modelling tools to the point where a variety of regional planning authorities would benefit from easy access to the model. To accomplish this, guidelines for the development of model-compatible input data will have to be developed.

1.8 ECONOMIC IMPACT

As has been pointed out in our Triennial Report, preliminary investigations during our first contract year revealed that considerable energy savings could be realized by retrofitting old houses with insulation. Our model results also helped us to arrive at the conclusion that the Public Service Company campaign to insulate attics was not as effective as one might have hoped because it addressed a wrong segment of customers. Well-founded criticism was also voiced against certain misdirected tax incentive plans fc retrofitting in order to conserve energy.

Because of severe funding restrictions during our second research year and our decision to place top priority on bringing our weather-dependent energy demand model on line, our involvement with economic and decision-making problems was halted temporarily.

We have now arrived at a point, where our modelling capabilities are being called upon with increased frequency to help in decisions on certain energy conservation measures and demand projections (see preceding section). We are therefore placing renewed emphasis in this proposal on the interdisciplinary aspects of weather-dependent energy use involving the economic sciences.

The input of economic expertise will be called for in three major ways:

(1) In order to facilitate the adaptation of our energy demand model to large geographic regions, we intend to develop economic parameters that can be derived from Bureau of Census data and other accessible sources and which will help to alleviate most of the time-consuming work needed to arrive at a building census.

(2) Work on an adaptive model will resume. This model will include economic and behavioral aspects and will be allowed to interact with the energy consumption model. The interaction between the two model components will allow an assessment of the economic benefits of certain retrofitting, pricing, etc. decisions.

(3) In a prelimianry small-scale study, using Greeley and Weld County, Colorado, as data bases, we will attempt to throw some light on the reverberation of energy conservation and pricing decisions through a community system. We will also expose this system, modelled in the computer, to weather and climate related stresses to gain a better understanding of when, how and where serious disruptions in the systems can be expected.

We realize that the proposed research program is as ambitious as the one submitted 3 years ago. Our research team has proven, however, that the goals outlined above are not unrealistic (see Triennial Report)."

Several reports, including this one, describe considerable progress achieved during the first year of our research program which, incidentally, had been extended for reasons beyond our control to March 31, 1980.

Tasks enumerated under 1.1 above were treated in detail by Reiter, 1979. Part of Task 1.2 is the subject of a M.S. thesis by P. Ciesielski, which is presently in the typing stage and will be issued shortly. The long-term behavior of SST anomalies in the Pacific has also been described by Middleton (1980).

Ding and Reiter (1980) investigated the interannual variability of typhoon frequency over the Pacific as a manifestation of regional weather anomalies (Task 1.3). More work in this area is in progress.

The present report concerns itself with the remaining tasks listed above. Modelling of the energy consumption in Minneapolis is described in detail in Chapters 2 and 3 (Tasks 1.4 through 1.7). Task 1.8 is the subject of Chapters 4 and 5.

We have deliberately separated our reporting activity into meteorological and energy-consumption modelling aspects in order to provide the readers with more coherent individual reports.

The following papers have been published during the present grant period:

Dreiseitl, E. and E.R. Reiter, 1978: Local Winds Inside and Outside a City. Arch. Met. Geoph. Biokl., Ser. B, 305-317.

Reiter, E.R., 1978: Air-Sea Interaction and Climatic Variations. Paper presented at the International Seminar Series, 1978, Univeristy of Bern, Switzerland.

Reiter, E.R., 1979: Trade-Wind Variability, Southern Oscillation, and Quasi-Biennial Oscillation. Arch. Met. Geoph. Biokl., Ser. A, 28, 113-126.

Reiter, E.R., 1979: Some Mechanisms Affecting Sea-Surface Temperature Anomaly Formation in the North Pacific. Arch. Met. Geoph. Biokl., Ser. A, 28, 195-210.

Reiter, E.R., 1979: On the Dynamic Forcing of Short-Term Climate Fluctuations by Feedback Mechanisms. Environmental Research Paper No. 21, Atmospheric Science Dept., Colorado State University, 62p. (Portions of this paper presented as an invited paper to the Symposium on Empirical and Model Assisted Diagnosis of Climate and Climate Change in Tbilisi, USSR, October 15-23, 1979.)

Reiter, E.R., 1979: On A Possible Link Between the Quasi-Biennial Stratospheric Oscillation and Regional Tropospheric Forcing. Paper presented at the IUGG Meeting, Canberra, Australia, December 2-15, 1979.

Reiter, E.R., 1979: Some Quasi-Periodicities Affecting the General Circulation of the Atmosphere. Paper presented at the IUGG Meeting, Canberra, Australia, December 2-15, 1979.

Leong, Heryee H. and Gearold R. Johnson, 1979: Modelling of Energy Consumption for Space Heating for a Community Via GMDH Approach. Paper presented at the IEEE International Conference on Cybernetics and Society, Oct. 7-10, 1979, Denver, Colorado.

2 MODELLING ENERGY CONSUMPTION

2.1 INTRODUCTION:

2.1.1 Modelling Philosophy.

In an age of affluence and abundance, as depicted in Fig. 2.1a, one does not have to worry much about the pathways by which resources are used and, perhaps, even squandered. Investments in resource and processing capacity development are more or less controlled by market forces. Small perturbations in the demand "box" will not cause a major upset in the market for that commodity, be it energy or food or anything else, as long as the general size proportions of the three boxes in Fig. 2.1a remain essentially the same.

Prolonged economic growth with subsequent depletion of natural resources will spawn an age of restrictions and regulations in which a bottleneck or

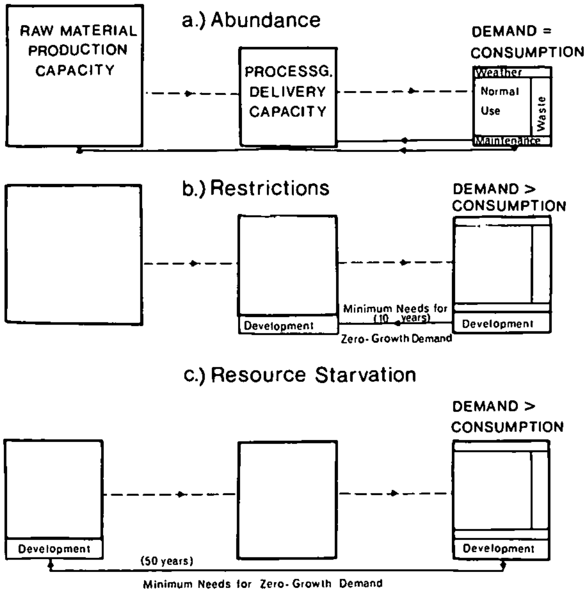

Fig. 2.1 Schematic relationship between production capacity (e.g. oil or natural gas production in Btu's), processing capacity (e.g. refining or electricity generating capacity, equivalent to Btu's) and consumption (in Btu's). "Waste" is loosely defined as resource utilization without enhancement in the quality of life (see text). "Weather" symbolizes a variability in consumption dictated by external factors. "Maintenance" and "Development" indicates necessary investment allocations in (Btu's) to maintain existing, or produce new, production and/or processing facilities.

barrier develops in the processing and/or delivery capacity. Such a bottleneck, most likely, is caused in part by factors external to the market place. Concern for the environment, for instance, might hamper the development of new energy generating capacity necessary to keep up with increased demand. The imbalance between "boxes" 2 and 3 in Fig. 2.1b will generate a "seller's market" with a tendency of increased prices which, most likely, will cause more regulations and restrictions of free development. Such restrictions may arise, for instance, from a concern for "unfair" profit-taking, or from priority assessments in the use of limited available resources. We can easily envision that, as soon as the processing capacity and demand boxes achieve comparable sizes, relatively small perturbations in the demand will lead to noticeable shortages and -- in a free market situation -- to relatively large price fluctuations of the respective commodity. In the case of energy or food, we have to look at weather and climate as causes for such perturbations.

Those who are searching for solutions to this dilemma will have to strive for a reproportioning of boxes 2 and 3 in Fig. 2.1b. Such proportioning can be achieved in various ways. The most sensible way would be to rapidly enhance the processing capacity. This approach, most likely, will necessitate a (temporary) diversion of resources from the consumer demand box to allow for the necessary capital investment for new development. This will increase pressure on the price of the commodity in question. For example, new coal fired generating plants embody fossil fuels. Oil and natural gas are consumed in the process of creating the steel, cement and other ingredients that makeup a generating facility.

Increased prices tend to diminish, at least temporarily, the demand by promoting conservation partly through elimination of waste. However, conservation alone can lead to only a temporary remission in the disproportion between boxes 2 and 3. A third but counter-productive way of adjusting the mismatch in the volumes of these two boxes is to curtail the allocation for reinvestment from the demand "box". A temporary relaxation of demand pressures, perhaps caused by price-induced conservation, might prompt the adoption of this third course of action in favor of the one mentioned first.

The third scenario, depicted in Fig. 2.1c, shows a demand that has outstripped the raw-material production or availability. Thus, box 1 constitutes the bottleneck by resource starvation in this scenario for either technological or political reasons. The possible solutions are essentially the same as in the scenario of Fig. 2.1b, namely the development of new or alternate sources, affected by the willingness and capacity to divert disposable resources for investment and conservation. The major difference between scenarios (b) and (c) lies in the time scales of possible cures to the malaise. Whereas we should allow a development time of the order of 10 years for new processing capacity (Fig. 2.1b), 50 years or more might be required to tap altogether new sources. For certain critical commodities, such as energy and food, we may well be left with a "one-shot decision", meaning that serious mistakes in long-range decisions may be too costly to be survived by our present form of society.

In Fig. 2.1 we have dealt with the "demand-consumption" boxes in a rather crude manner, considering mainly their sizes relative to the other boxes. We will now apportion this demand box into compartments whose relative sizes are dictated by either individual or collective decisions, depending on the size and structure of the societal segment under consideration (e.g. a family on welfare will apportion its resources differently than a family of upper-middle class standards, and even within similar classes there will be differences in apportionment between societies with strong or weak social security programs. There will be differences of average apportionment between different climatic and demographic regions -- rural versus urban --, even within the same country).

The center "box" of Fig. 2.2 depicts, on an arbitrary scale, the relative apportionment of expenses for energy or food by a societal unit of manageable size and homogeneity (e.g. a family, a small rural community, or a relatively homogeneous urban sector or neighborhood). As "bare survival" we could consider one room of a house maintained at 40°F during a winter day (no temperature control during summer), if adequate protective clothing and/or cover were available. A diet of 600 cal/day might suffice for a limited period of time if food curtailment does not coincide with an excessively cold period. Obviously, such low "survival" values of heat and food do not apply to the very young, old, or otherwise infirm, but only to healthy specimens of the societal unit. Commuting to work on foot or by bicycle (public transportation if available) may be accepted even in excess of 2 h one-way, 7 days a week.

An American or European family would consider diet of 1200 cal/day/person, and a temperature of approximately 60°F maintained during waking hours in

Relative Allocation of Resources (Energy)

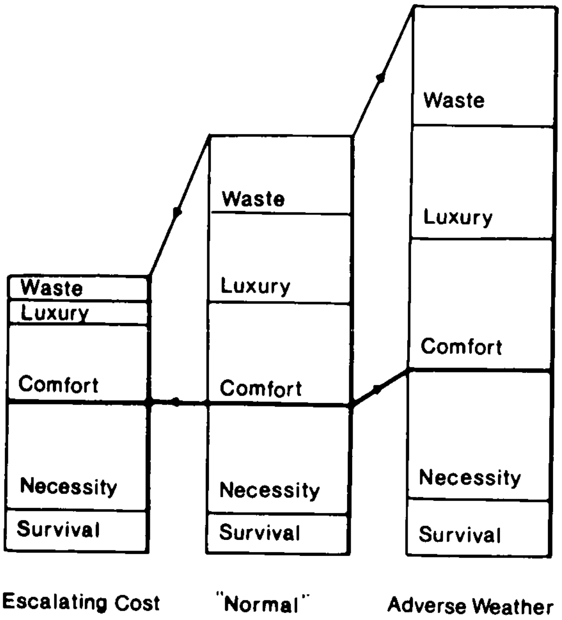

Fig. 2.2 Schematic apportionment of energy use (arbitrary scale, to be interpreted as Btu's per societal unit). For definition of categories, especially of "waste", see text.

at least one room of the house, and of not less than 50°F in the bedroom(s) a necessity -- again applying the yardstick of a healthy specimen. Air conditioning could most likely be considered "necessary" if indoor temperatures exceed 90 to 100°F. Commuting to work 5 days a week is deemed acceptable only up to a radius of approximately 1/2 hour by either foot, bicycle or public transportation. Beyond this radius either job or home relocation is advocated.

A comfort level will be reached if the living rooms (kitchen, family or workrooms) can be maintained between 65 and 70°F during waking hours of the cold season, and bedrooms at 60° during the night. Working and sleeping areas would be air-conditioned during the day and night, respectively, when indoor temperatures exceed 80°F. Depending on the level of activity, the caloric intake might be around 1200 to 3000 cal, including a sizeable proportion of high-quality fibrous food. Commuting to work by car-pool arrangement or public transportation will have job opportunity and desirability of neighborhood as primary focal points. Commuting distance only plays a secondary role in the choices of home or job location. Vacation trips will rely mainly on public transportation.

As luxury level we would consider uniformly heated and/or air conditioned houses, maintained at 72°F throughout the year, access to heated swimming pools, and a wide variety of not locally or seasonally grown foods packaged in small serving units. Commuting to work is mainly done in private vehicles with two, or fewer, passengers. Car-pooling or public transportation are used only if personal schedules are not inconvenienced. Vacation trips rely to a large part on privately owned or rented transportation.

Waste levels are dictated by deliberate or involuntary inefficiencies (e.g. dual-duct heating and air conditioning systems, over-heated or under-cooled houses, perhaps with windows open; heated garages; inefficient appliances; unnecessary luxury or "comfort" of private transportation which, furthermore, often places time and cost factors into wrong proportions). The "throw-away society" syndrome extends from the packaging to the consumption of food.

This definition of waste will undoubtedly raise the eyebrows of trained economists. At any point in time households must make decisions regarding expenditures for domestic appliances, for example, and the energy costs of their utilization. When energy prices are low, relative to the cost of the appliance, then it would be "wasteful" to pay more to improve technical efficiency. However, when energy prices rise, as they have recently, then these inefficient devices appear "wasteful" of energy. The term waste is used here in the spirit of the latter situation.

With this crude definition of "apportionment" into compartments ranging from waste to survival, we will now proceed to assess the impact of external cataclysms, such as a severe weather or climate change. A weather-related "catastrophe" is thought to be of only limited duration (up to the length of one season) whereas a climate "catastrophe" might entail several to many years. We anticipate that adjustments in the apportionment of available resources will depend strongly on the time scale at which the external cataclysmic event operates.

The right box in Fig. 2.2 anticipates involuntary waste of energy to increase dramatically, given extreme weather conditions. Energy use, especially for heating, will increase especially in poorly (wastefully) designed buildings. Slow or stalled traffic will consume disproportionally large amounts of fuel. Similar considerations hold for the food sector. Spoilage (e.g. by excessive heat, cold, or moisture) will endanger food at all stages, from production to storage.

Survival and necessity requirements will also increase considerably, depending on the severity and duration of the external disruption. In Fig. 2.2 we have pegged the anticipated increase at the top of the "necessity" compartment, because it is difficult to conceive of a cataclysmic event, short of a nuclear war, that would reduce societal units to a mere survival level for any length of time. The increase in resource allocation to "necessity" and "waste" will, most likely, not be balanced by reductions in the comfort and luxury allocations, unless such reductions are mandated by public appeal or by curtailments in energy delivery. Prolonged curtailments in these allocations will have economic effects of a widespread nature. Some of these effects are presently being gauged by newly developed economic models that deal with a regional scale of input parameters.

On the left side of Fig. 2.2 we have indicated anticipated effects of non-cataclysmic events, such as more or less rapid increases in price. When applied to food and energy, one would anticipate, again, that "necessary" allocations would receive a relative boost because of decreased purchasing power, while the luxury and waste allocations would see most of the curtailment.

Under the "double whammy" of a severe weather disturbance in the face of a rapidly eroding purchasing power, even the "comfort" allocation may be severely affected, to the point of complete cancellation, for an unacceptably large segment of society.

Such a scenario might severely and lastingly damage our economic system.

Without question it is difficult to determine a dollar or Btu value to fill the boxes shown in Fig. 2.2. It is even more difficult to obtain reliable data with which to predict the allocation decisions made by different sectors of society. Given that such data could be obtained, the next step would be to use these relationships in conjunction with econometric models so as to assess their impacts on local, regional and national economic developments.

Figure 2.3 illustrates possible factors influencing the motivation for energy conservation, which would have as its ultimate goal a reduction in energy use without curtailment of the comfort level. Attempts have been made by H. Cochrane (Chapter 4 of this report) to assess the relative importance of some of these motivation factors. Results of an inquiry conducted in Fort Collins, Colorado and involving 65 families revealed that most home insulators, and those that did not, were aware of energy shortages and believed that energy prices will continue to escalate. Adopters, however, had better faith in cost amortization of retrofitting than nonadopters. Cochrane's study also points out, that the payback period for the investment in retrofitting for many of the adopters was disappointingly high. The importance of this finding lies in the conclusion that misinformation on the relative effectiveness of various approaches to conservation practices (e.g. caulking, storm windows, weather stripping, added insulation) not only diminishes the return on investment but leads to a waste of resources.

The similarities and differences in the attitudes of adopters and nonadopters lead us to the conclusion that public appeal and advertising campaigns should focus on economic issues, stressing the savings that can be realized by conservation measures, rather than on the fact that an energy shortage exists and prices are going to rise. Cochrane, furthermore, suggests that general attitudes towards conservation could be enhanced by including the monthly cost of utilities (U) into the processing of mortgage applications by banks which presently consider only principal, interest, taxes and insurance payments (PITI) versus the applicant's income. If PITIU were adopted instead of PITI, a trade-off between interest on capital investment to reduce utility bills, and higher utility bills, may be critical in the acceptance and rejection of certain applications. PITIU thus would provide for better acceptance of conservation measures by the general public. For a sound evaluation of such a trade-off between interests and utility cost accurate computational and modelling procedures for energy consumption have to be available.

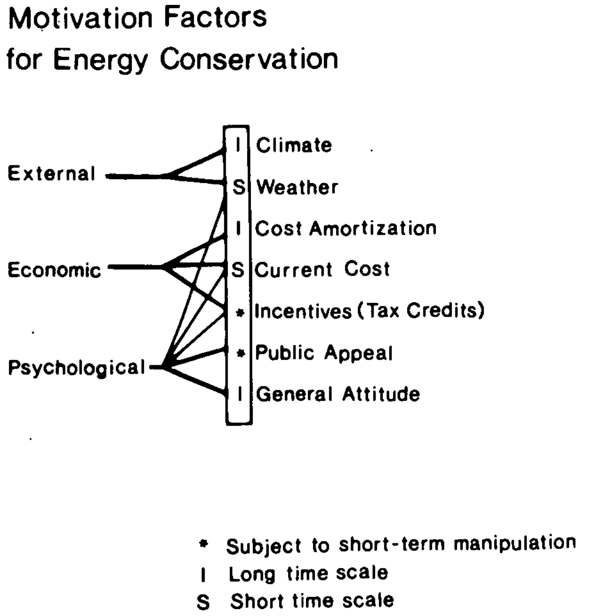

Fig. 2.3 Factors, and their time scales, influencing the motivation for energy conservation.

In the foregoing discussion we have pointed out several difficulties associated with the assessment of motivation factors influencing energy conservation. These factors will not diminish in their importance if they are incorporated into an energy consumption model for a community system (Fig. 2.4). In essence, we can identify three categories of factors that influence energy consumption: external factors, such as climate and weather; design factors, including use patterns and building codes; and last, but not least, economic factors. Different time scales are associated with different factors. Climate, architectural design and building codes can be assumed as either constant or slowly varying. Weather, on the other hand, will influence energy use on time scales of hours to days, perhaps weeks. Some economic factors, such as curtailments and price increases, as well as changes in use patterns and retrofitting designs, operate on intermediate time scales of months to years.

Several feedback mechanisms can be envisioned between various "boxes" shown in Fig. 2.4. Under ideal conditions one would presume that climate is a major motivator in architectural design and building codes. The recent energy shortage, indeed, has helped in aligning these codes more closely to climatic conditions than has been the case with the codes in effect through the early 1970's. Unfortunately, architectural design still is paying little attention to climatic variables. We anticipate that stimulation to do so will come mainly through the economic factors of price and investment amortization considerations.

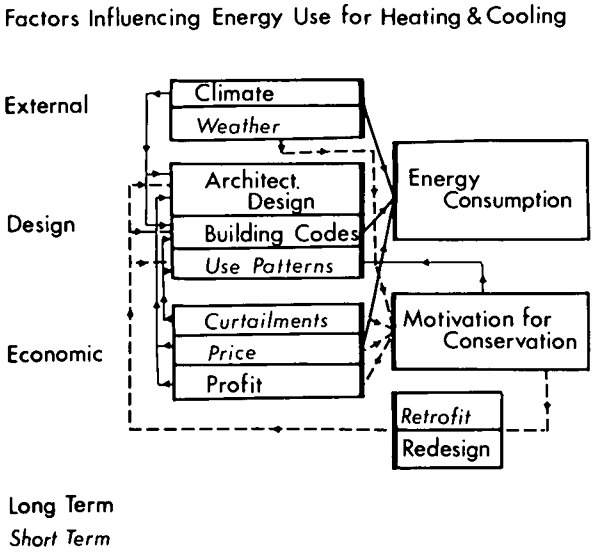

Fig. 2.4 Factors, and their time scales, influencing the energy use for space conditioning.

Weather and economic factors will be shown in Chapter 4 to be of influence on motivation for conservation. Decisions to conserve without new investments will mainly affect use and habit patterns (e.g. lowering thermostats in winter). If such decisions are widespread in a community, energy consumption will be affected in a significant way, rendering model calculations of such consumption, which are simply based on regressions between historic data sets, unreliable and inaccurate.

Decisions to retrofit and redesign operate on different time scales, as symbolized in Fig. 2.4. Both types of decisions affect energy consumption through the set of design factors as illustrated in that diagram. Most of our data have been collected to date over a relatively narrow range of variability in environmental and economic parameters. Over that range the correlations that become obvious (e.g. between weather and energy use, use patterns and energy consumption motivation and retrofitting, etc.) behave either linearly, or at least monotonously, and our limited understanding of feedback mechanisms is within the range of a stable systems behavior. It would be within the framework of such a stable system that increased energy prices will motivate conservation attitudes, leading to retrofitting decisions and to changes in use patterns, both resulting in reduced energy use and a stabilization of prices. What would happen, however, if the ranges of variability in some of these parameters exceed significantly the amplitudes manifest from current experience? E.g. a sudden drastic curtailment and/or price jump will have a drastic effect on energy consumption, that might result in a "runaway" feedback with economic factors, leading to a crash in a variety of sectors of the national or regional economy, even those which are not necessarily heavy energy users. Efforts should be taken to identify critical and potentially unstable feedback loops and to identify sets of parameters that might lead to a bifurcation between stable and unstable model behavior.

Our own modelling efforts at Colorado State University have concerned themselves mainly with aspects of space heating and air conditioning. One could think of more profound and wide-flung problems that should or could be modelled, including the various patterns of energy uses in industry, commerce and transportation and involving all forms of energy: fossil, nuclear and renewable. There were several compelling reasons that motivated our modelling attack on energy consumption for space conditioning:

(1) Approximately 1/3 of the energy resources are used in this sector of consumption.

(2) Data required for model development and model validation can be obtained with relative ease. This is not to say that a considerable effort in information network design, data collection, analyses and interpretation will not have to be expended.

(3) Since a meaningful data base can be established, numerical modelling tools can be developed and tested against the "real world" under relatively rigorous conditions and with a minimum of assumptions that cannot be substantiated.

(4) Energy use for space conditioning is subjected in a significant way to the external forcing parameters of weather and climate (Fig. 2.4), more so than many industrial uses of energy. Our natural data sources, therefore, provide us with a wide range of scenarios for model input. A composit model, such as envisioned in Fig. 2.4, will have to contend with such natural perturbations.

(5) Use patterns and decision-making patterns in this sector of energy consumption can be identified within relatively small elements of society (family, township, etc.) This limitation in scope makes it somewhat easier to collect data for an assessment of the relative importance of motivation factors involved in energy conservation (Fig. 2.3). Based upon such an assessment more effective ways of motivation manipulation can be designed and tested. Their effectiveness can be gauged quantitatively by changes in energy consumption in individual buildings as well as in larger communities.

(6) As home heating and cooling costs take an ever-increasing slice out of personal disposable income, the apportionment of energy use, sketched in Fig. 2.2, becomes a matter of concern and can be treated quantitatively with some degree of statistical significance. Considering a representative cross-section of income levels in typical communities, one should be able to first calibrate the effects of weather and economic factors, and later predict such effects under a variety of extreme factor combinations. The syndrome of "welfare economics" should reveal itself in such analyses.

(7) The development of numerical and statistical modelling tools, honed by stringent validation procedures, should benefit modelling attempts in other sectors of energy consumption as well as in food production where comprehensive data sources are more difficult to tap.

(8) Properly constructed models should allow the testing of new design and construction criteria and of economic decisions in a rather quantitative manner.

(9) Highly accurate and well-tested models for space heating and cooling which also allow a reliable assessment of the costs and benefits of certain retrofitting conditions are needed if banks and loan companies should be persuaded to integrate utility costs into an evaluation of the credit rating of mortgage applicants, as pointed out in Chapter 4.

2.1.2 The Colorado State University Model

From the very beginning of our modelling efforts (Reiter et al., 1976) we were aware of a variety of statistical models which explained over 90% of the variability in hourly system demands for electricity (e.g. Federal Power Commission, 1970) and gas (e.g. American Gas Association, 1969). Such models can claim a high degree of usefulness in separating weather-related energy demand from base loads on various energy systems. Their obvious advantage lies in the fact that usually a relatively easily and inexpensively obtainable amount of input data can lead to the desired answers. They suffer, however, from the disadvantage that the statistical regressions found from these models are strongly location dependent and usually also vary with time.

The accuracy of those load-study results depended upon the nonvariability of physical structures, use patterns and comfort levels. Indeed, within the framework of those studies, it was reasonable to assume that only the weather changed. However, our investigation is of far broader scope than load studies, in both space and time. Structures, space-conditioning equipment, and use and habit patterns may all be expected to vary between geographical regions, and over time within a particular region. Consequently, it is necessary for our investigation to account for possible changes in any of these variables mentioned above.

Historical data are of questionable value in constructing such a general model, because, heretofore, variables in the economic environment have either changed very little, or they have trended in one direction. Examples are real (adjusted for inflation) prices of energy which over the past several decades have trended downward, whereas at the same time real incomes have trended upward. Moreover, pronounced trends have been evident in improved efficiency and decreased cost of space-conditioning equipment. The combined effects of these changes have profoundly increased the weather sensitivity of summer electricity loads (McQuigg, 1974; NY Power Pool, 1975, Vol. I., p. 7-52). On the other hand, the economy is presently reeling under the impact of dramatic increases in real energy prices, and in the consequential rises in real prices of commodities which require relatively large amounts of energy for their production. The suddenness of the change and its political overtones also induced a "conservation ethic" whose effect and duration cannot yet be fully measured. Nevertheless, the effect was unmistakable (NY Power Pool, 1975, Vol. I, Exhibit 8), even though it differed regionally in terms of homeowner energy conservation (FEA, 1974).

As a consequence of limitations such as those discussed above, we decided to base our model on physical features which can be derived from basic heat-transfer relationships. Models of this type have been used extensively by architects and engineers (e.g., Kusuda and Powell, 1972; Kusuada, 1974; Meriwether, 1975; Johnson et al., 1975) concerned with space-conditioning system design. Their validity has been demonstrated for an individual structure in numerous studies (Fox, 1973; Jones and Hendrix, 1975; Kusuda et al., 1975; Kruger, 1974; Sepsy et al., 1975a, b,c; Peavy et al., 1975; Hill et al., 1975), which have shown that heat loads calculated from design procedures (e.g., ASHRAE, 1972) can be used effectively and that the results are reasonable.

The physical model used in this study is an extension of the models cited above and has been described in detail by Reiter et al. (1976, 1978). Here, however, the end result is not the sizing of space-conditioning equipment, but to compute the energy required for space conditioning -- a task with which only a few modelling efforts have been concerned (e.g., Fox, 1973; Petersen, 1974; Johnson et al., 1975). Of these previous attempts to apply a physical model for calculating space-conditioning requirements, the study of the Twin Rivers townhouse project in East Windsor, New Jersey (Fox, 1973) was perhaps the most ambitious. In view of the many simplifications used in that study, it was surprisingly successful.

On the other hand, heretofore heating and cooling systems have generally been oversized by a factor of two, and load calculations have not had to be of great accuracy. Thus, even though computations of heat losses or gains due to infiltration have not been as satisfactory as those for heat transmission, this should not be judged as a shortcoming of the procedures used. For example, detailed infiltration calculations are quite complex, and simplification procedures which yield conservative estimates (such as the air-change method for computing infiltration or the use of degree-day data rather than hourly weather observations for calculating heat loads) are customarily introduced to reduce the number of required calculations. However, for our purpose of predicting the total space-conditioning energy requirement of an entire city, composed of many diverse structures -- each subject to modifications in their physical anc adaptive characteristics --, it was apparent that the model must incorporate every feasible procedural refinement.

The physical model developed at CSU is based on heat transfer equations and on a heuristic, adaptive, self-organizing computation learning approach. The model has been "trained" on a number of individual buildings which were considered to be typical structures. A community's energy use is arrived at from heat loss computations for these typical buildings within the community. To date the program contains 52 such typical buildings, each with up to three age categories. The age classifications are based upon our assessment of changes in building technology and comprise pre-1940, 1940-1970 and post-1970 structures. The model was tested extensively in the early validation projects conducted in Greeley, Colorado and Cheyenne, Wyoming.

The basic elements of the modelling procedure are as follows: first the physical relationships for heat loss and gain for the subcomponents (i.e. walls, ceilings, windows, etc.) of individual buildings are described. These steps are sufficient to calculate the energy consumption for a building constructed from the subcomponents and operated within a given behavioral pattern. The individual buildings which represent the given building classification are then lumped together into an "average building" for each category in terms of size and thermal characteristics. Then the energy consumption for each representative building type is calculated in response to the meteorological parameters. The over-all energy use by the community is computed by aggregating the individual building classifications and age groups according to their actual distribution encountered in the respective city or its subdivisions. This scheme can be used to calculate the energy demand for a community, city or region. Because of the large number of buildings within each classification, the statistically averaged representation of such a system has been found to be very accurate as previously reported. Whereas, large errors may be found in the energy consumption esitmates for individual buildings, the large numbers of buildings within a certain classification tend to make the overall error quite low. If sufficient input information is available to characterize a community to the detail needed, the physical model has been shown to give very good results.

The primary problem associated with the use of the physical model is that the necessary input information is very extensive. Information on thermal and structural characteristics, on size and on behavioral and usage patterns is required in order to characterize each building. In Greeley, the input information was obtained by a survey of each structure within the community. As we moved our modelling efforts from communities to cities, and eventually to regions, the volume of detailed information became prohibitive. To circumvent this problem, a statistical sampling technique was developed and tested in Cheyenne, Wyoming. The results were presented by Reiter et al. (1978). It was found that these results were not quite as good as those obtained for Greeley, Colorado. We think that the primary difference i quality was due to the level of detail in the avail able input data on the individual buildings within the community. Not nearly as much work had gone into creating the Cheyenne data base as had gone into the Greeley data base, and consequently the modelling results were also not as good. Even using statistical sampling schemes, the amount of work in data collection was still significant for a community the size of Cheyenne, Wyoming. Again, if the model were to be used for larger communities or perhaps even entire regions, some other approach to data collection will be required.

It was this very problem which led to the development of a statistical reference model (see Appendix 2A and Reiter et al., 1979). This model uses the same heuristic algorithm as was employed in the physical model for the identification of the coefficients of the heat transfer equations used to model individual buildings within a certain typical structure category. However, instead of using the actual building information, the statistical reference model attempts to use the meteorological input information and the actual response of a community in terms of energy consumption to identify a single high-order equation which can be used to model the response of the entire community. This model was initially developed for estimating the performance confidence interval which is used to show acceptability regions of the model output and which indicates when the real community is changing in complexion over time in contrast to the earlier identified physical model assumptions.

It was also found that the reference model could be used as a stand-alone model to identify individual communities without a need for a prohibitively large amount of historical data and particularly without the detailed information required about individual structures within a community or a subset thereof, from which the community data base might be synthesized. The statistical reference model can be used as a first-cut model for new communities in anticipation of more detailed information to be gathered in order to support the physical model. In fact, it has been found through our studies within the Minneapolis-St. Paul region, that the identified statistical reference model is nearly as accurate as the physical model.

The limitations of the statistical reference model are the same as for any regression-type model. Even though our model is rather sophisticated it is still based on coefficients -- in contrast to the physical model -- and does not entail explicitly the physics of the processes involved in a need for energy consumption for space heating. It is, therefore, not possible to "ask" this model decision-making question as one can do with the physical model. That is, we can not assess how various energy conservation policies might affect the energy consumption within a city. For questions of this type or questions relating to the effects of behavioral changes, structural changes, etc., the physical model is required because that model incorporates actual physical heat-loss processes. However, the statistical reference model can play an extremely important role in assessing the energy use of communities with a small amount of data. It can also be used in conjunction with the physical model to provide levels of acceptability of the output from the physical model associated with the computed response to environmental or systems changes.

To summarize, both models are useful and can be run as stand-alone computer model systems. The physical model can be used if sufficient data are available. The statistical reference model can also be used if only climatological and actual consumption figures are available and predictions can be made based on these inputs. The two models can also be combined to form a hybrid statistical-physical model. The statistical reference description could be used to model the existing energy consumption pattern based upon past history, whereas the physical model would be used to model new or projected buildings and developments to predict how growth will alter the pattern of energy consumption. This hybrid model should be most useful for large cities or metropolitan regions. Its concept has not been tried to date, however.

Over the next year, both models will be subject to modifications to include cooling as well as space heating. The cooling modifications which will be necessary for the reference model are straightforward and will be accomplished easily because it is only necessary to obtain the proper meteorological and energy consumption data and to identify the appropriate model equations. For the physical model, it is necessary to include the physics of building space cooling which is not nearly as easily handled as the space heating situation. Section 2.7 describes our preliminary work associated with space cooling. Basically, the framework of each model will remain the same. We do anticipate that additional input information, such as humidity levels, will be required in order to obtain reasonable energy consumption estimates.

2.2 ENERGY USE FOR SPACE HEATING IN MINNEAPOLIS

To fulfill the ambitious goal of modelling the space conditioning energy demand as a function of weather for a large metropolitan region, it was necessary to extend the identification scheme and modelling technique previously reported (Reiter et al., 1976, 1978 and 1979) to handle considerably more input data than was required before. The first goal was to model the Minneapolis energy demand only crudely with a limited time schedule and restricted man power. To do this required collecting the necessary raw building data, setting up a sufficient weather station network, and synthesizing the general building types into different categories. All of these data were put together in our computerized adaptive self-learning identification framework which is heuristically interfaced under human supervision to obtain the necessary threshold criteria, e.g. precision level, tolerance probability, maximum number of iterations, perturbation allowance, etc. for generating a best set of system descriptions to represent the energy consumption as a response function for the known community and weather characteristics, as well as of some presumed general stochastic mechanisms.

The building data were acquired from the Minneapolis city assessor's files. Although they were not completely compatible with our input demands, we were able to create a useful data set as described in detail in Chapter 3. The weather data were collected for two consecutive winter seasons. The details of their reliability and accuracy are also presented in Chapter 3.

To prevent the identified model from being too sensitive to extreme events or errors, two parallel model descriptions were constructed, namely the physical model and the statistical reference model. These models were developed simultaneously and independently so that the result of one could be used to check the other. By using this parallel modelling approach it was possible to detect unexplained or "never thought about" events, as well as to narrow the range of discrepancy between simulated and observed consumption values.

Two distinguishing features of Minneapolis, besides its size and population density, lie in the climatological effects on the energy consumption and had not been encountered before in either Cheyenne, Wyoming or Greeley, Colorado. These are the snow cover on the building roofs and the steady heat island built up over St. Paul-Minneapolis. The preliminary results obtained from the first winter season data, from December 1, 1977 to February 28, 1978, showed that the physical model consistently over predicted the energy demand by a nearly constant amount for each abnormally cold period. On the other hand, the statistical reference model produced inconsistent estimates of energy demand for days corresponding to holidays or weekends. Both were important hints for improving the model descriptions.

The identification procedures of a physical model, as described in the previous reports by Reiter et al. (1976, 1978 and 1979), required for the Minneapolis area that the input weather conditions be adjusted because of the heat island effect which varys from section-to-section of the city. Also the insulation R-multiplier of the attics of the buildings was changed to take into account the fact that the insulation of the buildings, even for the older residential houses, was considerably better than that in similar buildings of Greeley or Cheyenne. Although a detailed survey of the insulation characteristics of all buildings could not be performed, interviews with building contractors and other personal contacts substantiated our confidence in this assumption. The severity of winters in Minneapolis and associated high cost of heating would tend to make people more conservation minded and induce them to insulate attic areas. Snow on top of the roofs can also act as an additional layer of insulation to reduce heat leakage. Furthermore, its prolonged presence is an indicator for relatively good attic insulation.

For correcting the variation of energy consumption from weekday to weekend or holiday periods, three step functions were designed for computing the weighting factors according to the weekday index from 1 to 7. These three step functions correspond to three broad categories of buildings, namely the residential, the public and commercial, and the industrial buildings. A special step function may also be assigned for a particular building type, for example nursing homes where there are more visitors during the weekend than on weekdays. This changes the energy use patterns to heat loss through infiltration.

Simulation of various conditions from two parallel but independent models provides the opportunity of double checking the formulations and of isolating discrepancies. This procedure makes it possible to overcome part of the limitations encountered using only one model. It is not surprising that the formulations and the end product, the estimation of energy consumption from either the physical model or the statistical reference model for Minneapolis, are not worse than the results of the pilot cities of Greeley, Colorado and Cheyenne, Wyoming. The performance indices expressed as daily absolute errors were 6.26% and 5.54% for the physical and statistical reference models, respectively, over the period 12/1/77-2/28/78. This period was used to construct the model descriptions. The computed and observed energy consumptions from the physical and reference models for Minneapolis during the 1977-78 heating season are shown in Fig. 2.5 and Fig. 2.6, respectively. The model descriptions adjusted by the residual time series identified from the 1977-78 season were then applied to the second period 1/1/79-3/31/79 for which the resulting performance indices, given as daily absolute errors, were 5.39% and 5.94%.

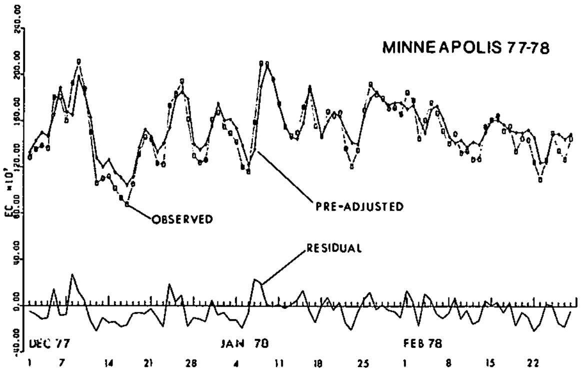

Fig. 2.5 Energy consumption estimation of the physical model during the 1977-78 heating season in thousands of cubic feet of natural gas for Minneapolis. The residual curve represents the observed minus the preadjusted consumption.

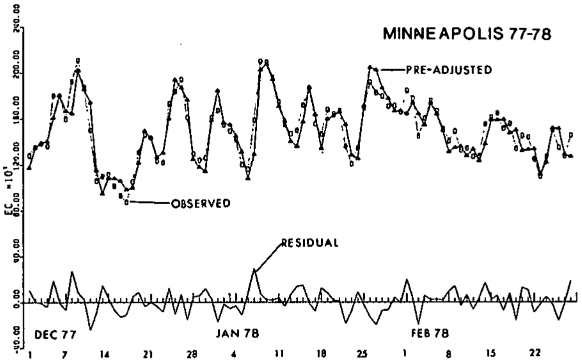

Fig. 2.6 Same as Fig. 2.5, except for the statistical reference model.

Through the use of the physical model time series component we have reduced the daily absolute error by 3.1% during the evaluation period; the reduction is 2.2% for the statistical model results. A procedure change in the construction of the time series descriptions may be the cause of this difference. The time series description of the physical model was evaluated by using the entire data set of 90 days during the 1977-78 season. However, the statistical reference time series was evaluated on the basis of only the first 60 data points, of which the first 40 were used as training and the following 20 were used as the testing set. The last 30 days were not used in the evaluation. The reference time series was evaluated in this manner to see if reasonable results could be obtained using a shorter data set. Indeed, a difference of only 1% was noted using the shorter data set in the reference description as compared to using the full 90 days in the physical description. We were further motivated to try this change in procedure since at that time we did not have the 1978-79 data set to use as a model performance verification. Therefore we had to use the last 30 days of the 1977/78 season as the "prediction" period for the time series description. If the time series evaluation fo the statistical reference model had used all 90 days its accuracy would probably have been improved by the same order as the physical model.

It has been pointed out that a growing community could not be perfectly represented by a stationary model. The adaptive identification scheme was employed along with our modelling techniques to check the performance of the identified models in which various actions may be required depending on the outcome of statistical tests.

The performance indices and other statistics for Minneapolis were thus computed from time to time. Tables 2.1 and 2.3 are results of the physical and the reference models, respectively, for the evaluation period. Tables 2.2 and 2.4 are for the prediction period. The procedures used for these statistical tests for performance checking were explained in detail by Reiter et al. (1979).

The statistics in Table 2.1 show that neither the Runs test nor the Kolmogorov-Smirnov test was significant at a 1% probability level. When the Runs test on the residual time series (observed response minus computed response) of energy computation is not significant it implies that there is no sufficient evidence to disprove that the model has only random patterns in its residual. When the Kolmogorov-Smirnov test shows that the cumulative distribution function

TABLE 2.1 Performance statistics for the evaluation period, 12/1/77-2/28/78, applying the physical model to the city of Minneapolis, Minnesota.

	Without Residual Time Series Adjustment	With Residual Time Series Adjustment
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	35	40
Mean of Runs	42	41.98
Std. Div. of Runs	4.32	4.49
Test Statistic	-1.68	-0.44
Critical Value	-2.33 †	-2.33 †
Significance Level	1%	1%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	132.5x10^3 to 143.7x10^3	133.1x10^3 to 140x10^3
Test Statistic	0.169 †	0.085 †
Critical Value	0.172	0.180
Significance Level	1%	1%
Performance Indices		
Root Mean Square Error %	7.49	3.93
Absolute Daily Error %	6.26	3.19

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

TABLE 2.2 Performance statistics for the prediction period, 1/1/79-3/31/79, applying the physical model to the city of Minneapolis, Minnesota.

	Without Residual Time Series Adjustment	With Residual Time Series Adjustment
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	26	31
Mean of Runs	44.58	29.09
Std. Div. of Runs	4.57	3.07
Test Statistic	-4.07 *	0.62 †
Critical Value	-2.33	-2.33
Significance Level	1%	1%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	176.1x10^3 to 199.4x10^3	120x10^3 to 130x10^3
Test Statistic	0.133 †	0.085 †
Critical Value	0.172	0.180
Significance Level	1%	1%
Performance Indices		
Root Mean Square Error %	8.46	6.64
Absolute Daily Error %	6.77	5.39

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

TABLE 2.3 Performance statistics for the evaluation period, 12/1/77-2/28/78, applying the reference model to the city of Minneapolis, Minnesota.

	Without Residual Time Series Adjustment	With Residual Time Series Adjustment
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	41	38
Mean of Runs	45.64	40.80
Std. Div. of Runs	4.68	4.37
Test Statistic	-0.99 †	-0.64 †
Critical Value	-2.33	-2.33
Significance Level	1%	1%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	160×10^3 to 170×10^3	166×10^3 to 169×10^3
Test Statistic	.067 †	0.061 †
Critical Value	.172	0.180
Significance Level	1%	1%
Performance Indices		
Root Mean Square Error %	7.01	4.34
Absolute Daily Error %	5.54	3.39

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

TABLE 2.4 Performance statistics for the prediction period, 1/1/79-3/31/79, applying the reference model to the city of Minneapolis, Minnesota.

	Without Residual Time Series Adjustment	With Residual Time Series Adjustment
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	40	46
Mean of Runs	45.91	41.78
Std. Div. of Runs	4.71	4.48
Test Statistic	-1.26 †	0.94 †
Critical Value	-2.33	-2.33
Significance Level	1%	1%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	125×10^3 to 140×10^3	130×10^3 to 140×10^3
Test Statistic	.056 †	0.049 †
Critical Value	.172	0.172
Significance Level	1%	1%
Performance Indices		
Root Mean Square Error %	9.69	7.84
Absolute Daily Error %	7.50	5.94

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

(cdf) of the observed population is not significantly different from the simulated population, it means that there is no sufficient occurrence of frequencies at any value of the observed variate and the simulated variate which behave in different patterns.

According to the adaptive identification scheme, no action is necessary to improve the current model (without time series adjustment) until new data arrive since no tests results of the first column in Table 2.1 or Table 2.3 were significant. It is, however, still possible to improve the current model through the use of the time series description. Nevertheless, in the case where this option is taken one must be cautious of putting too much emphasis on the time series description for it might only reflect a white noise process. In the case of our Minneapolis modelling endeavors, we have found some evidence through the autocorrelation plots of the residual sequences (Appendix 2B) that the residual has an unexplained regularity. This indicates that a time series description would not be a trivial addition to our modelling results.

As discussed in Section 2.3 by Reiter et al. (1979), and also in Appendix 2A, the GMDH[1] time series description is constructed to take into account the stochastic variation of the energy consumption which is realized in the residual time series. The residual time series is the daily difference between the observed and the computed energy consumption. The GMDH time series description is constructed for both the physical model residual and for the reference model residual. The procedure for identifying these time series descriptions is similar to constructing a autoregressive process but also takes into account the effects of the related weather input variables. The construction of the physical and the statistical reference time series descriptions were accomplished on the basis of the residual time series shown in Fig. 2.5 and Fig. 2.6, respectively. The final model description is then the original physical model (or statistical reference model) augmented by the respective time series descriptions.

The improved physical and statistical reference models for Minneapolis during the 1977-78 winter season and their corresponding residual and estimated time series are plotted in Fig. 2.7 and Fig. 2.8. The performance indices of the absolute daily errors become 3.18% and 3.39% for the physical and statistical reference models, respectively. The second column in Table 2.1 or Table 2.3 show other related statistics after adjustment.

Based upon the statistical reference model results it is possible to simulate a (1-α) performance confidence interval of a statistical reference response with a 1/K allowance of variation, where both (1-α) and 1/K are some preassigned probabilities. The procedure was also reported by Reiter et al. (1979), Section 2.2.5.2. The performance interval indicates a range of variation of the model's response to a specific input condition (i.e. the weather variables). This specific input condition is perturbed according to an empirical joint probability distribution function (pdf) created from a subset of the input conditions in the neighborhood of the specific input. The neighborhood is defined as having a 1/Kth change of occurrence with respect to the total observed input data set from our evaluation period. Using this subset of input conditions, we compute 200 possible model responses and form a conditional response pdf from these data. We then choose symmetrically (1-α) bounds which contain 100 x (1-α)% of all computed values. These bounds are called the upper and lower limits of the performance interval and it is these values which are plotted in Figs. 2.9 and 2.10 for the evaluation and prediction periods, respectively. Both figures show the comparison between the observed response and the response computed from the physical model along with the region defined by the lower and upper performance confidence limits simulated with respect to the statistical reference model. Here the values of (1-α) and 1/K were preassigned as 90% and 1/10, respectively. The observed response, the response from the physical model, and the response from the reference model are all representations or approximations to the true but unknown system response. For the evaluation period, 90% of the responses simulated from the statistical reference model fall inside the performance confidence interval. Since the reference model and physical model were tuned over this period, they should give a good representation during this time of a possibly slowly time-varying system. Therefore, about 90% of the observed values and of the values from the physical model are expected to fall within the interval, which is seen to be the case in Fig. 2.9.

Usually it is more interesting and meaningful to look at the response of both models during the prediction period (Fig. 2.10) rather than the evaluation period (Fig. 2.9). This provides a chance to examine whether the predicted values obtained from the physical model are reliable and/or whether the observed values, which represent the real system, are undergoing changes. An examination of these results, such as in Fig. 2.10, serves as a first check of the merit of performance of our models and triggers a warning signal to the model user if the values of the observed or computed responses consistently fall outside the

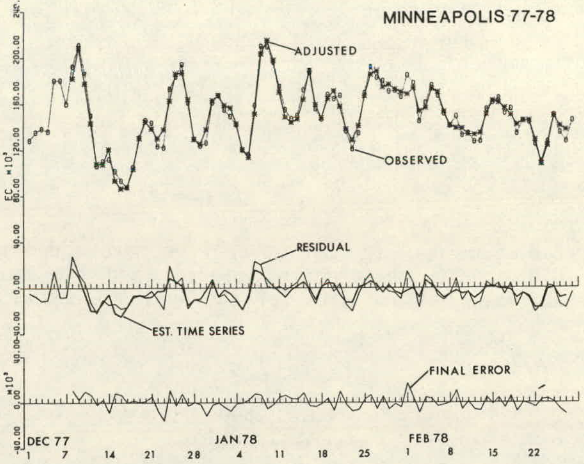

Fig. 2.7 Energy consumption estimation of the physical model which has been adjusted by the time series description during the 1977-78 heating season, in thousands of cubic feet of natural gas for Minneapolis. The middle curve shows the estimated time series which was used to adjust the physical model. The bottom curve is the final model error which is the observed minus the adjusted consumption.

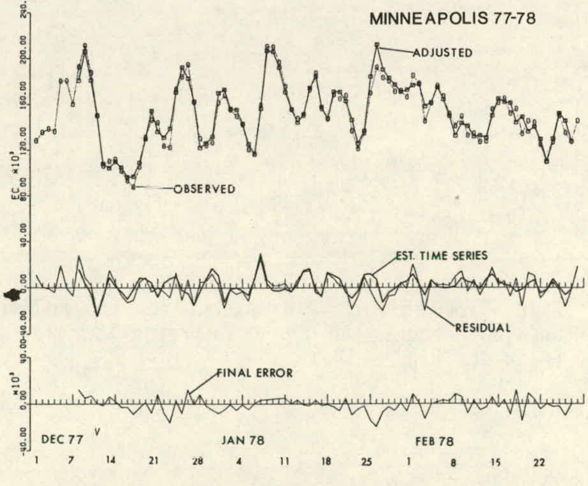

Fig. 2.8 Same as Fig. 2.7, except for the statistical reference model.

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[1] Grouped method of data handling.

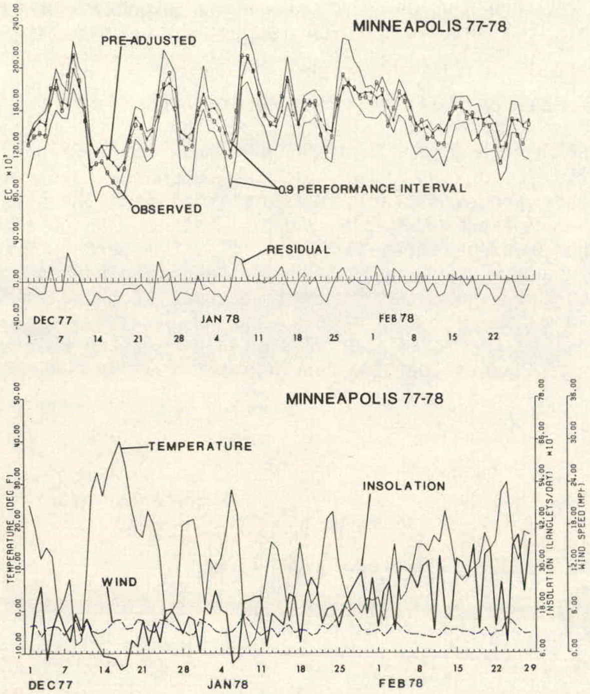

Fig. 2.9 Same as Fig. 2.5, except we have added the 0.9 or 90% performance interval and the daily averaged weather data for the evaluation period.

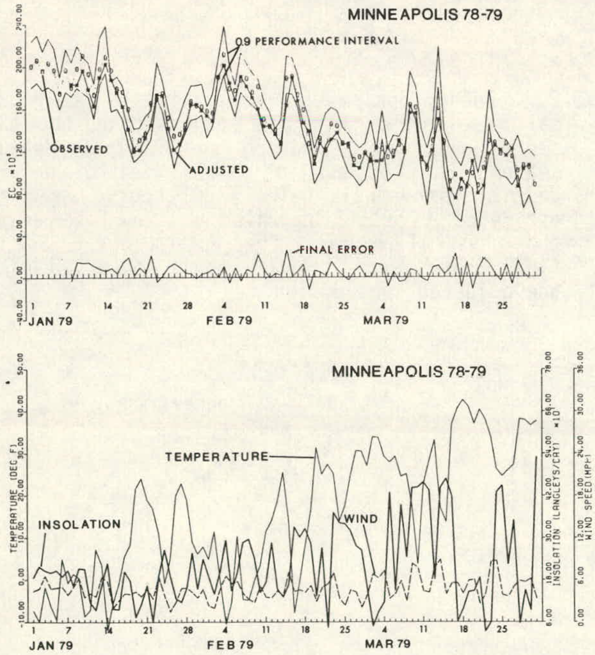

Fig. 2.10 Same as Fig. 2.9, except for the adjusted physical model during the prediction period. (Also see Fig. 2.12.)

simulated performance confidence region. For the whole prediction period of 1979, as shown in Fig. 2.10, the model behaves closely to the observed response most of the time, except for 8 occasions out of 90 days when either the observed or the computed energy consumptions fell slightly outside of the performance confidence bounds.

The results from the statistical reference model for the 1978-79 heating season in Minneapolis are given in Fig. 2.11. An examination of the second column in Tables 2.2 and 2.4 show that the performance indices of the statistical reference predictions are comparable to those of the physical model predictions.

It is worthwhile to note that the physical model seems to under-predict the energy consumption whenever the community has a peak energy demand. In several of these instances the statistical reference model over-predicts relative to observed consumption, as can be seen from a comparison of Fig. 2.10 with 2.11. There is evidence that the peaks in the final error time series may be associated with an exceptional behavior by the residents of the modelled area in response to changing weather. For example, the largest positive day-to-day differences between observed and computed adjusted consumption in Fig. 2.10 occurred on dates associated with the passage of strong weather systems. Specific cases of the onset of these storm periods are Jan. 18, Feb. 10 and March 17, 1979. On these dates rising humidity and rapidly increasing low cloudiness led eventually to precipitation. Similarly, on Jan. 22, Feb. 15 and March 23 clearing skies were associated with rising winds and rapidly falling temperatures. In all cases relatively large underestimates of energy demand were associated with these major changes in the weather. Many smaller positive error spikes in Fig. 2.10 were also tied to changing weather conditions. Similar associations are also seen in our other energy consumption analyses. That our energy consumption model so consistently underpredicts demand during changing weather suggests that space heating energy consumers may temporarily increase thermostat settings more as a reaction to the onset of wet or cold weather rather than in accommodation of extended periods of unpleasant conditions.

Although the addition of the stochastic component (i.e. the time series description) to the physical or the statistical reference model did not provide much improvement over the deterministic component (i.e. the descriptions without the time series) during the period of model evaluation, the time series definitely provided a significant contribution to the final estimation of each model for the prediction period 1/1/79 to 3/31/79. The hypothesis test statistic with respect to the Runs test (Table 2.3) for the physical model without time series is 4.07, which is rejected at a 1% significance level. The test statistic value for the physical model adjusted with time series is 0.62 which is accepted at a 1% significance level. The Runs test statistic for the statistical reference model (Table 2.4) is also improved from 1.25 for the description without time series to 0.94 for the description with time series. The Kolmogorov-Smirnov test statistics also show substantial improvement by use of the time series components as listed in Table 2.3. and Table 2.4. The model residual statistics which were compiled in Appendix 2B reveal similar improvements to the model after adjustment.

Figure 2.12 shows the prediction from the physical model with and without time series descriptions along with the observed value for the whole heating season of the second year. Notice that in the central part of Fig. 2.11 and Fig. 2.12 the estimated residual time series curves closely follow the pattern of the original residuals.

The models identified for the metropolitan area of Minneapolis are sufficiently accurate to account for most of the variation in energy consumption corresponding to variable weather conditions. Both models yield about the same order of accuracy in terms of performance indices for the evaluation period and the prediction period.

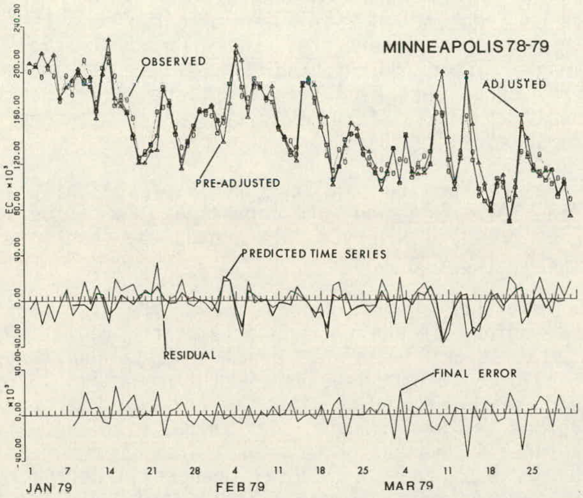

Fig. 2.11 Energy consumption prediction of statistical reference model during the 1978-79 heating season in thousands of cubic feet of natural gas for Minneapolis. Both the preadjusted (without the times series description) and the adjusted (which includes the time series description) model outputs are presented. The middle curve shows the predicted time series which is used to adjust model results. The residual curve is the observed minus the preadjusted consumption. The final error curve is the observed minus the adjusted consumption.

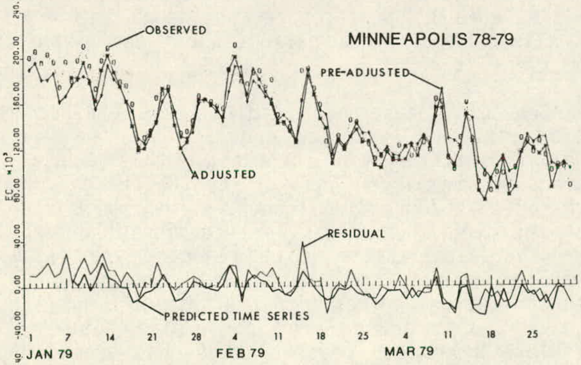

Fig. 2.12 Same as Fig. 2.11, except for the physical model.

A further discussion of the physical model results for Minneapolis is presented in Section 2.6. The daily values of energy uses for the 49 building types during the month of January 1979 are given in Appendix 2D.

2.3 REEVALUATION OF THE ENERGY CONSUMPTION OF CHEYENNE, WYOMING

One of the important features in the adaptive identification framework was demonstrated during the evaluation of the energy consumption data from Cheyenne, Wyoming for two consecutive winters. We were able to check whether the model identified in one period was still valid in another period or, assuming that the identified system is slowly varying, to what degree the departures from the reference pattern were significant from a probabilistic point of view. The conceptual approach to this method of performance checking was introduced by Reiter et al., (1978) and illustrated by Reiter et al. (1979). The following analysis serves as another illustrative example of the procedure.

Cheyenne, Wyoming was selected as our second pilot site for verification of the energy demand modelling technique. It was the first city in which we tested the statistical sampling scheme as an alternative method for assembling the building data base of a community (Starr, 1978). As a continuing effort, last year we obtained data for an additional heating season. These data were for the period 11/1/75 to 3/31/76 which was a year earlier than the data used for the identification of the Cheyenne physical model. Since we established a local weather network only during the 1976-77 winter, it was necessary to simulate the local weather conditions in Cheyenne for the 1975-76 period using the urban weather patterns reported by Reiter et al. (1979) for the 1976-77 season and the local weather records from the Cheyenne Airport National Weather Service station for 1975-76. With these simulated weather data it became possible to use our identified physical model to perform an energy demand computation. In addition, it was equally challenging to use this new data set to construct a complete statistical reference model as described in Section 2.1 and Appendix 2A. Here we will present the intermediate steps to illustrate the detection of an incorrect response pattern and to show what action was taken once the inconsistency was identified.

Figure 2.13 contrasts the observed energy consumption during the 1976-77 heating season with the prediction of the statistical reference model identified from the 1975-76 winter. Immediately, disapproval signals were generated from the reliability test because most of the observational points were below the 90% performance confidence limit (based on the 1975-76 reference model, with a 10% perturbation allowance around a given input weather condition). When a point falls outside of the 90% performance confidence interval we can expect that there is only a 10% chance that this should occur if the model still truly represents the behavior of the community. In other words, outlier points belong to extraordinary events. The fact that most of the 1976-77 response points were observed to belong to such "extraordinary events" indicates that either the energy use pattern of the 1975-76 season was quite different from that of the 1976-77 season, or one of the two data sets was in error.

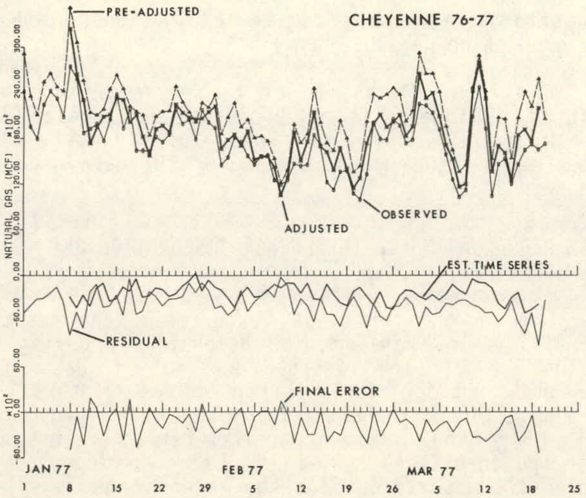

Fig. 2.13 Energy consumption prediction of the statistical reference model during the 1976-77 heating season, in thousands of cubic feet of natural gas, for Cheyenne, Wyoming. Both the preadjusted (without the time series description) and the adjusted (which includes the time series description) model outputs are presented. Note that this model is identified from the 1975-76 evaluation period data only. The rejection of the identified model by our performance checking algorithm led to the revision of the earlier model and data source. The middle curve shows the predicted time series which is used to adjust the model results. The residual curve is the observed minus the preadjusted consumption. The final error curve is the observed minus the adjusted consumption.

When the Runs test was applied to the residual time series the test statistics were far below the critical value at the 1% significance level, strongly suggesting to reject the hypothesis, that the sequence of unexplained energy consumption values (residual time series) were generated from a purely random mechanism. In other words, since the chance of such runs (patterns) being observed in a purely random process was far less than 1% probability, it should be inferred that the pattern associated with the unexplained residual had a high likelihood of being caused by nonrandom factors.

The goodness-of-fit between the observed and the estimated energy consumption distributions was also abruptly rejected by the Kolmogorov-Smirnov test at a very high probability significance level. In comparing these two empirical, cumulative distribution functions (cdf), the absolute difference between the functions at each energy consumption value was found to be as much as 0.38, whereas the critical value at 1% significance level was 0.18.

All these indications led to a reexamination of our weather information for both seasons. No obvious discrepancies were found in either observed or simulated weather conditions. Thus, it seemed that the only possibility was a change in the observed energy consumption data or in our building census. Two possibilities existed: either Cheyenne was shrinking in size and was less populated in 1976-77, or the data for energy consumption for each year were measured in a different manner. Cheyenne is booming from energy industry development and has recently attracted much new investment and many new residents. Consequently, it was decided to closely reexamine the originally collected energy consumption data.

With the cooperation from the local utility company a systematic bias in the observed consumption data was isolated. In Cheyenne there is an interruptible customer who uses a large amount of natural gas for processing purposes. This gas consumption was included in the original daily totals of the city's natural gas usage. Since this usage is monitored on a daily basis, it was easy to subtract the amount of gas used for processing from the original city totals. Unfortunately, in the data received for the 1976-77 winter season, the daily totals were given for 14.65 psia and the large interruptible customer's usage was given at 10.65 psia line pressure. This pressure difference was not noted in our original computations of gas usage. Therefore, the gas consumption of Cheyenne, after subtracting the interruptible customer's usage, had been computed to be lower than the correct value. This created a systematic bias for the whole season of 1976-77.

Before the reestimation, a few of the daily data for the 1975-76 season were corrected. As can be seen in Fig. 2.14 the observed data around the Thanksgiving week are also suspicious.

A further surprising result was that the performance indices of the energy consumption prediction by the statistical reference model (identified through the 1975-76 winter season data) over the 1976-77 winter season computed with the corrected data outperformed the performance index values with respect to the 1975-76 evaluation period. The absolute daily error is 5.9% for the 1976-77 prediction period when actual weather data were available, and 7.36% for the 1975-76 evaluation period when weather data had to be inferred from just one station. Other statistics and hypothesis testing results, given in Table 2.5, also favor the 1976-77 prediction period. It is believed that changes in the performance indices are partly a consequence of changes in the habit patterns of the people expressed by using more uniform thermostat settings or by adopting conservation measures as a result of the campaign conducted recently by the local utility company. On the other hand, the local network of weather stations used during the 1976-77 season yielded high quality weather information as input to the model and thus resulted in more accurate predictions. For completeness, Figs. 2.14 and 2.15 present estimations from the statistical reference model during the 1975-76 and 1976-77 seasons, respectively, along with the simulated 90% performance confidence region with a 10% allowance of perturbations about the given input conditions.

The above mentioned results were obtained using the statistical reference model. When the physical model (identified via incorrect 1976-77 data) was subsequently employed to estimate the energy consumption for 1975-76 heating season, it was not surprising that the predicted values were consistently low. All the statistical tests which rejected the estimated response pattern from the physical model led to the same conclusion derived from the statistical reference model -- erroneous energy consumption data -- and therefore a revised physical model was deemed necessary.

The most important revision to the physical mode was in adjusting the insulation characteristics of th Cheyenne residential buildings to the level indicated by Greeley buildings. When Cheyenne was first modelled on the basis of the incorrect 1976-77 data, it was

TABLE 2.5 Reference model performance statistics for the evaluation period, 11/1/75-3/31/76, and the prediction period, 1/1/77-3/20/77, for Cheyenne, Wyoming.

	Evaluation Period	Prediction Period
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	74	31
Mean of Runs	72.78	35.22
Std. Div. of Runs	5.96	4.00
Test Statistic	0.21 †	-1.05 †
Critical Value	-0.84	-1.28
Significance Level	20%	10%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	$14x10^3$ to $15x10^3$	$17.5x10^3$ to $18.5x10^3$
Test Statistic	.047 †	0.083 †
Critical Value	.089	0.126
Significance Level	20%	20%
Performance Indices		
Root Mean Square Error %	7.49	6.43
Absolute Daily Error %	5.83	4.89

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

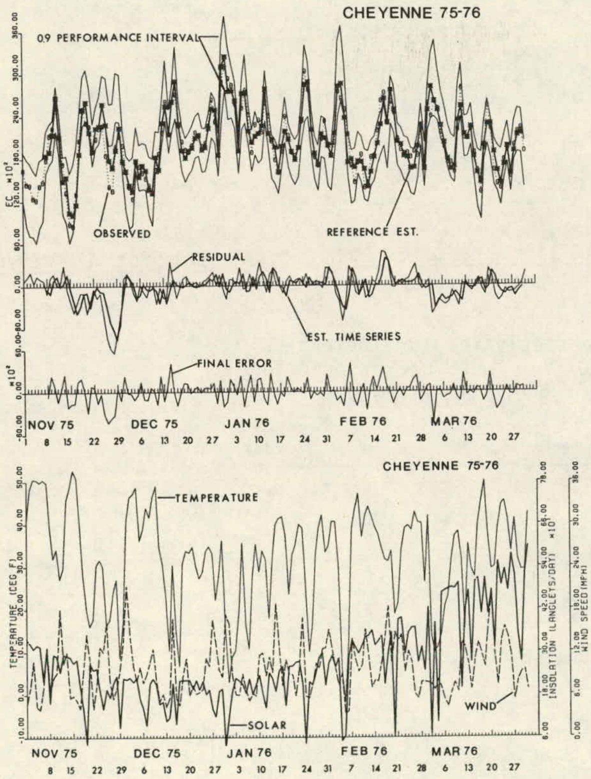

Fig. 2.14 Revised energy consumption prediction of statistical reference model during the 1975-76 heating season in thousands of cubic feet of natural gas for Cheyenne, Wyoming. The computed results include adjustments for the estimated time series. The residual curve is the observed minus the preadjusted consumption. The daily means of weather conditions and the 0.9 performance intervals are also shown.

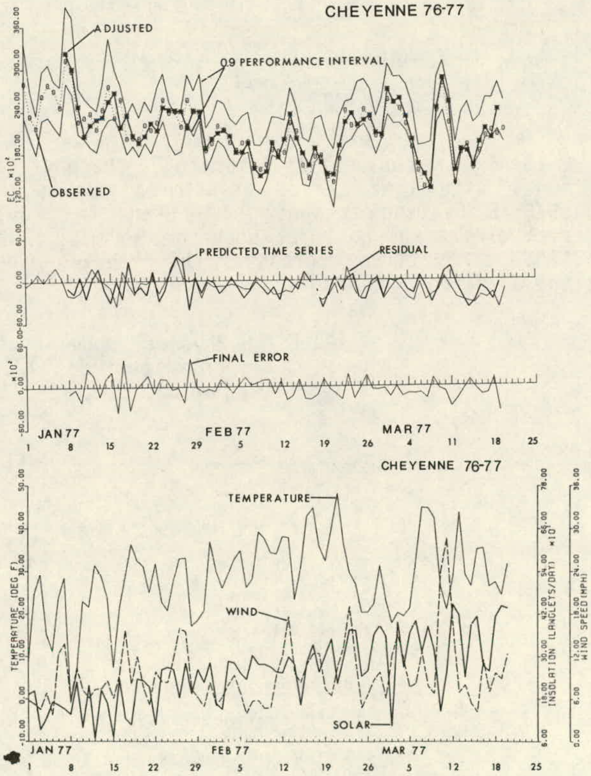

Fig. 2.15 Same as Fig. 2.14, except for the 1976-77 prediction period.

disturbing to find that similar building types and age groups subjected to a similar climate regime but higher infiltration rates (due to high winds) did not suffer heat losses at a level similar to buildings in Greeley. A faulty conclusion was made that the Cheyenne dwellings had better insulation characteristics. It is "fortunate" that our adaptive identification framework could detect our mistake and it is comforting that the assumption of a "typical building" is again revalidated.

Figures 2.16 and 2.17 represent the results of the physical model for the prediction period in 1975-76 and for the evaluation period of 1976-77, respectively. The performance indices and the test statistics are summarized in Table 2.6. In reviewing this table it should again be stressed that the physical model was tuned using the 1976-77 data and then used to predict the 1975-76 season, while the statistical reference model was formulated in reverse order. In general, it is always preferable to use the data set with the higher degree of accuracy when evaluating the parameters of a model and to use the data of lesser or unknown precision for the prediction period. This was done for the physical model case but was not done in the construction of the reference model. One would expect the evaluation performance indices to be better than the predicted performance indices. This expectation did not hold true for our reference model results but did hold true for the physical model. This finding would make us then believe that our modelling results are not heavily dependent upon the evaluation period but are highly dependent upon the accuracy of our weather input data.

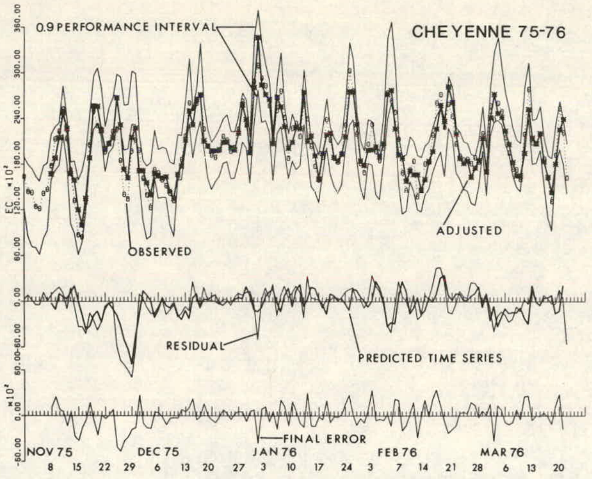

Fig. 2.16 Energy consumption estimate of the physical model with time series adjustment during the 1975-76 heating season, in thousands of cubic feet of natural gas, for Cheyenne, Wyoming. The final error curve represents the observed minus the adjusted consumption.

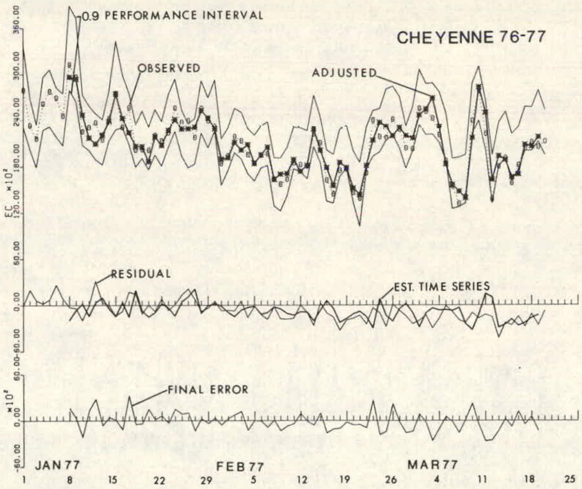

Fig. 2.17 Same as Fig. 2.16, but for the 1976-77 heating season.

TABLE 2.6 Physical model performance statistics for the evaluation period, 1/1/77-3/20/77, and the prediction period, 11/1/75-3/30/76, for Cheyenne, Wyoming.

	Evaluation Period	Prediction Period
Runs-Test		
Ho: The residual sequence is purely random		
Number of Runs	40	66
Mean of Runs	36	68.41
Std. Div. of Runs	4.09	5.78
Test Statistic	0.98 †	-0.42 †
Critical Value	-1.28	-0.84
Significance Level	10%	20%
Kolmogorov-Smirnov Test		
Ho: cdf (computed response) = cdf (observed response)		
Most Discrepancy Range	19.5×10^3 to 20.5×10^3	13.5×10^3 to 14.5×10^3
Test Statistic	.069 †	.052 †
Critical Value	.126	.092
Significance Level	20%	20%
Performance Indices		
Root Mean Square Error %	6.02	10.42
Absolute Daily Error %	4.77	7.82

*: Indicates significance and rejects the null hypothesis, Ho.

†: Indicates insignificance and accepts the null hypothesis, Ho.

2.3.1 A Graphical Representation of a Performance Confidence Interval for the Input Variables.

The scheme that we have derived to simulate a performance interval for our energy consumption predictions can also be applied to the model input values (i.e. temperature, wind speed and solar radiation). A plot of each input variable (along with its performance interval) with respect to the energy consumption illustrates the dependency of the energy consumption on the individual weather variables. Figs. 2.18a, b, and c show the 0.9 performance confidence interval as developed from the statistical reference model for the input variables as used in Cheyenne, Wyoming. The light solid center curve on each graph represents a smoothed response of energy consumption to the input or weather variable and is actually an average of the 7 surrounding points. The dashes indicate the actual simulated upper and lower limits of a given input value. The upper and lower solid lines are the smoothed upper and lower limits of the simulated performance confidence interval and are also the average of 7 surrounding points.

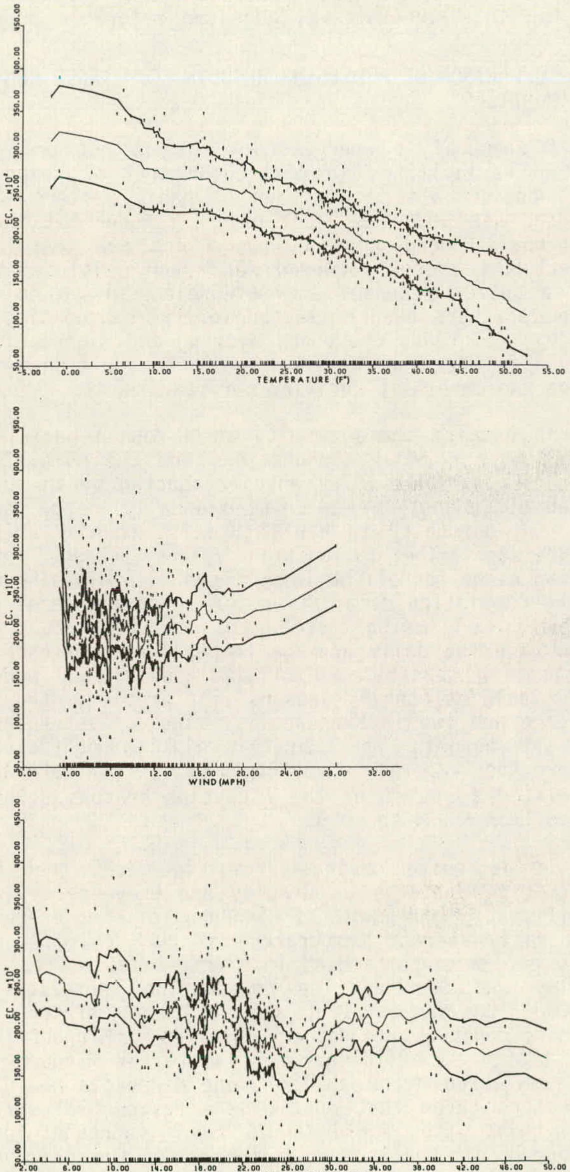

Fig. 2.18 Performance confidence interval (0.9) for average daily temperature, wind speed and solar radiation as a partial function of estimated daily energy consumption from the statistical reference model for Cheyenne, Wyoming 1975-76 and 1976-77 data. The mean response and the upper and lower confidence limit curves represent the averages of seven surrounding input values (small dashes).

Figure 2.18a shows the performance confidence interval from the statistical reference model for the daily average temperature as a partial function of the estimated energy consumption level. The response of energy consumption to the temperature variable is, as expected, a relatively uniform linear function. Figures 2.18b and c represent the response to wind speed and to solar radiation, respectively. No straightforward pattern is observable in either case. This is due to the dominance of temperature as the major forcing function of energy consumption. In the wind speed case a relatively consistent response is observed only at high wind speed values.

2.4 PRELIMINARY EVALUATION OF GREELEY FOR THE 1979 HEATING SEASON

As part of our on-going effort, we resumed the investigation of the energy demand of Greeley, Colorado. As stated in our recent proposal the city-wide network of meteorological stations was reestablished to study whether President Carter's order for a mandatory 65°F thermostat setting in public buildings during the winter, or other conservation practices, such as energy auditing of residential homes by the local utility company, had any significant impact.

The actual energy consumption for the 1978-79 winter has been provided by the utility company and is available in machine readable form. Weather patterns for the entire city for the corresponding time period were simulated by using records from one weather station operated by Dr. Glen Cobb at the University of Northern Colorado. As a first step, these preliminary 1978-79 meteorological and consumption data were used with the 1976 Greeley building data base as input into the models. However, no updating was done for any model parameters or coefficients to check on how much the performance of the model might have departed from the actual response of the growing community.

The performance indices in terms of percentage error from both the physical and the statistical reference models increased considerably from the previous results. The comparison of the physical performance indices between the 1975-76 and 1978-79 heating seasons are as follows:

	75-76	78-79	Difference
Absolute daily error	4.54%	12.29%	+7.75%
Root mean square error	5.78%	14.74%	+8.96%

If it is assumed that the pure random noise variation level of the system was unchanged from the previous evaluation period, i.e. the 1975-76 season, to the current 1978-79 season, and we agree that the existing model represents the average energy consumption pattern corresponding to the evaluation during the 1975-76 season and, furthermore, that the currently observed energy consumption represents the current pattern, then the large departure of performance indices from 1975-76 to 1978-79 can be attributed to a true community change. The series of statistical hypothesis tests in our adaptive identification framework (Reiter et al., 1978, 1979) showed strong warning signals that the discrepancy between the estimated and the observed values were statistically significant at the level of 5% and 1% for the Runs test and the Kolmogorov-Smirnov test, respectively. From the physical model residual in Fig. 2.19 it is also clear that a consistent pattern is vividly appearing through the whole season.

It was, therefore, necessary to update the Greeley building data base, adding buildings constructed during the past two years, and to tune the model to reflect changing habit patterns, fuel conservation, etc. We intend to use the sequential GMDH, an extension of the current GMDH algorithm now under testing, and to make a full and detailed study during the coming year of the variation of energy consumption patterns in Greeley.

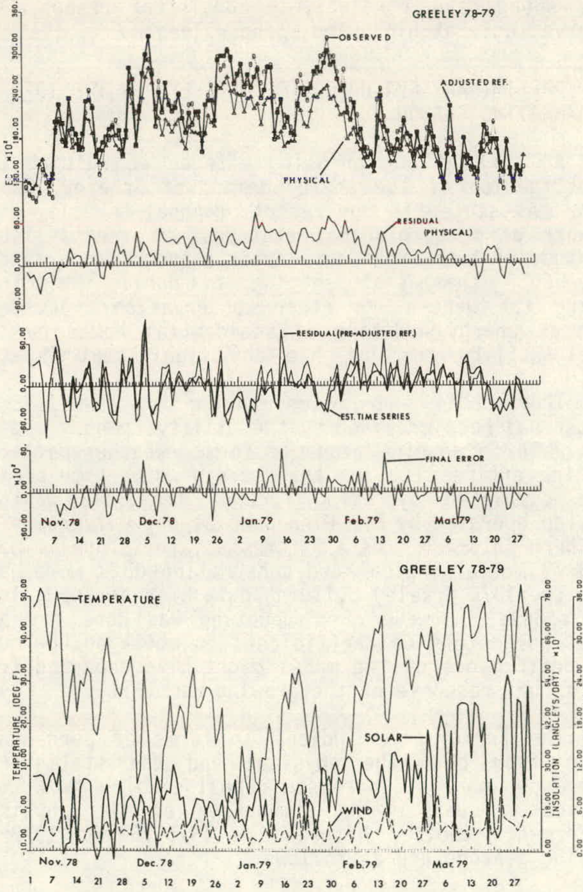

Fig. 2.19 Energy consumption prediction of the adjusted statistical reference model and the physical model during the 1978-79 heating season, in thousands of cubic feet of natural gas, for Greeley, Colorado. The reference model (identified in the 1975-76 season) was adjusted with the current (1978-79) time series. The physical model (also identified in the 1975-76 season) does not include the current time series adjustment. The upper residual is the difference between the observed energy consumption and that predicted by the physical model. The residual for the reference model without the time series adjustment is plotted with the estimated time series. The final error curve is the observed minus the adjusted reference consumption prediction.

While awaiting the updated physical building information to fill the gap of the past two years, the residual time series over the 1978-79 season computed from the statistical reference model was used to reidentify the time series descriptions. The results of this new time series description were employed as a compensator to correct the discrepant prediction of energy consumption computed on the basis of the 1975-76 reference description. The adjusted reference estimate for the energy consumption, along with the observed energy consumption and the estimate from the 1975-76 reference description, are shown at the top of Fig. 2.19. In this figure the estimate of the time series description is shown in contrast with the adjusted and preadjusted residuals. The absolute daily and RMS errors are 6.61% and 8.60%, respectively, for this preliminary, adjusted reference model.

2.5 COMPARISON OF MODELLING RESULTS FROM THREE COMMUNITIES

A community's energy use responds not only to weather variability (in particular that of temperature) but is also a function of habit patterns and building use patterns. Our physical model has these functional dependencies built in and can therefore predict the energy consumed for space heating based upon a building census and meteorological variables. These data have been collected for the communities of Greeley, Colorado, Cheyenne, Wyoming and Minneapolis, Minnesota, where we have applied our modelling techniques and carefully verified our results.

To compare these results on a common basis, we have used our model computations and the population estimates from the 1970 census conducted by the U.S. Bureau of Census. We calculated a daily energy usage for each community in Btu's (British thermal units) per person. The consumption values include space heating usage for all building types within the bounds of the population demarcation. A regression analysis was performed, using these daily values of Btu's per person and the daily average temperatures for each of the heating seasons we had simulated in our model. This includes three seasons in Greeley, two in Cheyenne and two in Minneapolis. The 7 least squares fits are shown in Fig. 2.20. Correlation coefficients between the temperature and Btu's per person were also calculated for each of the 7 heating seasons. These ranged from -0.94 to -0.99.

It is quite obvious from Fig. 2.20 that the consumption patterns of Greeley and Cheyenne deviate significantly from those of Minneapolis. For example, at a daily average temperature of 20°F only 310,000 Btu's per person are used in Minneapolis, whereas in Greeley and Cheyenne the consumption increased to 410,000. One can attribute part of this difference to building construction methods observed in Minneapolis. Even though no building codes existed in Minneapolis for insulation prior to 1965, one Minnesota building inspector stated that most of the residential structures built after World War II had 3½ inches of insulation in the walls and 6 inches in the ceilings. These numbers are consistent with answers we obtained during interviews with several contractors in the Minneapolis area, including representatives of the Minneapolis Builders Association. Such insulation practices are probably a result of the severe winters which are commonly experienced in this part of the country. During personal visits to the Minneapolis area, we observed that the vast majority of single family dwellings had storm windows and, although hard

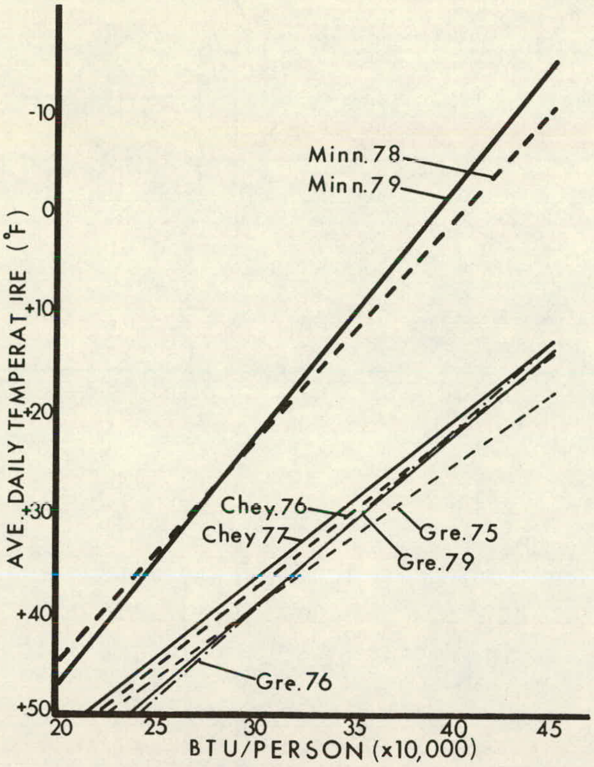

Fig. 2.20 Least squares analysis of average daily energy consumption per person versus average daily temperature in Greeley, Colorado, Cheyenne, Wyoming and Minneapolis, Minnesota.

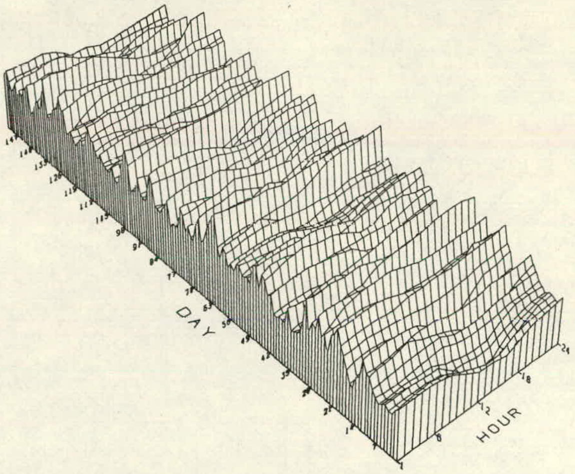

Fig. 2.21 Hourly energy consumption for single family dwellings in Cheyenne, Wyoming as a function of hour and day. Day 1 is November 1, 1975 and day 152 is March 31, 1976. Hour 1 refers to midnight and hour 12 is noon.

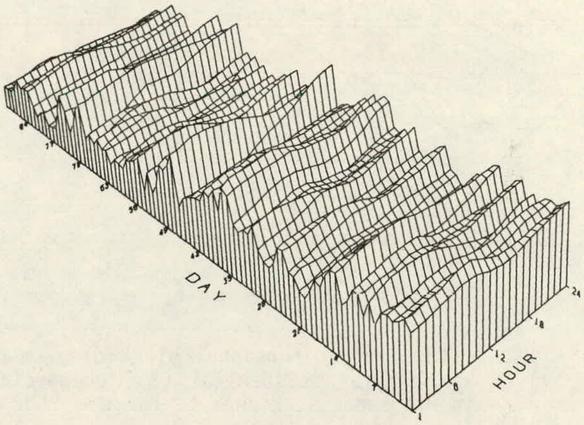

Fig. 2.22 Same as Fig. 2.21, except for Minneapolis from January 1, 1979 to March 31, 1979.

to verify, it is believed that most homes had been retrofitted with at least 3 inches of ceiling insulation. These construction practices were not observed in Greeley and Cheyenne.

Another possible reason for the diversity in the three communities may be the difference in population characteristics. In Minneapolis we estimated a population density of approximately four people per building, whereas in Greeley and Cheyenne this density falls to about three people per building. We have also found that the Minneapolis allocation of residential space is about 350 square feet per person, whereas in Greeley and Cheyenne it was found to be about 400 square feet per person. All of these facts tend to confirm the results presented in Fig. 2.20.

The fact that Minneapolis is a metropolitan area located in a severe climate seems to have compounding effects on its energy consumption pattern. These effects were foreseen in our past research proposal in which we stated that it would probably be necessary to model at least one urban and one rural community in each of the major climatic zones in order to produce a nationwide modelling skill. The results of our work thus far seem to verify this projection.

2.6 GRAPHICAL DISPLAYS OF ENERGY DEMAND IN URBAN COMMUNITIES

Through the use of three-dimensional plots one can view a community's hourly space heating energy demand for an entire heating season in one display. In Figs. 2.21 and 2.22 we present our modelling results for single family dwellings in Cheyenne during the 1975-76 heating season and in Minneapolis during the 1978-79 heating season, respectively. Hour 1 refers to 1 A.M., hour 12 to noon, and hour 24 refers to midnight in both of these figures. A characteristic mid-afternoon decrease in consumption is noted during most days in both cities but seems to be a much more prominent feature in Minneapolis. The irregularity of the hourly consumption in Cheyenne was also noted during the 1976-77 heating season reported by Reiter et al. (1979). A pronounced seasonal trend can be observed in the Minneapolis data (Fig. 2.22) with much larger values occurring in January and February (Day 1 through 59) than in March. A late morning (10 to 11 A.M.) maximum is also evident during much of the heating season in Minneapolis. This may be due to the reduced effectiveness of solar heating in Minneapolis because of clouds and snow cover which allowed ground temperatures to remain quite cold during the morning hours.

The spatial distribution of energy consumption for space heating is shown graphically in Figs. 2.23a, b, c, and d for the city of Minneapolis during the 1978-79 heating season. In these figures the height

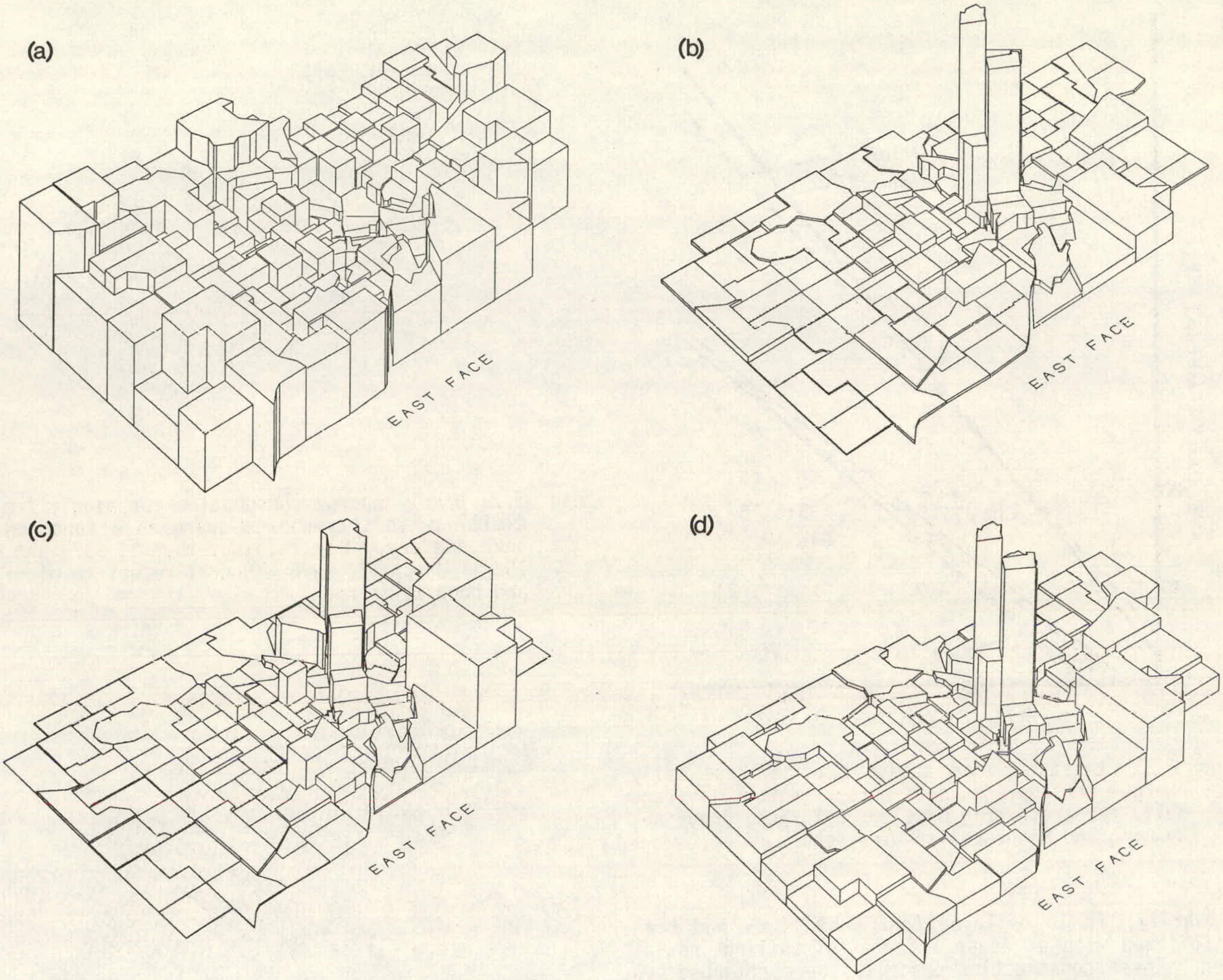

Fig. 2.23 Three-dimensional block diagram of comparative daily average energy consumption for space heating for residential (a), commercial-plus-public (b), industrial (c), and all buildings (d) in Minneapolis, Minnesota for the 1978-79 heating season.

of each block is indicative of the normalized energy consumption in that block. As discussed in a subsequent chapter, the city is broken down into 127 sections for which meteorological and building census data are enumerated. Our physical model produces consumption rates in each of the sections for the specific building information given as input. The energy usage of residential, commercial-plus-public, and industrial buildings is displayed in Figs. 2.23a, b, and c, respectively, for each of the 127 areas. Figure 2.23d shows the total consumption for all building types.

The residential space heating demand, Fig. 2.23a, is fairly uniform beyond the periphery of the central downtown business district. This "ringed" type of distribution of residential build-up has been noted in many studies on urban development and would be even more notable had we included the surrounding suburbs in our modelling effort. The spatial distribution of the commercial-plus-public and industrial space heating energy use (Figs. 2.23b and c) shows, as expected, high usage in the downtown areas and relatively low consumption in the outlying residential areas. As we can see from the total consumption, Fig. 2.23d, the nonresidential sectors tend to dominate the over-all consumption picture, so that extreme values are observed in the small downtown area. This information could be quite valuable in the planning of alternative energy systems such as proposed in the district heating/cogeneration study reported by Margen et al., 1979.

2.7 SPACE CONDITIONING COOLING MODEL

As a test of the applicability of our energy consumption modelling approach to the cooling season, summertime energy use was modelled for four relatively large buildings in Fort Collins, Colorado. Whereas this study was quite limited in scope and duration, we were able to identify situations under which more efficient mechanical systems and operating schedules might show large energy savings.

Using the same GMDH approach described in Appendix 2A of this report and in our previous reports, the energy use for each building was simulated with the statistical reference model. Ambient weather conditions were again the input signals and energy demand, presumably for space cooling, the output signals. Variation in heat gain (or loss) due to the number of door openings, changes in the number of occupants and other heat-generating activities occurring in the building was considered noise input to the system.

The correlation between the various meteorological input variables and observed energy demand is usually highest for temperature during both the heating and cooling seasons. The absolute difference between the degree day reference temperature, 65°F, and the mean outdoor temperature for the cooling season in Fort Collins is only 6°F as compared to 34°F for the heating season. For this reason the signal-to-noise ratio for modelling space conditioning energy consumption during the cooling season in such a climate is much lower than during the heating season. Consequently, distinctions between the energy consumption responses to signal and to noise are much more difficult to identify in modelling the cooling season. In contrast with the heating season, the GMDH algorithm determined that midday wet bulb temperature was to be given more weight than daily mean dry bulb temperature for three of the four buildings and, surprisingly, solar radiation was rejected as a variable to construct the model.

We shall refer to the buildings modelled as Buildings 1 through 4 to protect the confidentiality of these data. Figures 2.24, 2.25, 2.26 and 2.27 show the observed and computed energy uses during portions of August and September, 1978 for Buildings 1 through 4, respectively. Table 2.7 presents a summary of the structural characteristics and some model performance results for the four buildings. Comparative energy consumption statistics are shown in Table 2.8 for Buildings 1 through 3. The unavailability of a meter calibration factor at Building 4 precluded determination of the actual energy use for this building. Consequently, the curves in Fig. 2.27 represent the relative variations in consumption rather than the absolute amounts of energy used.

Buildings 1 and 2 were commercial office buildings in adjacent locations in downtown Fort Collins. These buildings experienced heavy use on week days but greatly curtailed usage on weekends. In addition to reduced usage, the cooling systems in these buildings were shut down on weekends. This operating schedule variability was accommodated by a step function that

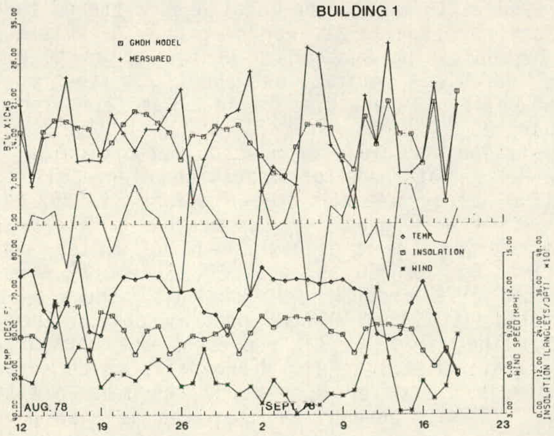

Fig. 2.24 Comparsion of energy consumption predicted by the statistical reference model and the observed daily energy consumption for Building 1 from 8/12/78 to 9/19/78. Lower graph shows average daily (24 hour) weather conditions.

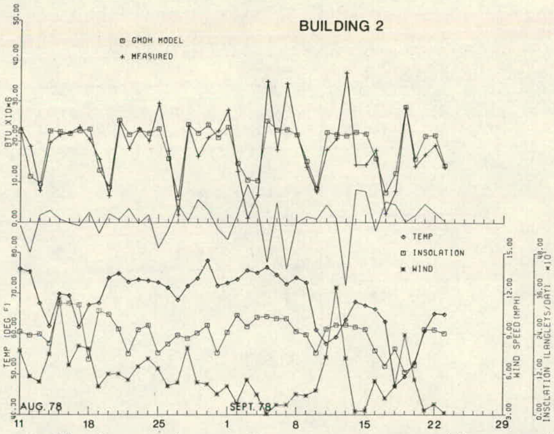

Fig. 2.25 Comparison of energy consumption predicted by the statistical reference model and the observed energy consumption for Building 2 from 8/11/78 to 9/23/78. Lower graph shows average daytime (10 A.M. to 3 P.M.) wet bulb temperature, insolation and average daily (24 hour) wind speed for this same period.

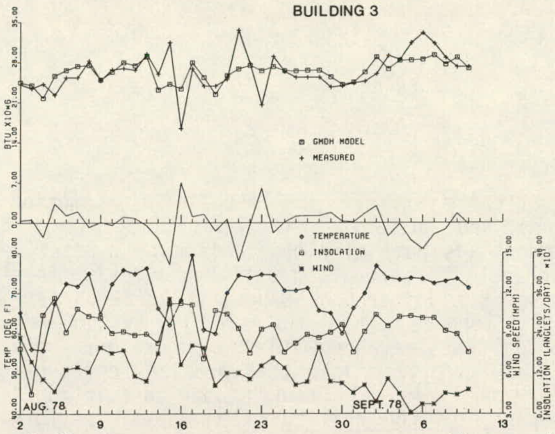

Fig. 2.26 Comparison of energy consumption predicted by the statistical reference model and the observed daily energy consumption for Building 3 from 8/2/78 to 9/10/78. Lower graph shows average daily (24 hour) weather conditions.

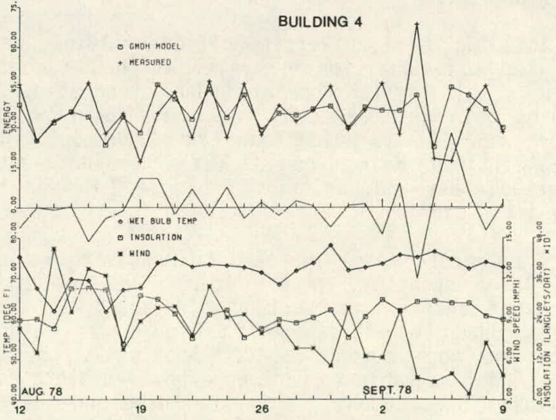

Fig. 2.27 Comparison of predicted energy consumption variability from statistical reference models with time series adjustment and observed daily energy consumption variability for Building 4. Lower graph shows daytime (10 A.M. to 3 P.M.) weather conditions from 8/12/78 to 9/9/78. The peak in the graph representing measured energy consumption occurred on September 4, Labor Day.

TABLE 2.7 Structural characteristics and cooling model performance results for Buildings 1 through 4.

Building	Floor Area	Number of Floors	Glass to Wall Ratio	Wall Construction	Energy Source	Type	Daily Error	RMS Error
1	42,609	7	33%	Brick/ Concrete	Natural Gas	Office	31%	39%
2	71,894	11	60%	Brick	Electric	Office	20%	27%
3	22,757	3	25%	Precast Concrete	Natural Gas	Office Classroon	7%	10%
4	82,000	1	6%	Brick	Electric	Retail Store	18%	26%

TABLE 2.8 Comparative energy consumption statistics for Building 1 through 4 for a 30-day period.

	Energy Consumption	
Building	Btu/Day	Btu/Sq. Ft./Day
1	15.0×10^6	350
2	18.5×10^6	250
3	25.5×10^6	1100
4	--	--

systematically reduced the modelled consumption on weekends and holidays. The effectiveness of this adjustment was partially compromised by a meter reading schedule that recorded daily consumption for each building in midafternoon. Hence, consumption for late Sunday afternoon, when the cooling system was not operating, was averaged with the Monday morning pulldown load to give a less than precise representation of the actual, in this case, Monday consumption. The discrepancy in the quality of the model performance for Buildings 1 and 2 and the rather large overall errors for both reflect the inability of the GMDH to consistently describe energy consumption for cooling solely through the use of outdoor weather as input data. Indoor temperature data and more detailed operating schedule information would allow considerable improvement.

Building 3, a university office building, had a dual duct air conditioning system which ran continuously. This system operated by circulating and blending both warm and cold air to maintain building temperature. As is evident in Fig. 2.26, Building 3 showed little or no response to either ambient weather or variable use and, as shown in Table 2.8, was terribly inefficient.

A reference model approach to modelling Building 4, a large one-story retail store, was not at all successful and a time series adjustment was tried. This adjusted model, shown in Fig. 2.27, followed energy use much more closely. Apparently the time series model was able to pick up a pattern dictated by the number of occupants in the building and the heat gain was more sensitive to this variable than to the ambient weather conditions. The high single peak seen in Fig. 2.27 occurred on Labor Day.

The high percentage error values shown in Table 2.7 are largely a consequence of the very limited data set available for this evaluation and of the low signal-to-noise ratio discussed previously. The results confirm our proposed request for an expanded cooling season monitoring system during the forthcoming contract period.

3. ENERGY MODEL INPUT DATA

3.1 MINNEAPOLIS METEOROLOGICAL INPUT DATA

The importance of accurate weather data for obtaining proper model results has been demonstrated repeatedly in our past reports. In a large metropolis such as Minneapolis cross-town temperature gradients of 10°C and wind speed reductions of 50% have been observed. We have shown that wind and temperature differences of this magnitude can effect energy demand in individual locations by more than 20%.

Meteorological input to our energy consumption model includes spatially resolved distributions of bihourly temperature, wind speed and solar radiation values. To obtain these meteorological input data for our Minneapolis program and to further refine our understanding of regional urban climate, meteorological monitoring networks were operated in the Minneapolis area during the past two winter seasons. As described by Reiter et al. (1979), meteorological data were collected from December 1, 1977 through February 28, 1978 at 19 monitoring locations scattered throughout the Minneapolis-St. Paul region. A revised array of 14 monitoring stations, located so as to provide more detailed information about the metropolitan Minneapolis temperature field, was operated from January 13, 1979 to March 31, 1979. Figure 3.1 shows all station locations from which meteorological input data were obtained for modelling Minneapolis space heating energy consumption. Stations 21, 33, 34, 38, 40 and 44 were used for the weather monitoring programs during the aforementioned two winter seasons. Stations 53, 54, 56, 57, 59, 60, 61 and 62 were used for the 1979 program only and all others were associated with the 1977-78 program only. The solid light lines in Fig. 3.1 represent the boundaries of the census districts for Minneapolis which served as the basic units for our energy consumption computations. The topography of the area is also given in Fig. 3.1.

The meteorological parameters monitored at each of the stations operative in 1979 are listed in Table 3.1. Notable are the National Weather Service Station

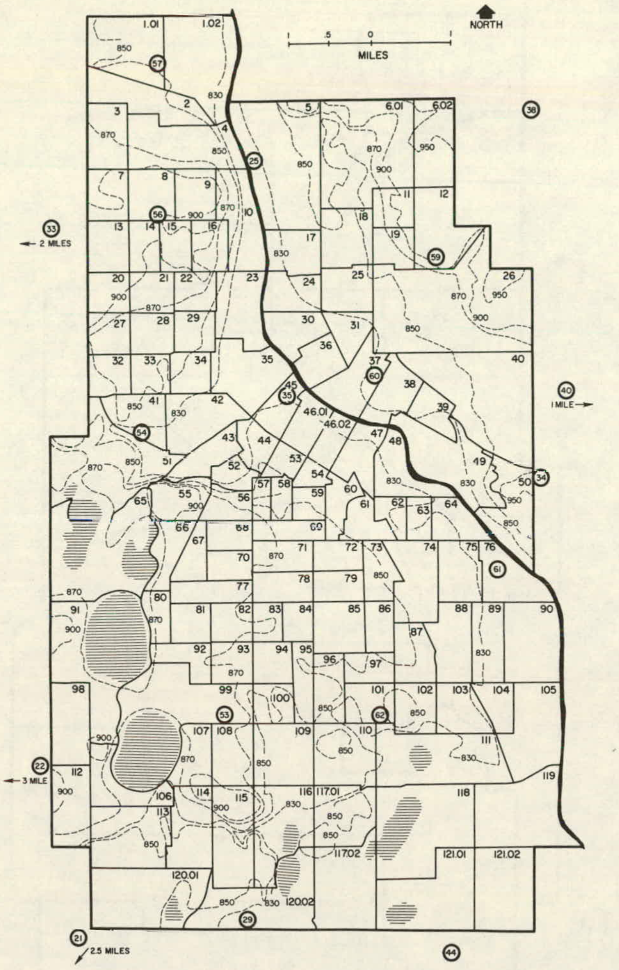

Fig. 3.1 Map of Minneapolis, Minnesota. The circled numbers represent the locations of meteorological monitoring stations. The 127 census districts within the city limits are also shown. Dashed topographic contour lines are labelled in feet (MSL).

TABLE 3.1 Parameters measured at 1979 Minneapolis monitoring stations.

Station Number	Parameters
21	T, WS, WD
33	T
34	T , WS, WD (three levels)
38	T,WS, WD
40	Solar Radiation
44	T,WS,WD, Cloud Cover, Precipitation
53	T, WS, WD
54	T
56	T
57	T, WS, WD
59	T
60	T, WS, WD
61	T
62	T

T is temperature
WS is wind speed
WD is wind direction

(44), the University of Minnesota, St. Paul campus (40), and the 152 meter KSTP Television Transmission Tower (34). Solar radiation data were provided by Dr. Donald Baker of the University of Minnesota. Wind speed, direction and air temperature at three tower levels were provided by the station personnel of KSTP.

Much of the monitoring equipment used in the program was supplied on loan by the National Center for Atmospheric Research and by the U.S. Forest Service. A shortage of equipment forced us to lease several items from commercial vendors. All equipment not already in place and operating independently from our program was calibrated on installation. Temperatures were recorded by sheltered mechanical thermographs at a uniform height of 1.5 meters. Wind speed and direction sensors were at elevations ranging from three to ten meters. The thermographs were routinely checked against calibration thermometers during the program by the network operators. To allow for better comparisons between individual instruments, all thermographs were carefully transported to a common site (Station 38) and operated side-by-side for three days at the end of the program. Instrument failures resulted in some lost data at nearly all stations, but only at Station 53 were losses so severe that the data sets could not be salvaged for use in our energy consumption modelling.

Data from the various monitors were reduced to hourly or bihourly values and corrected for calibration and other systematic errors specific to each instrument. Data provided by the National Weather Service, Mr. Bruce Watson and Dr. Donald Baker (Stations 44, 38 and 40, respectively), were assumed, on good authority, to be accurate. Examination of the data from the T.V. tower suggests some slight inaccuracies in the temperature data and means for correction are still being studied.

Since the various station data represent local meteorological conditions only, it was necessary to subdivide the area to be modelled for energy demand into tracts that could be associated with either data from one station or with interpolated values from two or more stations. Various urban areas were associated with data from a specific station or from a combination of stations by considering station location, topography and land use. The boundaries of the designated tracts for energy demand modelling and the stations supplying data to represent the meteorological conditions within each tract are presented in Figs. 3.2 and 3.3 for the 1977-78 and 1978-79 winter seasons, respectively. The input data sets employed for the 1979 energy demand calculations were derived from ten temperature and four wind speed stations. Eight temperature and three wind speed stations were used for the 1977-78 calculations. Solar radiation was assumed to be uniform throughout the area.

The requirement for complete sets of bihourly average values of wind speed, temperature and solar radiation for our energy consumption computations necessitated interpolation for periods of missing data caused by intermittent instrument failures. These supplemental data were generated by modifying the data collected at the National Weather Service Station (Station 44) to reflect the average observed differences between the National Weather Service and the specific monitor location for which data were needed. Initially, missing temperature data were interpolated through analyses of mean temperature difference between the National Weather Service station and other network stations. These differences were stratified into 12 daily time periods, four wind speed classes and three cloud cover classes. This procedure had

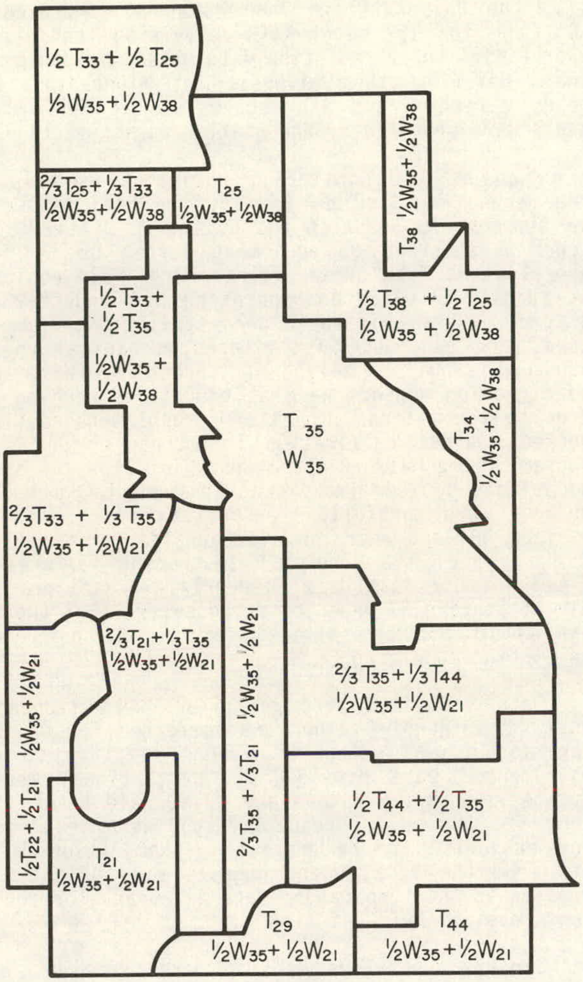

Fig. 3.2 Map of Minneapolis showing the combinations of wind speed and temperature monitoring stations used to represent conditions with-in specific areas of the city for 1977-78 energy consumption modelling.

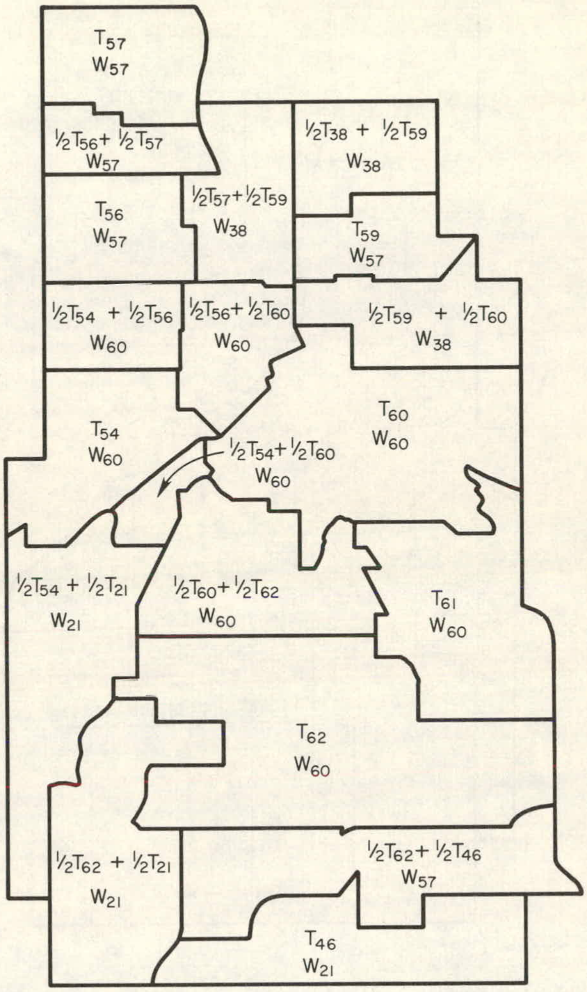

Fig. 3.3 Same as Fig. 3.2, but for the 1979 program.

been developed previously and used for simulating missing data in our Cheyenne, Wyoming program. The scheme worked adequately for the 1977-78 Minneapolis data for which only a minimal amount of data simulation was required.

Temperature data losses in the 1979 Minneapolis monitoring program were somewhat more substantial than in the 1977-78 season. Some stations missed nearly 30% of the possible measurements. Even though funding uncertainties delayed initiation of monitoring until well into January 1979, we hoped to model energy consumption for the entire three-month period of January 1 through March 31, 1979. Consequently, we needed to simulate as many as several weeks of intermittently missing data for some stations as well as the first 12 days of January for nearly all stations. For this task a revised simulation scheme was developed. The largest and most consistent temperature differences between stations were observed to be functions of time of day and wind speed. Because many of the 1979 monitors were in peripheral locations surrounding the core of the Minneapolis urban area, we anticipated that advected effects of urban heat sources would also be directionally dependent. A low frequency of clear, sunny days further suggested that we should accommodate wind direction rather than cloud cover in our simulation procedure. The limited size of the data set precluded simultaneous stratification by wind speed, wind direction and cloud cover; therefore, only speed and direction were used.

Ideally the temperature simulation procedure would employ mean data for the diurnal variation of the temperature difference between the National Weather Service and each station for all combinations of wind speed and direction. However, the 900 possible bihourly temperature observations taken at each station during our monitoring period were not sufficient to provide reliable estimates of the 288 mean difference values (12 bihourly x 8 direction x 3 speed) needed to accommodate all possible cases. An example of typical data used for simulating temperature at one station is shown in Table 3.2. Mean bihourly values for the temperature differences between Station 59 and the National Weather Service station are shown in the upper half of Table 3.2 fo three wind speed classes. Table 3.2 also shows mea temperature differences between these stations fo each of eight direction classes averaged over all hours and stratified by wind speed. The speed and direction stratifications are based on mean bihourly

TABLE 3.2 Mean temperature differences (°C) between Station 59 and the National Weather Service station, stratified by wind speed and time of day and by wind speed and direction.

	WIND SPEED		
TIME	< 2.5 m/s	2.5-7.5 m/s	> 7.5 m/s
0-2	0.6	0.2	-0.9
2-4	1.1	0.1	-0.9
4-6	1.3	-0.3	-0.8
6-8	0.6	0.0	-0.8
8-10	0.7	0.0	-0.2
10-12	1.5	0.4	-0.1
12-14	0.6	0.8	-0.1
14-16	0.3	0.8	-0.1
16-18	0.3	0.2	-0.6
18-20	0.2	-0.1	-0.4
20-22	0.7	-0.2	-0.4
22-24	0.2	0.0	-0.4
WIND DIRECTION			
NNE	0.7	-0.4	-1.2
ENE	0.8	-0.4	-0.6
ESE	0.9	0.4	-0.7
SSE	0.8	0.9	0.2
SSW	0.8	0.3	0.0
WSW	0.8	0.9	0.0
WNW	-0.2	-0.2	-0.3
NNW	-0.1	-0.6	-0.6
Mean	0.7	0.1	-0.4

wind data from the National Weather Service station. These two sets of mean temperature differences, one for time-of-day dependence and the other for wind direction dependence, contain comparable information because all temperature values from Station 59 were used for deriving both data sets. Therefore, both differences could not be applied simultaneously without some compensation for the fact that the two values contained some of the same information. To minimize this effect of twice compensating for overall mean differences, the temperature difference values shown for each wind direction in Table 3.2 were subsequently adjusted by removing the mean temperature difference for each wind speed class (last line in Table 3.2). Combinations of the appropriate corrections for time of day, wind speed and wind direction were then added to specific National Weather Service temperature values to generate individual station data points as needed.[1]

This temperature simulating procedure was tested by generating completely simulated data sets and comparing these artificial data with actually observed data. Results from one such test are shown in Fig. 3.4. Station 60 used in Fig. 3.4 proved to provide a particularly difficult test in that this thermograph location was rather closely bounded on three sides by two-story residential buildings but had uninterrupted exposure to the south-southwest. Excessive trapping of radiant energy on clear afternoons occasionally generated comparatively high temperature values at this station which could not be anticipated by our wind-direction weighted simulation procedure. The mean diurnal temperature cycle for the duration of the program at Station 60 was reproduced to within 0.3°C in the mean simulated data. However, some individual daily and bihourly simulated values deviated from corresponding actual values by more than 1.0°C and 3.0°C, respectively. The standard error of estimate in this test was 1.2°C for all bihourly data and 0.6°C for the 78 daily-mean values shown in Fig. 3.4. The standard error of estimation for all bihourly values in the time period with the poorest accuracy (1200-1400 CST) was 1.6°C, whereas the best period (2000-2200 CST) had a bihourly standard error of 0.9°C. The major portion of the variance occurred as too low simulated temperatures on sunny afternoons and as slightly too high simulated temperatures on cloudy days. All other station locations were either fairly well protected from similar effects of trapped direct sunlight or were in completely open areas.

Missing wind speed data were simulated through the application of simple regression equations relating wind speeds measured at the National Weather Service station to speeds at the other network stations. Correlation coefficients between the National Weather Service bihourly average wind speed values and those at the other stations ranged from 0.7 to 0.9. This synthesizing procedure for wind speed data was also used previously for generating supplemental data for Cheyenne, Wyoming (Reiter et al., 1979) and was quite adequate for this purpose.

A few hours of missing radiation data were filled with estimated values based on the National Weather Service cloud-cover information.

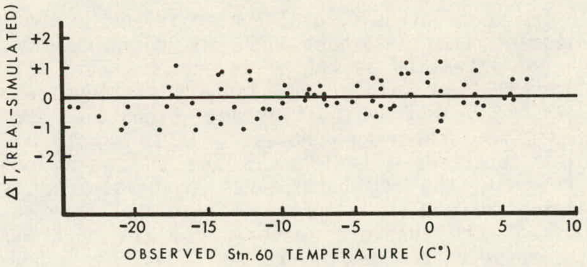

Fig. 3.4 Deviation of simulated daily mean temperatures of Station 60 from corresponding observed daily mean temperatures.

3.2 ANALYSIS OF THE 1979 MINNEAPOLIS WINTER METEOROLOGICAL DATA

The 1979 winter season in the Minneapolis area was abnormally cold and wet. The severity of the winter is evident from Fig. 3.5 which shows long-term monthly mean temperatures at the National Weather Service along with daily average temperatures for January 1 through March 31, 1979. Precipitation totaled 130 to 140% of the long-term monthly means, and snow cover approached or exceeded 50 cm throughout much of the area from mid-January to mid-March. Average wind speeds were near normal.

After finalizing the 1979 meteorological input data sets for our energy consumption modelling, we set about exploring the Minneapolis urban temperature

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[1] For example, with a wind speed of 2 m/s and wind direction of SSE a missing value at 6-8 AM for Station 59 would be:

$$T_{59} = T_{NWS} + 0.6 + (0.8 - 0.7)$$

Where 0.6 = the temperature difference for a wind speed < 2.5 m/s at 6-8 AM

0.8 = the temperature difference for a wind direction of SSE

0.7 = the mean temperature difference for all wind direction.

Values taken from Table 3.2

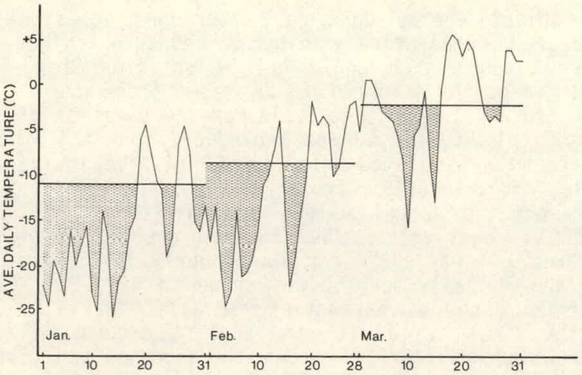

Fig. 3.5 Average daily temperatures at the Minneapolis National Weather Service station for January, February and March, 1979. The shaded areas represent negative departures from the long-term monthly means.

field in greater detail. Mean monthly temperatures for each of the 1979 network stations and comparative 1978 monthly mean temperatures at the four station locations common to both programs are listed in Table 3.3. The temperature field analysis shown in Fig. 3.6 represents the mean values for all temperature data from the 1979 monitoring program. The spatial positioning of the isotherms in Fig. 3.6 and in the other heat island analyses shown below incorporates some details of the temperature field identified in data collected at 1977-78 monitoring stations (Reiter et al., 1979) along with data taken in the 1979 program. The dashed elevation contour lines in these figures represent approximate 15-meter increments beginning at about 240 meters MSL near the Mississippi River at the southeastern corner of the city.

The mean intensity of the heat island in the 1979 monitoring area is about 2°C. We might define the index of intensity as the difference between Stations 33 and 61, the coldest and warmest stations respectively. Some extreme heat island intensities exceeding 7°C were observed. However, in 1979 both of the coolest stations (Stations 33 and 38) were located well within the region of suburban development surrounding metropolitan Minneapolis and therefore do not represent the absolute intensity of the heat island with respect to nearby rural locations. Several 1977-78 stations were located more than 25 km from downtown Minneapolis in genuinely rural areas west and north of the city. These rural stations occasionally recorded temperatures in excess of 10°C colder than simultaneous values in the urban center.

Figures 3.7, 3.8 and 3.9 demonstrate the effects of wind speed and direction on the urban temperature field. In Fig. 3.7 moderately strong north-northwesterly winds have largely eroded the heat island and displaced the warm center toward the southeast. The temperature distribution analyzed in Fig. 3.8 occurred under calm and rather stable conditions. The accumulation of cold air in low areas in Fig. 3.8 created cold zones within the heat island even though the topographic height differences are rather minimal. The data analyzed in Fig. 3.9, with the exception of those from the National Weather Service (Station 44), are from the pre-monitoring period of early January and are therefore totally simulated by the procedure described previously. Allowing for the more westerly wind direction represented in Fig. 3.9, the simulated temperature field compares favorably with the real data analyzed in Fig. 3.7.

A summary of the response of the Minneapolis heat island to wind direction and speed is shown in Fig. 3.10. The radial elements shown in this figure represent the average temperature difference between each station and Station 33 for each of eight-wind direction classes and two-wind speed classes. The wind speed stratification in this analysis was based on data taken at the top of the 152 meter tower (Station 34). The wind direction data were taken from the 10 meter tower at the National Weather Service station. The use of suburban Station 33 for reference temperature data in this analysis enhances the illustration

TABLE 3.3 Monthly averaged temperatures (°C) for stations in the Minneapolis area. Temperature in parentheses are comparative 1978 values.

Station No.	January 1979	February 1979	March 1979
21	-14.9 (-13.8)	-10.8 (-10.7)	-1.1
33	-16.5 (-14.8)	-12.8 (-11.6)	-2.6
38	-16.2 (-14.1)	-12.6 (-11.1)	-2.2
44	-15.4 (-14.2)	-11.5 (-10.8)	-1.3
54	-15.8	-11.2	-0.9
56	-15.4	-11.6	-1.3
57	-15.6	-11.2	-0.8
59	-15.3	-11.3	-1.2
60	-15.0	-10.9	-0.9
61	-14.3	-10.7	-0.4
62	-15.1	-11.1	-1.0

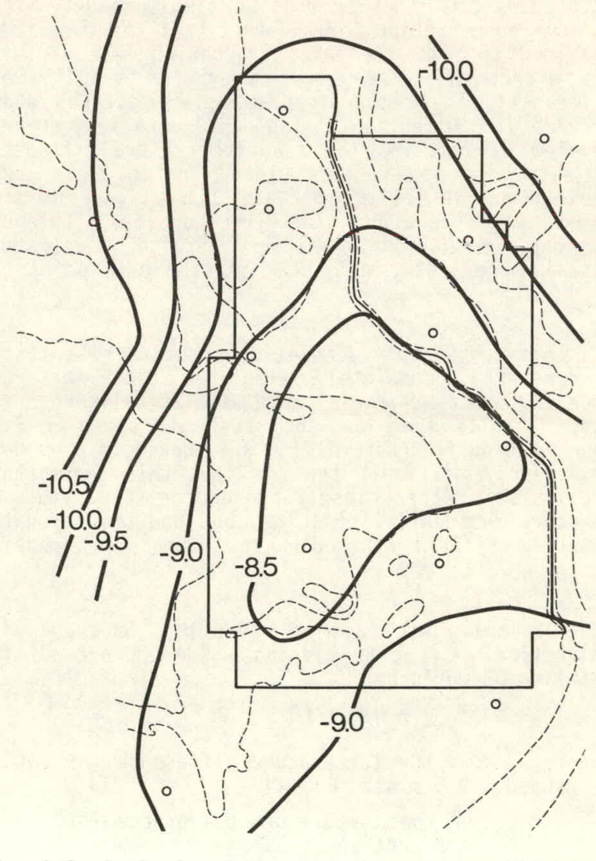

Fig. 3.6 Analysis of the mean temperature field (heat island) in the Minneapolis area for all data from January 1, 1979 through March 31, 1979. The circles represent temperature monitor locations.

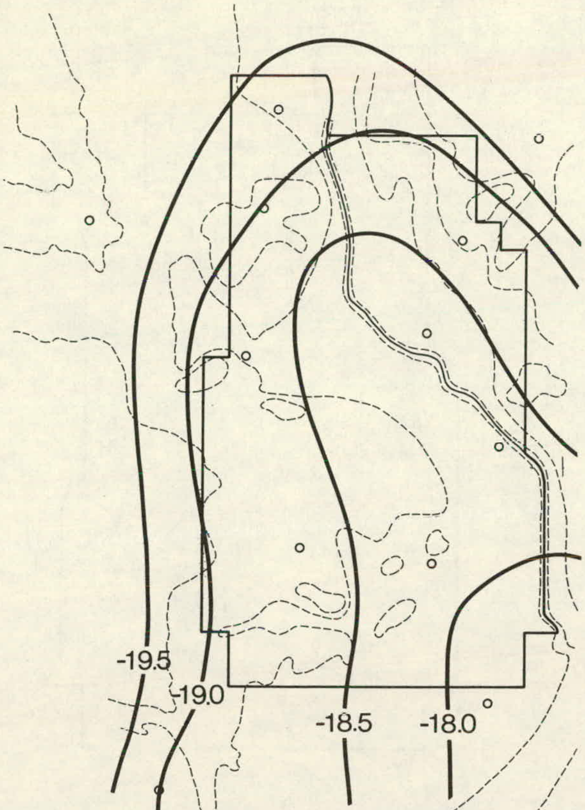

Fig. 3.7 Minneapolis heat island for 2000-2200 CST, January 13, 1979. During this two-hour time period, winds of the National Weather Service station (Station 44) were from the north-northwest (330°) at an average speed of 8.0 meters per second.

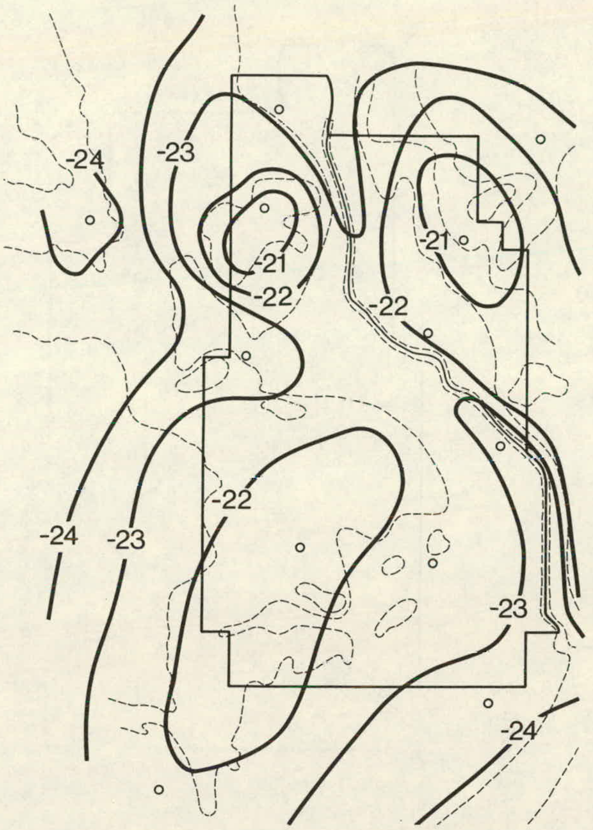

Fig. 3.8 Minneapolis heat island for 200-400 CST, January 25, 1979. During this time period skies were clear, and calm conditions were observed at all surface monitors. Winds at the top of the 152 meter tower (Station 34) averaged 2.0 meters per second from the northeast.

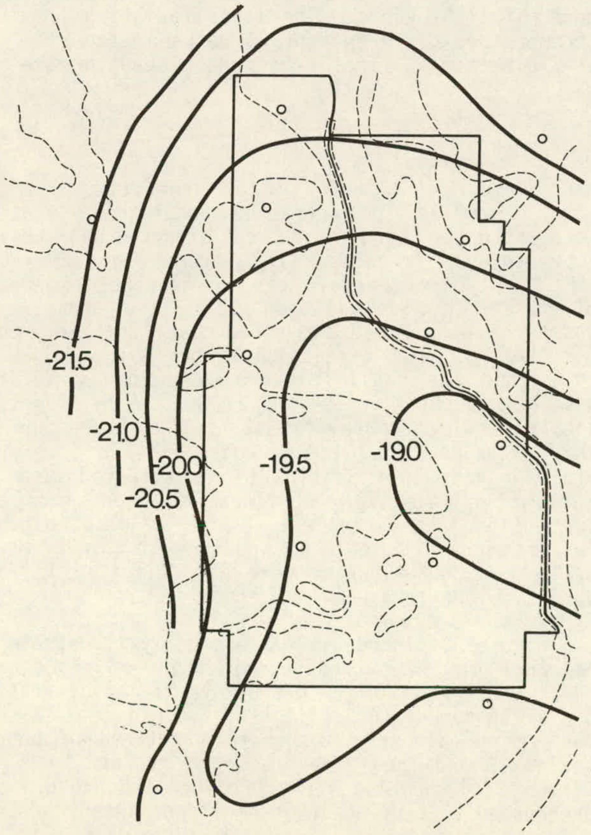

Fig. 3.9 Minneapolis heat island for 2000-2200 CST, January 9, 1979. With the exception of the National Weather Service station (Station 44) all data points for this analysis were simulated by the method described in the text. Winds at the National Weather Service station during this time period were from the west-northwest (280°) at 5.8 meters per second.

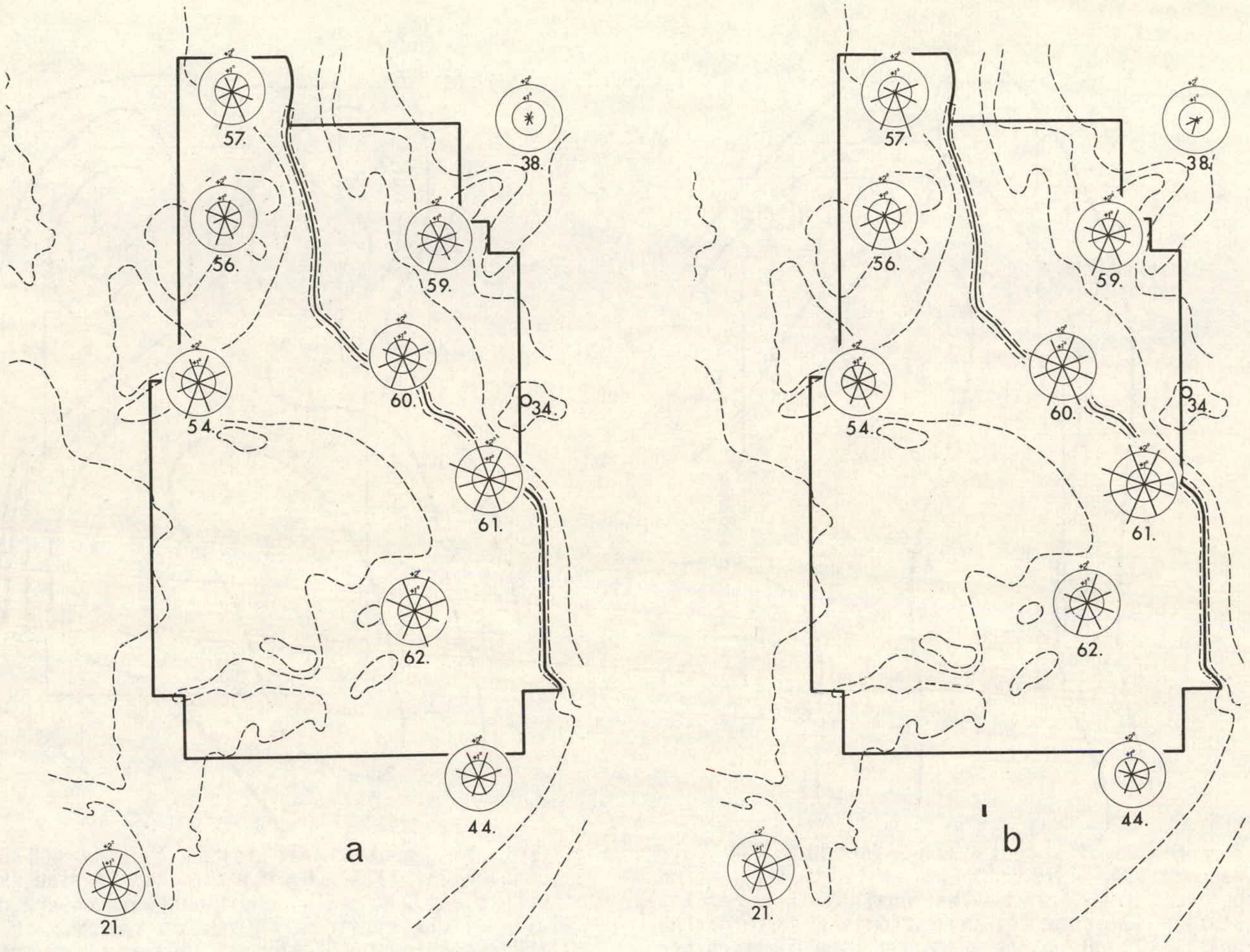

Fig. 3.10 Directional dependence of temperature differences between Station 33 and other 1979 network stations for (a) relatively strong winds, and (b) light winds. The lines radiating from the centers of the station plots represent mean temperature differences (°C) between each station and Station 33 associated with each of 8 wind directions. The large number beneath each plot is the station number.

of the warming effects of the city. Some apparent directional dependence in the contributions of anthropogenic heat is observed at most stations. Larger average positive urban-suburban temperature differences generally occur where air arriving at a station has crossed proportionally larger spans of urban development. Not shown in Fig. 3.10 are adjacent urban areas such as St. Paul and Bloomington which significantly effect temperature at Stations 61, 44 and 21. The results in Fig. 3.10 are surprisingly reasonable considering that no accommodations have been made either for spatial variations of wind direction or for substantial blocks of missing data at some stations. Advection of anthropogenic heat at Station 33 is also very probably subject to some directional bias which we have not accurately quantified at present. We anticipate that comparative directional temperature difference analyses between 1977-78 data for Station 33 and data taken at the presumably bias-free 1977-78 rural stations will clarify the nature and magnitude of directional influences at Station 33, and permit appropriate adjustments to be made to the information represented in Fig. 3.10.

The average temperature differences between Station 33 and Station 54 are noticeably greater during the moderate and high wind case in Fig. 3.10a than during light wind or calm conditions in Fig. 3.10b. This is in contrast to most other stations where stronger winds tend to erode urban-suburban temperature differences. This trend also appears in Table 3.4 where several sets of average temperature differences between station pairs are analyzed by classes of wind speed and cloud cover for early morning, daylight and evening time periods. Table 3.4 shows that the smallest average temperature differences between Stations 54 and 33, and hence disproportionately cold temperatures at Station 54, occur with clear skies and low wind speeds. This is consistent with the fact that Station 54 is situated near the bottom of a relatively confined low area where cold air would likely collect under calm conditions. Similar wind speed effects are seen in Fig. 3.10 for Stations 62 and 44 which were also situated in relatively low but less confined areas.

Figures 3.11 and 3.12 more clearly illustrate the influence of the extreme combinations of cloud cover and/or wind speed on the diurnal variation of station-to-station temperature differences. Figure 3.11 shows the average bihourly temperature difference between Station 33 and four other network stations. For each station we have also stratified the temperature differences by a low wind and a small percentage of cloud

TABLE 3.4 Mean temperature differences (°C) between station 33 and four other 1979 stations, stratified by cloud cover, time of day, and wind speed.

		Wind Speed (152 meter tower data)					
		WS < 7 m/s			WS > 7 m/s		
		(Time)			(Time)		
	Cloud Cover	0-800	8-1600	16-2400	0-800	8-1600	16-2400
Station 38	<.3	1.1	-0.8	0.3	0.5	-0.7	0.4
	.3-.7	1.2	0.0	-0.1	0.7	-0.6	1.0
	>.7	0.3	0.2	0.2	0.4	0.1	0.3
Station 54	<.3	0.3	0.2	0.8	2.1	0.9	1.6
	.3-.7	2.1	0.4	1.7	2.1	0.2	1.9
	>.7	1.7	1.2	1.8	1.8	1.4	1.9
Station 56	<.3	2.8	-0.4	1.8	1.5	0.1	1.3
	.3-.7	1.9	-1.0	2.1	1.8	0.3	2.4
	>.7	1.7	0.9	1.9	1.3	0.8	1.2
Station 61	<.3	3.4	1.8	3.8	2.3	2.0	2.7
	.3-.7	3.2	1.5	2.8	2.7	1.3	3.1
	>.7	2.2	1.7	2.1	2.1	1.8	2.1

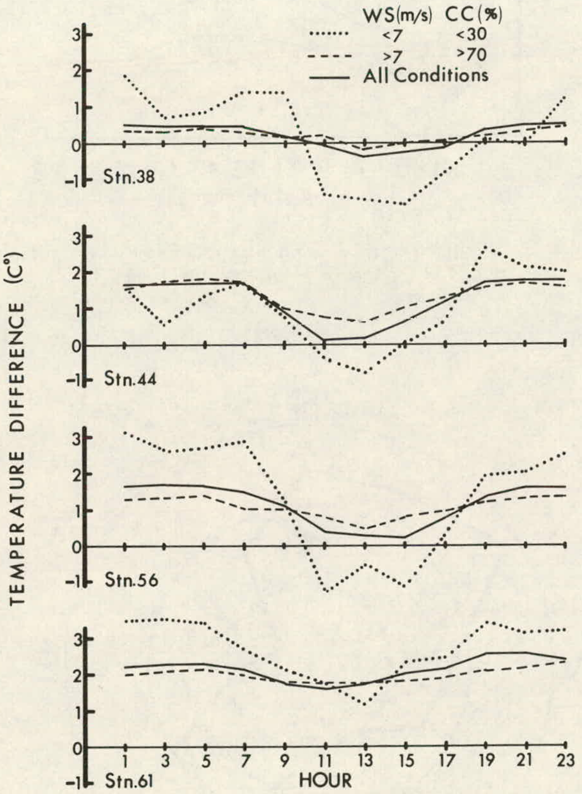

Fig. 3.11 Mean bihourly temperature differences between Station 33 and four other network stations stratified by wind speed (152 meter tower) and cloud cover (CC).

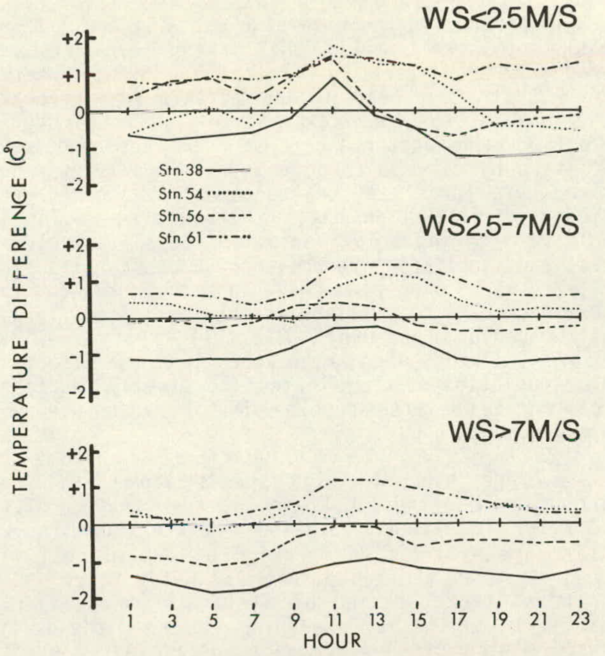

Fig. 3.12 Mean bihourly temperature differences between Station 44 and four other network stations for three wind speed classes. The wind speed stratification is based on Station 44 (10 meter tower) data.

cover condition and by a high wind and a large percentage of cloud cover condition. In Fig. 3.12 the mean bihourly temperature differences between Station 44 (National Weather Service) and four other network stations are compared for three wind speed classifications. The comparatively small departures of the mean urban-suburban temperature differences (Fig. 3.11) for strong winds and heavy cloud cover from the mean differences for all conditions is indicative of the prevalence of cloudiness and wind during the monitoring period. The displacement of the clear sky and light wind temperature differences from the values for all conditions again points to the effects of the approximate elevations of the station locations. Station 44 in Fig. 3.11 and Station 54 in Fig. 3.12 show the accumulation of cold air in the evening and early morning at these relatively low elevation stations. Station 56 and, to a limited degree, suburban Station 38 are examples of the reverse effect on higher ground. Station 61, though in a low-lying area, was apparently more influenced by diminished heat dissipation from this urban core location than by subsiding cold air under light wind conditions.

Conspicuous in Fig. 3.12 are the midday bulges in mean temperature differences rather than the consistent midday dips in Fig. 3.11. The midday bulges are the consequence of the relatively low temperature maxima at Station 44 and an overall smaller amplitude of the mean diurnal temperature cycle at this station. That the quasi-rural airport location of Station 44 is warmer than suburban Station 38 is a consequence of the generally down-wind position of Station 44 relative to the major areas of urban development. The smaller mean diurnal temperature range at Station 44 may be a result of better exposure to freely moving winds at its comparatively open airport location.

The trends in the data of Figs. 3.11 and 3.12 are consistent with similar analyses of urban climate found in the literature (Peterson, 1969). Whereas summertime urban heat island effects are generally attributable to the comparatively strong daytime retention and nocturnal release of absorbed solar radiation by city pavement and buildings, winter heat islands are largely a consequence of the concentrated release of combustion heat in urban areas. The low angle of incoming solar radiation, persistent cloudiness, and significant reduction of urban-rural surface differences by lingering heavy snow cover suggest that the Minneapolis heat island effect in 1979 was largely anthropogenic in nature. Nevertheless it is evident in Fig. 3.11 that when skies were clear the effects of solar radiation were sufficient to greatly reduce and occasionally reverse daytime urban-suburban temperature gradients.

Average bihourly wind speeds from five "near surface" monitoring locations and from the top of the 152 meter T.V. tower (Station 34) are shown in Fig. 3.13. The contrasting behavior of the diurnal wind speed cycle at the top of the 152 meter tower is the result of the deepening of a surface based layer of stable air in the early morning hours and the daytime upward mixing of slowly moving surface air. At Stations 44 and 21 wind sensor heights of 10 and 7 meters, respectively, experienced faster velocities than at other stations where the sensors were at heights of 2.5 to 3 meters, depending on snow depth. The mean wind speeds at Stations 38, 57 and 60 are generally in proportion to the degree to which the sensor locations were sheltered from the prevailing winds and should not be considered definitive representations of urban roughness effects.

Figure 3.14 illustrates the relative frequency of wind directions of the National Weather Service station (44) during the monitoring period. The principal components of moderate and strong winds were from the north, northwest and southeast. Light winds appeared to show a southerly and westerly preference. The inclination of the terrain surrounding the National Weather Service station would cause downslope subsidence flow to move from the northwest. The generally southerly flow observed under light wind conditions may be evidence of thermally induced convergence over the urban center.

The results shown here represent our initial exploration of the Minneapolis data sets. It is assumed that the data presented above reveal the interaction of regional weather with an array of differing surface cover and heat-flux related parameters within a radius of undetermined extent surrounding the individual stations. In our continuing analyses we are looking closely at more aspects of the station-to-station temperature differences with additional meteorological stratifications including snow cover and atmospheric stability.

The effects of heavy snow cover on the heat island phenomenon are of particular interest. We obtained only three weeks of snow-free heat island data in nearly 6 months of monitoring in Minneapolis. However, during the 81 days of our 1976-77 Greeley, Colorado monitoring program a total of only 7 cm of snowfall occurred during December, January and February. We are presently operating again the same Greeley monitoring network as before. Effects of the record snowfall of the 1979-80 winter in Greeley should provide us with very useful contrasting data for separating and quantifying solar surface heating effects and urban combustion heat input. This information, coupled with detailed data on surface cover

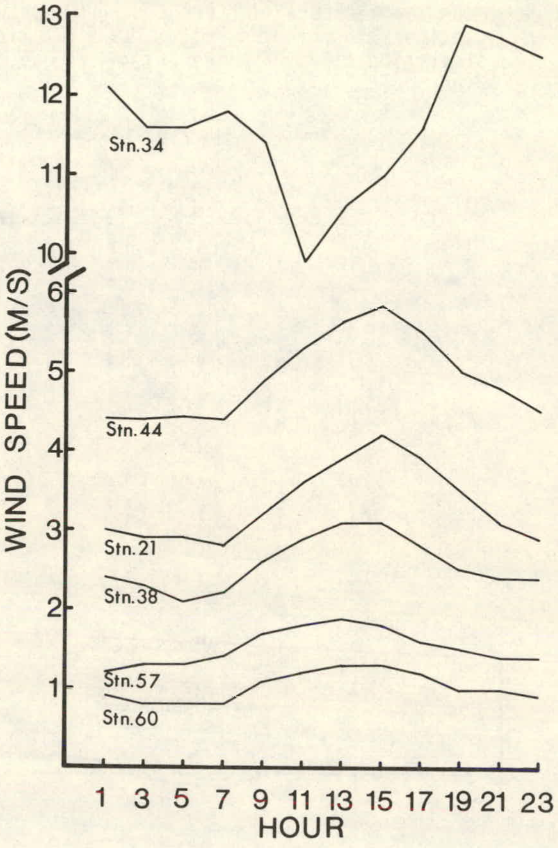

Fig. 3.13 Mean bihourly wind speeds from five network stations for January 1 to March 31, 1979.

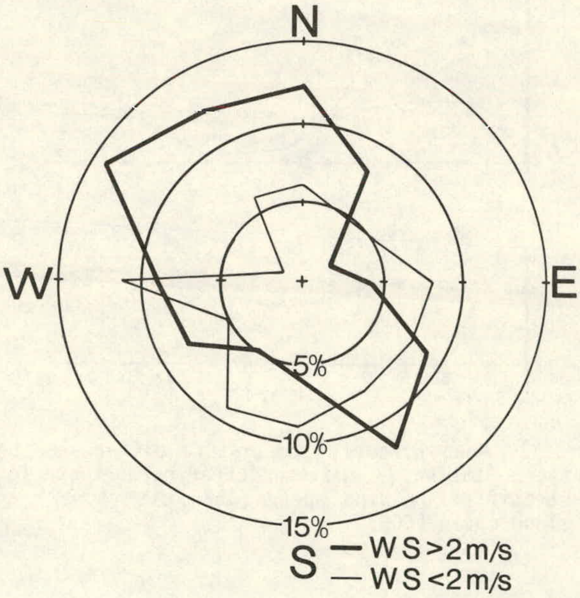

Fig. 3.14 Percent frequency of occurrence of wind directions at Station 44 for winds greater than and less than 2 m/s. Frequency values for each speed class are normalized to 100%. Actual distribution of speeds for all data was 92% greater than 2 m/s and 8% less than 2 m/s.

from aerial photographs of Minneapolis and Greeley, should refine our understanding of factors governing urban heat island formation and allow better interpretation of widely spaced data points such as those used in Figs. 3.11 and 3.12. The next step will involve the development of qualitative relationships between solar and anthropogenic heat input parameters and the observed weather dependent urban temperature distributions. The generation and refinement of the required heat storage and transfer equations will be a straightforward application of the same GMDH techniques used to parameterize heat loss from the array of building types included in our energy consumption model library (Reiter et al., 1978). These heat source relations will then be merged into an advective boundary layer dispersion model for simulating urban temperature distributions. Our large and diversified meteorological and energy consumption data sets will provide the means for calibrating, testing, and verifying our model's ability to simulate time-varying urban temperature and wind fields. Success in this area will enable us to model energy consumption in other urban areas with a minimum of site specific meteorological monitoring.

3.3 MINNEAPOLIS BUILDING CENSUS

One of the major inputs into our physical model for space heating energy consumption is a building census of the area to be simulated. In the past we have had to rely on written records and actual personal observations (in Greeley and Cheyenne) of building characteristics to composite such a census. This has been a hinderence to the wide-spread application of our model. In Minneapolis the computerization of the city's records has made it possible for us to apply our physical model to an area encompassing more than 100,000 structures. It is through the acquistion of the city's assessor's files that we have been able to accumulate a wealth of information on the structural characteristics of all the buildings located within the city limits, which define our simulation region. Had this data set been in a more complete form, it could have been quickly manipulated to a format readily used as input into our physical model. Unfortunately, as reported by Reiter et al., 1979, only 13% of the total number of structures had any building use information (i.e. single family dwelling, office, church, etc.) recorded in this file. Since the physical model is based on representative structural and use pattern characteristics for each building type (this refers to our "typical building" approach), the building type information is necessary for the successful application of the model.

It was, therefore, necessary to complete this data set as a first step in its manipulation into a useable form. Based upon our experience in Greeley and Cheyenne, we judged that the easiest methodology would be to first isolate as many nonresidential buildings as possible (7 to 8% of the total building count in Greeley and Cheyenne) and then use a sizing scheme to identify single family dwellings. Any building still not identified as to its use is assigned a function based upon the average statistics which can then be generated.

To identify the nonresidential buildings, we used the Minneapolis Yellow Pages telephone directory to locate the addresses of buildings with specific use patterns. Approximately 4500 structures were thus identified using this methodology. They were consequently cross-referenced by addresses and entered into our building survey. We also received assistance from the Minneapolis public school system which provided us with structural information concerning all of the public schools within the city limits.

In addition to the delineation of building types, it is necessary to distinguish the interruptible customers who may be curtailed by the utility company. Such identification is done for the express purpose of model validation. The scheduling of these curtailments is very complicated (frequently times the energy supplied is for purely processing purposes). Because our true concern was in model validation of space heating requirements, we felt that the best strategy would be to simply eliminate these buildings occupied by interruptible customers from our survey. Excluded from our computations also was a group of 20 downtown buildings which use a central heating system not fueled by the local gas-supplying utility company. We could then use the "firm" natural gas consumption rates (as given by the local utility company) to validate model results. A "firm" customer is one that is guaranteed service during all weather situations. Fortunately, the utility company could also supply us with a listing of the addresses of all of their interruptible customers within the city limits. This list consisted of about 1200 buildings to be removed from our census file.

The final step in data preparation was to interpolate for all other missing data and then put everything in a format which could be readily used by our physical model. After dividing the city into 127 areas as shown in Fig. 3.1, corresponding to the existing U.S. Bureau of Census tracts, all missing data were substituted by using the average value of the remaining buildings of that type in the census area under consideration. For example, if the square footage of a single family dwelling was missing, then the average square footage of all remaining single family dwellings in that section was substituted for the missing value. Then, as in Greeley and Cheyenne, the average structural characteristics for each of the 43 building types in each of our three building-age categories (pre-1940, 1940-1970 and post-1970) were calculated for each of the 127 sections.

The final building census contained 105,722 buildings. An over-all picture of the size, the total gross square footage, and distribution in percent of total count, for these buildings in Minneapolis is given in Table 3.5. Also included are some model results showing the amount (in percent) of natural gas consumed for each building type during the month of January 1978. For comparison purposes, similar statistics are given for the cities of Greeley, Colorado and Cheyenne, Wyoming. Surprisingly, Minneapolis contains the largest percentage of residential structures among the three communities, with single family dwellings being by far the most dominant. The absence of mobile homes is also a notable feature which distinguishes the residential make-up of the city of Minneapolis from the other two smaller cities. Even though the count distribution of the nonresidential structures is similar in all three communities, the average square footage of these buildings is more than twice as large in the metropolitan area of Minneapolis. This difference in size accounts for the comparatively larger percentage of natural gas consumed by the nonresidential structures in Minneapolis.

TABLE 3.5 Summary of building data and gas consumption by building type for Minneapolis, Greeley and Cheyenne.

M = Minneapolis (Jan. 1978)
G = Greeley (Dec. 1975)
C = Cheyenne (Jan. 1977)

Building Type	Average Size (Sq. Ft.)			% of Total Building Count			% of Gas Consumed		
	M	G	C	M	G	C	M	G	C
Single Family									
pre-1940	1397	1157	1196	70.1	22.0	19.1	-	18.63	-
1940-1970	1190	1252	1097	21.0	39.0	50.0	-	20.25	-
post-1970	1277	1666	1506	.8	14.6	8.9	-	6.93	
							42.71	45.81	44.21
Duplex	2104	1616	2549	1.3	1.2	1.9	.92	.88	2.45
Triplex	2654	3219	1789	.02	.06	.23	.02	.06	.15
Fourplex	18077	1825	5262	.01	.10	.10	.03	.17	.24
Sixplex	-	1900	7530	-	.02	>.01	-	.02	.02
Mobile Home	-	730	821	-	11.4	11.5	-	3.67	4.83
Apartments	15818	5552	7262	1.0	3.3	1.2	3.98	5.67	3.86
Total Residential	1514.	1391.	1239.	94.3	91.7	93.0	47.7	56.3	55.8
Business Sales	12236	5847	5346	2.4	3.5	1.6	17.69	16.93	8.14
Business Service	16681	3431	5237	.05	.21	.14	.44	.50	.65
Laundry	-	5106	4336	-	.13	.08	-	.45	.28
Bank	78492	10346	13296	.04	.15	.04	.80	.89	.43
Church	14175	7264	5624	.18	.39	.48	.78	2.45	2.11
Nursing Home	10569	11137	33970	.03	.17	.02	.22	1.27	.43
School (Elem. & High)	68083	28043	49707	.12	.26	.22	2.25	1.95	3.98
School (Colleges)	17577	9836	18725	.03	.11	.09	.30	.65	1.05
Government Buildings	119642	15291	12191	.11	.15	.43	4.05	1.64	2.70
Cafes & Restaurants	8500	3469	4830	.50	.38	.25	2.62	.94	.95
Library	13466	8000	15638	.01	.01	.02	.06	.03	.19
Bowling, Pool Halls	13746	7855	14933	.01	.03	.03	.07	.14	.36
Fire Dept.	-	6273	4595	-	.02	.02	-	.08	.10
Grocery	12552	12310	13309	.02	.11	.09	.17	.90	.98
Office	47821	6992	6705	.82	.20	1.00	10.64	.95	6.64
Community Building	36136	8902	6205	.03	.04	.05	.25	.23	.13
Bars	-	2226	4976	-	.08	.03	-	.17	.16
Theaters	11059	7644	16348	.01	.02	.02	.07	.09	.47
Private Buildings	15734	10276	7223	.07	.10	.04	.68	.63	.32
Department Stores	78461	22000	21362	.06	.01	.03	2.61	.10	.53
Malls	-	5325	-	-	.45	-	-	1.20	-
Motels, Hotels	47900	13620	6414	.02	.14	.55	.30	1.13	1.74
Bakery	18904	2097	1344	.02	.02	.01	.19	.04	.01
Ice Cream Store	-	1097	1678	-	.02	.03	-	.02	.03
Greenhouse	-	7240	2485	-	.02	.03	-	.19	.04
Hospital	8386	69555	34023	.04	.03	.09	.20	1.08	2.34
Univ. Northern Colo.	-	44268	-	-	.34	-	-	2.65	-
Museum	4002	-	-	.01	-	-	.02	-	-
Sauna	7284	-	-	.01	-	-	.01	-	-
Total Commercial & Public	24015	9353	9283	4.6	7.1	5.4	44.4	37.3	34.8
Auto Repairs	5875	4598	7876	.18	.19	.08	.65	.68	.53
Auto Sales	3008	5698	7868	.04	.18	.06	.08	.77	.40
Machine Shop	11471	3760	29090	.01	.01	.02	.06	.07	.52
Warehouse	26338	14745	8124	.13	.24	.65	1.93	2.44	5.29
Gas Station	1963	2185	1588	.09	.43	.44	.12	.72	.58
Clothes Prod.	-	24000	-	-	.01	-	-	.10	-
Distributing Co.	7000	13500	18520	<.01	.01	.01	.01	.13	.07
Bottling Co.	-	15200	-	-	.01	-	-	.13	-
Transportation Station	49600	6000	10608	<.01	.01	.02	.05	.03	.24
Steel & Metal Co.	-	3200	3660	-	.01	.01	-	.01	.02
Grain Storage	9600	40740	-	<.01	.01	-	.01	.34	-
General Storage	28726	3683	1713	.06	.04	.07	.95	.09	.09
Garage	21199	7610	6568	.14	.08	.14	1.63	.50	.93
Stockyard	-	7500	-	-	.01	-	-	.03	-
Manufacturing Co.	9993	18125	17121	.36	.01	.07	2.15	.29	.75
Industrial Laundry	12737	2880	2014	.04	.01	.02	.27	.01	.04
Creamery	-	10000	-	-	.01	-	-	.05	-
Asphalt	1426	3000	1435	.01	.01	.02	.01	.02	.02
Refinery	2533	-	-	<.01	-	-	>.01	-	-
Generating Plant	7000	-	-	<.01	-	-	<.01	-	-
Total Industrial	12976	6851	6527	1.1	1.3	1.6	7.9	6.4	9.5

3.4 ENERGY CONSUMPTION DATA FOR MINNEAPOLIS

To validate our modelling effort in metropolitan Minneapolis we were extremely fortunate to have the cooperation of the Minnesota Gas Company. This company is the major local supplier of natural gas to Minneapolis and the surrounding areas. From information attained by the building census and as reported by Reiter et al., 1979, we found no single family dwellings with electric heating units within the city limits. We are, therefore, fairly confident in using natural gas as the sole fuel in validating our physical model for space heating.

One of the problems we were facing, as stated in our 1978 proposal, was the lack of daily disaggregated consumption figures for the city of Minneapolis. Daily values were only available only for a larger area which included some of the surrounding communities, for which readily accessible building data were not available. Since our building census was confined to the area within the city limits, we needed natural gas consumption corresponding to this same area to accurately validate our modelling results. To overcome this inadequacy in the available data, we used monthly totals of the city's consumption (which were measured by the utility company) and calculated a ratio between these and the total area-wide monthly values (which were obtainable from a daily data basis). This ratio was then used as a constant correction factor to obtain daily values of the city's consumption. We computed this ratio for each month of 1976 and found it to vary between 0.404 and 0.448. However, if we only considered the winter months of January, February, March, November and December, the range of fluctuations of this ratio decreases to between 0.438 and 0.448 and had an average value of 0.442. We therefore modified the daily "firm" natural gas sendout (as given to us by the Minnesota Gas Company) by a factor of 0.44 to use as the "observed" daily natural gas consumption for the city of Minneapolis. The rational for using "firm" usage only was given in Section 3.3.

3.5 PARAMETERIZATION OF HOUSING DATA

For the past several years (Reiter et al., 1978 and 1979) we have been expending a moderate effort in developing a parameterization scheme to utilize readily available economic data, such as per capita income, as indicators of structural building information, such as types and size distributions of dwellings. Although we had found some encouraging correlations for the Greeley and Cheyenne data sets, the inclusion of the Minneapolis data showed considerable deviations from the past statistics. This prompted a re-examination of our strategy, giving rise to some serious doubt as to its feasibility and its final applicability.

A comparison of the residential building makeup (Table 3.5) of the three modelled communities quickly leads one to the realization of the great diversity between rural (Greeley and Cheyenne) and metropolitan (Minneapolis) communities. These differences would probably be even greater if we had considered an Eastern metropolis where apartment-type dwellings are a more prominent feature. The prevalence of pre-1940 single family dwellings can also be considered a distinctive feature of Minneapolis housing. Factors such as these would not be revealed in a parameterization scheme, and thus the results from such a scheme would be quite ambiguous when used as input into our physical model.

In our latest proposal we have recommended a totally different approach to the problem of modelling large areas without having to create a detailed building census of that area. This new approach would make use of the statistical reference model which uses only past observations of energy consumption and weather as input. Although this modelling technique has not been tested for large areas, it has worked extremely well in the rural communities of Greeley and Cheyenne and in the metropolitan area of Minneapolis. New buildings added to the community could then be entered through a physical model, thus providing us with a "hybrid" modelling approach. We are quite optimistic that this technique will be a more feasible methodology than an economic parameterization scheme in the modelling of large areas.

4. THE DECISION TO CONSERVE: INSULATION AS A TEST CASE

4.1 INTRODUCTION

Any forecast of space heating requirements is comprised of two parts: a calculation of the heat losses experienced in different structures over a range of environments, and a forecast of the likely changes to these structures as price conditions and public policy unfold. The former of these tasks is the subject of Chapters 1 through 3. The study reported here was designed to shed light on the latter component of the problem. It was felt that too little was known about who was attempting to conserve through the use of insulation, and why. All too often it is presumed that economics is the primary motivating force in conservation. The issue of dollars and cents may indeed prove to be important over the long run; however it appears that a sizable number of homeowners have not made full use of the conservation options open to them, though the economics of many of these alternatives appear to be quite favorable. This may be due to lack of information, the feeling that the problem is not yet serious enough to warrant attention, or simply that family income is insufficient to mount a full-scale conservation effort.

A review of literature revealed an amazing lack of attention to these considerations. Very little could be found to broaden understanding about how people adjust to escalating energy prices. Most of what was uncovered followed the traditional line of inquiry, i.e., estimating the short- and long-run demand for various energy products. Without question, the efforts yield valuable insights, but they do not provide much guidance as to how policy can accelerate the conservation effort. This study was initiated as a result of these considerations. Because of resource limitations, it should be viewed as a pilot effort. Even so, the results are provocative, yet credible.

4.2 DESIGN OF THE STUDY

The design of the study from the very outset was tied to the idea that traditional approaches to demand estimation did not adequately account for the rather modest efforts toward conservation. It was puzzling to observe this relatively mild interest in saving energy, in spite of an acceleration in price, amounting to an annual rate in excess of 13 percent. Was it simply that the return on a dollar invested was less than could be earned elsewhere? Or, was it that households could not obtain the right type of information to make reasonable choices? Could it be that a sizable portion of the population believes that escalating price is not a long-term phenomenon, but a short-term attempt by oil companies to extract extraordinary levels of profit? Could it be that households believe that the problem is not their responsibility? There is no scarcity of anecdotal evidence surrounding each of these possibilities. However, a perusal of literature reveals very little in the way of sound scientific inquiry to test such hunches.

The purpose of this study was to do just that. A framework was developed to model the decision process. Both, households which have purchased insulation and those which have not were surveyed to determine the factors which led to the decision. Natural gas consumption records were obtained from the Public Service Company of Colorado. These were used to calculate the effectiveness of insulation in reducing energy requirements. The conclusions that were drawn from the data were related to the model of choice and several potential policy options discussed.

4.2.1 Model of Choice

Theories of choice-making are nearly as abundant as the variety of researchers who have attempted to unravel the mysteries of the subject. The models which have been developed thus far range from the naive yet precise economists' version to the complex and fuzzy frameworks offered by the discipline of social psychology. The economic models of choice presume that individuals are adequately informed about events which are significant to their lives. If they are ignorant, it must be that they chose to remain so. Given these presuppositions, the individual simply weighs the benefits and costs of undertaking alternative courses of action and elects that option which maximizes his or her net benefit. The social psychologists counter with their own bevy of theories which thrust beliefs, attitudes, and values to the forefront of the problem. They contend that choices may indeed reflect the economic forces of benefit and cost but such influences are shaped by what an individual believes. That is, the final selection turns on the subjective interpretation of the likelihood of various events occurring and the preceived results of various protective measures. Therefore, the action chosen to deal with a threatening situation (escalating energy prices) will be guided by the information the individual possesses. If the information is faulty, so will the choice be faulty. It is, of course, possible that the decision-maker possesses all the relevant information yet believes that the most economically beneficial course of action deviates from the norms of the community. For example, a person may be unwilling to construct an energy-efficient home if the architectural design differs substantially from that of his neighbors.

Economists often overlook the fact that choices can only be made if the decision-maker believes that a problem is begging resolution. Given that all of us are entitled to, at most, 18 waking hours each day and that much of that is absorbed by the routine tasks of daily life, this leaves little time left to ponder solutions to tens of thousands of other problems emerging in our community and nation. As a result, problems must compete with each other for our limited span of attention. Those that persist and pass a threshold of our awareness will then be evaluated. Those that do not will simply remain on an invisible agenda.

If the economists were right in their understanding of decision making, then deaths on the highway would command as much attention in the news media as major aircraft accidents. Flood plain residents would be willing to accept the 90 percent subsidy offered by the federal government for purchase of flood insurance. Business cycles would be easier to predict. In short, human behavior would be reasonable and, therefore, more amenable to analysis with the tools of supply and demand. Since no illustrative examples cited above lend much credence to the economic view of the world, the approach offered in this study blends the rational aspects of choice-making with the acknowledged limitations of individuals to accurately perceive problems and events. The result is a model which has been referred to as "Bounded Rationality".[1] The term captures the basic elements of theory; that is, man is basically reasonable, but is subject to a series of constraints, some of which are of his own making and some of which are imposed upon him by the community.

The model used to analyze the conservation issue embodies the consideration highlighted above. Figure 4.1 shows the choice process in schematic form. The first step is to determine whether the decision-maker is aware of the problem. Is energy conservation on his or her agenda of problems needing attention? If not, then one could be safe in assuming that no action had or is being taken. If a problem is perceived but no socially or economically feasible alternative is envisioned then once again the decision-maker can't be expected to be actively engaged in conservation. Similarly, no efforts would be expected if it was thought that in spite of feasible alternatives, it wasn't his or her responsibility. For example, if high energy prices were perceived to be a product of monopoly power in the oil refining and distribution business, then the individual may wish for the government to intervene on his or her behalf and enforce antitrust legislation. If such sentiment was not strong, then one could expect that the chronic escalation in fuel prices would stir the homeowner to seek out additional information concerning the options. If the information received is conflicting, complex, or simply not in terms that can be easily understood, then the decision-maker may well opt to stand pat until a trustworthy appraisal of the situation is at hand. Lastly, if the information received is deemed credible, and once the information is digested, one can anticipate the selection of a feasible alternative. The choice at this stage of the process will be shaped by the economics of the various alternatives.

Here, too, the factors which enter into the picture are shaped by the availability of information. Ideally, each alternative would be evaluated in terms of net benefits. That is, the decision-maker would compare the cost of pursuing a course of action with the potential savings. Equation (4.1) summarizes the major elements of the decision.

$$NPV = \int_0^T S \cdot [P_0 e^{rt}/e^{it}]dt - C_0(1 - TC) \qquad (4.1)$$

where: NPV is net present value,

S is annual reduction in the rate of use,

P_0 is the current price of natural gas,

e^{rt} is the growth factor for natural gas prices,

e^{it} is the discount factor,

C_0 is the cost of the energy conservation device,

TC is the tax credit which enables the homeowner to subtract a percentage of investment from his or her tax liability,

T is the payback period.

The results given by Equ. (4.1) would provide reasonable guidance to the decision-maker. It is unlikely that many prospective buyers would pencil out the net benefits precisely as shown above. The growth in prices, r, may be ignored or an estimate of the potential savings may be unavailable. In such instances, the perceived benefits may be substantially different from that which eventually materializes.

The modest level of funding for our present research effort limited testing to only the major components of the model just sketched. Two groups of families were established, those that had insulated in the last five years and those that had not. Each family was asked a series of questions which indicated the point along the decision tree where adopters and nonadopters parted company. Was it in recognition of the problem (Step 1) or further down the tree, selecting from among the feasible options? In addition to these attitudinal data the survey yielded insights into the perceived economics of conservation, the gas consumption pattern for each household, and the extent to which measures other than insulation had been adopted.

4.2.2 Data Collection

In the early stages of the project it was anticipated that the Public Service Company of Colorado would make available names of those who had elected to participate in their retrofit program. These names would have yielded a population from which a sample of insulators could be drawn. As is often the case in research, what appeared to be feasible early in the project evolved into a formidable obstacle. No names could be released. At that point, the design was modified to obtain the needed information from an established, local insulating firm. These billing receipts became a valuable resource. A sample of adopters was drawn for several areas of the city. The areas were selected so as to minimize travel distances but, more important, they were thought to be representative of a cross section of the city's residents. In exercising this strategy we were able to normalize for the size and type of home and income level. A sample was taken from each section of the city which could be considered homogenous in income and architectural style. This left differences in personality and attitude as the basic factors which could have separated adopters from nonadopters.

The questions asked of the two groups are provided in Appendix 4A. The three-page questionnaire was developed based on the model of choice described earlier. It contains basic socioeconomic questions along with inquiries to determine how families interpreted the severity of the problem and the economics of conservation.

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[1] The term was coined by Herbert Simon, a Nobel Laureat, who has spearheaded the attack on those in the economics profession who steadfastly adhere to the image of economic man.

4.3 SUMMARY OF RESEARCH FINDINGS

With nearly 7,000 pieces of information in hand, it is easy to lose focus. The possible tests that could have been performed became nearly endless. In looking back to the framework developed above, a clear set of tasks emerged. First, and most important, the distinguishing characteristics of adopters had to be isolated. To do so, the responses of both groups to the opinion questionnaire were compared. The profile of a typical adopter was then related to the sequential choice model displayed in Fig. 4.1. A similar approach was taken for the nonadopters. A glance at the differences yields a clear picture, one rich in insights for those engaged in the formulation of policy. Second, the effectiveness of insulation was estimated for both individual families and across the entire sample. Again, the findings are provocative; they point to several policy changes which, if implemented, could enhance the pace of conservation.

Attitudes

Purchasers of insulation tend to favor solar energy as an alternative to oil, gas, and electricity (see Table 4.1 for the detailed breakdown of the results). They also tend to be more trustful of experts, oriented toward conservation (recycling), and believe that the energy shortage can be solved with new and better technologies. These findings should not stir too much in the way of debate. However, the data also point to a few surprising conclusions. Nonadopters do not differ from insulators on the following points. They both:

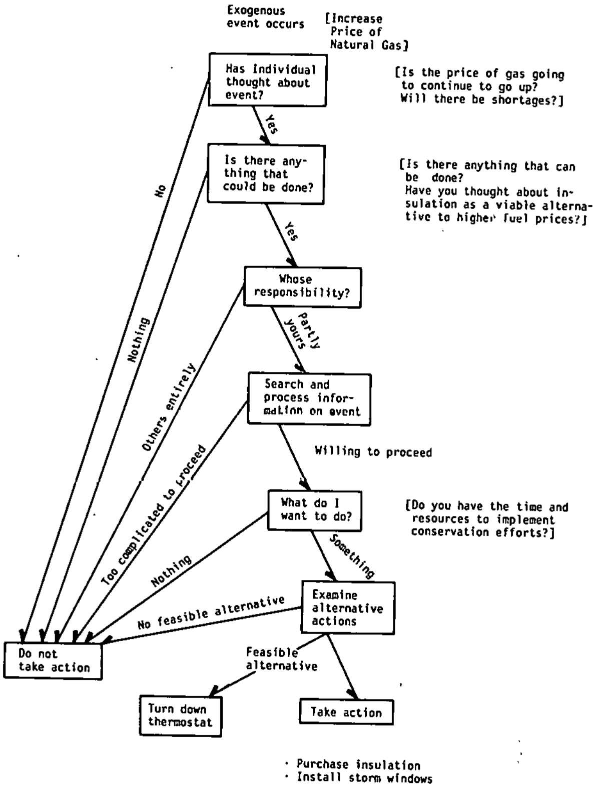
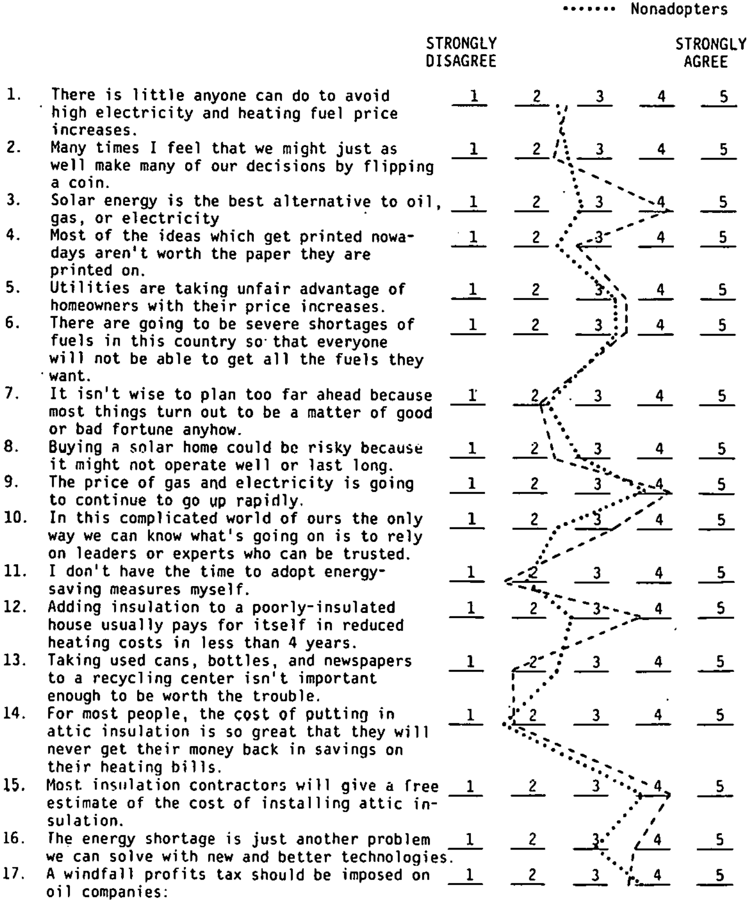


Fig. 4.1 Threshold model of decision making (adapted from Kunreuther et al., 1978).

TABLE 4.1 Summary of Attitudes
Adopters vs. Nonadopters



1. There is little anyone can do to avoid high electricity and heating fuel price increases.
2. Many times I feel that we might just as well make many of our decisions by flipping a coin.
3. Solar energy is the best alternative to oil, gas, or electricity
4. Most of the ideas which get printed nowadays aren't worth the paper they are printed on.
5. Utilities are taking unfair advantage of homeowners with their price increases.
6. There are going to be severe shortages of fuels in this country so that everyone will not be able to get all the fuels they want.
7. It isn't wise to plan too far ahead because most things turn out to be a matter of good or bad fortune anyhow.
8. Buying a solar home could be risky because it might not operate well or last long.
9. The price of gas and electricity is going to continue to go up rapidly.
10. In this complicated world of ours the only way we can know what's going on is to rely on leaders or experts who can be trusted.
11. I don't have the time to adopt energy-saving measures myself.
12. Adding insulation to a poorly-insulated house usually pays for itself in reduced heating costs in less than 4 years.
13. Taking used cans, bottles, and newspapers to a recycling center isn't important enough to be worth the trouble.
14. For most people, the cost of putting in attic insulation is so great that they will never get their money back in savings on their heating bills.
15. Most insulation contractors will give a free estimate of the cost of installing attic insulation.
16. The energy shortage is just another problem we can solve with new and better technologies.
17. A windfall profits tax should be imposed on oil companies:

1. disagree that little can be done to avoid high energy prices;
2. disagree that planning one's future is unimportant;
3. agree that insulation eventually pays off; and
4. agree that shortages will materialize and the price of fuels will escalate rapidly.

From these results, it appears that nonadopters believe there is a problem; they could do something about it but are unconvinced as to whether insulation is the most desirable solution.

4.3.1 Effectiveness of Conservation

From the results presented above, it appears that nonadopters doubt insulation's effectiveness in reducing monthly expenditures. This implies that the sequential choice process has run its course, and the major difference between the groups lies in their perception of the economics of different alternatives. It was decided that it would be worthwhile to determine the payback period for those who opted to retrofit their homes. If it could be demonstrated that the return on insulation was poorer than could be earned on other investments, then it may simply be a matter of time before escalating gas prices induce people to conserve.

Payback period was computed by estimating the effectiveness of a dollar's worth of insulation in reducing monthly gas usage rate. This savings was multiplied by price and discounted by the appropriate opportunity cost. The details of the procedure are described below. The savings in natural gas was computed by regressing monthly consumption vs. factors related to temperature, housing characteristics, and conservation effort. The specific equation is given below Equ. 4.2.

$$\begin{aligned}\mathrm{CONS} &= a\ \mathrm{DEGDAY} + b\ \mathrm{BLOAD} + c\ \mathrm{INSCOST} + d1\ \mathrm{WN1} + \\ &+ d2\ \mathrm{WN2} + d3\ \mathrm{WN3} + d4\ \mathrm{WN4} + d5\ \mathrm{WN5} + e \qquad (4.2)\end{aligned}$$

where:

CONS	is the monthly gas consumption.
DEGDAY	is heating degree day by month from 1974 to 1979.
BLOAD	is base load for each family. It is the average monthly rate of consumption for July through September.
INSCOST	is the amount of insulation, in dollars. It is a variable which is either 0 or that dollar amount; the value attached to a month depends upon the point in time when the insulation was installed.
WN1	is apply weather stripping.
WN2	is install storm windows.
WN3	is caulk windows.
WN4	is turn down thermostat.
WN5	is undertake other conservation measures.
e	is the regression constant.

The reason for such a lengthy expression is that gas consumption is affected not only by the installation of insulation but by the variation in outside temperature and, just as important, by the choice of other measures such as reducing the thermostat setting. To ignore these complementary adjustments would bias the effectiveness of insulation upwards. The results for all 52 families are given in Table 4.2. Results for individual families are reported in Appendix 4C. As one would expect, in both studies the weather factor exerts the most powerful influence on consumption. In Table 4.2, the coefficient attached to the insulation variable indicates that without question its use does reduce the gas usage rate. However, if one observes the magnitude, it is not that significant. The value .0226 means that for every dollar's worth of insulation installed, consumption will fall by .0226 hundred cubic feet. In other words, \$350[1] worth of the material would reduce the rate of use by eight hundred cubic feet per month. This amounts to approximately 7 percent decline for the average household.

In looking at the coefficients for individual families, it became apparent that this relatively low level of effectiveness stemmed from the uneven performance among the adopters. Figure 4.2 illustrates this observation. The coefficients range from 0 (statistically insignificant) to .25. This wide range of effectiveness could have been due to data problems or simply that installation procedures varied considerably across jobs. The important point raised by these results is that in some instances insulation is being wasted. As of now it is not known why.

The estimates provided in Table 4.2 and Fig. 4.2 can be easily converted to payback period by using the general formula given by Equ. (4.1). This equation shows how payback period T is related to the other factors. In order for the insulation to pay for itself, the stream of savings growing at a rate r and discounted at the interest rate i must just equal the original purchase price. If both r and i are 0, then T = c/s, where c is the cost and s is the savings. This result also holds if the rate of growth in energy prices is equivalent to the interest rate. In the event that r exceeds i, then the value of T must be

TABLE 4.2 Measuring the impact of insulation on natural gas consumption.

Variable	Coefficient	t-value
DEGDAY	.1736	73.80
BLOAD	1.0915	15.58
WN3	21.16	3.59
INSCOST	-.0226	3.61
WN5	--	--
WN4	-19.62	6.13
WN1	--	--
WN2	--	--
e	-6.48	1.92

R^2 = .73, coefficient of determination
N = 2118, sample size

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[1] This figure represents the average insulation bill for the sample.

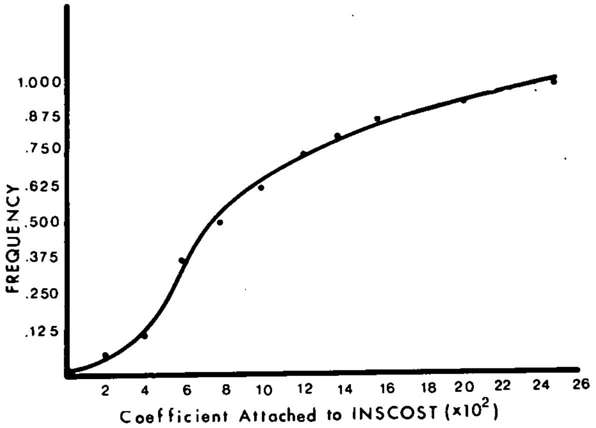

Fig. 4.2 Cumulative distribution of insulation effectiveness.

arrived at through interpolation. The right-hand side of Equ. 4.1 is the present value of an annuity which can be solved to yield Equ. 4.3.

$$c = s\left[\frac{1 - e^{-i'T}}{i'}\right] \qquad i' = r - i \qquad (4.3)$$

The term in brackets can be solved using various values of T. T is given from the solution which is closest to c/s.

The rate of growth in the price of energy was determined with the use of gas consumption data. The Public Service Company provided the current rate structure for billing residential users, in addition to the 11 changes made between January 1974, and August 1978[1]. A program was written to merge these changes with the rate of gas used by nonadopters (see Appendix 4B). This group was isolated because the usage rate depends upon the existence of conservation measures. Because of this, it would be misleading to try to measure the rate of growth in energy expenditures for conservers. It would be difficult to sort out the effects of time from the adoption of insulation which is also a function of time.

The rate of growth in price was then determined by regressing monthly payments against the various factors which influence consumption in addition to time. The specific relationship is given below in Equ. 4.4.

$$\ln \text{BILL} = a \ln(\text{SQFT}) + b \ln(\text{AGEHM}) + c \ln(\text{DEGDAY}) + r\,(\text{TIME}) \qquad (4.4)$$

where:
BILL is the monthly bill including sales taxes,
SQFT is the floor area of the house,
AGEHM is the age of the structure (years),
DEGDAY is heating degree days by month,
TIME is the time in months from January 1974 to June 1979.

The value estimated for r is the rate of growth in energy prices. This stems from the fact that Equ. 4.4 is derived from Equ. 4.5.

$$\text{BILL} = \text{SQFT}^{a} \cdot \text{AGEHM}^{b} \cdot \text{DEGDAY}^{c} \cdot e^{r \cdot \text{TIME}} \qquad (4.5)$$

The last term is the growth factor sought. From the data, it appears the heating bills have risen at an annual rate of 13 percent per year. The results are shown in Equ. 4.6.

$$\begin{aligned} \ln \text{BILL} = {} & .278 \ \ln(\text{SQFT}) - .172 \ \ln(\text{AGEHM}) + \qquad (4.6) \\ & (5.90) \qquad\qquad (6.71) \\ & + .269 \ \ln(\text{DEGDAY}) + .0105 \ \text{TIME} \\ & (33.78) \qquad\qquad (13.62) \\ & R^2 = .68 \\ & N = 742 \end{aligned}$$

( ) designates "student t" value.

The coefficient for TIME represents the growth rate in monthly gas bills. There is a very strong indication that these costs have risen at a compound rate of one percent a month since 1974; this amounts to an annual rate of 13 percent. It is interesting to note that a similar study of all families (adopters and nonadopters) revealed an annual growth rate of 10.4 percent. This estimate too proved to be highly significant.[1] From this, one can conclude that the use of insulation reduced the growth in natural gas costs from 13 to 9 percent.[2]

All the ingredients for estimating the payback period have been assembled except one. That is the dollar savings for one hundred cubic feet of natural gas.

Prior to August 1978, the rate structure was biased in favor of heavy users. The rate schedules for the period beginning in October 1973, and ending in August, 1978 are shown below in Table 4.3. Since insulation or other actions will reduce consumption on the margin, any gas savings realized would yield a lesser amount in the form of dollars. In August of 1978, the rate structure was revised so that all gas carried the same charge of .0911 per 100 cubic feet.[3] Rate increases were then funneled through the gas cost adjustment factor which is applied against total consumption. Because of this change, the dollar savings is much easier to compute--the reduced consumption is multiplied by .0911 plus the cost adjustment factor.

TABLE 4.3

	1973	1978
Monthly Rate	Cost/100 Cubic Feet	Cost/100 Cubic Feet
First 400 cubic feet	$1.327	$1.61
Next 1,600 cubic feet	.124	.154
Next 6,000 cubic feet	.067	.0965
Next 6,000 cubic feet	.060	.0797
Next 6,000 cubic feet	.058	.0797
All over 20,000 cubic feet	.056	.0797

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[1] In addition to these 11 changes, this period was punctuated by approximately 37 changes in the cost adjustment factor. This too was brought into the computation.

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[1] The t value was 17.9

[2] The 9 percent figure was computed for adopters.

[3] In addition to this, residential customers are required to pay a monthly service charge of $2.48/month.

Given Equ. 4.1 and the various assumptions with regard to the rate of growth in prices and discounting, several solutions could be developed. Table 4.4 illustrates the sensitivity of payback period to these factors.

If the homeowner uses a reasonable discount rate[1] and perceives that price will continue to escalate at a rate approaching that observed for the period 1974 to 1979, then insulation must reduce gas consumption by .04 hundred cubic feet per month per dollar. Any level of effectiveness less than that would prove to be uneconomic. If the homeowner did not discount savings and assumed that price remained fixed at the current level, then the effectiveness must be .06. If the discounting occurs while prices are assumed fixed, the level of effectiveness must be .09. By referring to Fig. 4.2, a rough picture of the variation in payback period can be observed in the following way:

If column 3 (Table 4.4) assumptions are used, it appears that 8 of the 16 families <u>may</u> never recover their investment. The word "may" is underscored because there may be reasons why insulation could still prove to be significant for these families. For example, they tended to be the later adopters. As a result, the regression analysis may not have been able to detect the influence of insulation. Of those that did experience a reduction in consumption, 38 percent will not break even. Another 25 percent of the families experienced payback periods comparable to that earned elsewhere in the economy. The remainder experienced returns significantly in excess of that earned elsewhere, even in real estate.

One can easily adjust the values shown in Table 4.4 to include federal tax credits. For example, if the current credit of 15 percent remains in effect, then a homeowner could subtract 15 percent of the insulation's purchase price from his/her taxes. This would adjust the coefficients shown in Fig. 4.2 in the following fashion. The numbers represent the reduction in consumption per dollar expended on insulation; the expense to the homeowner is just 85 percent of purchase price. As a result, the effectiveness of a dollar's worth of insulation, net of the tax credit, is boosted by 18 percent. If the coefficient had been .030 prior to the credit, after the credit it would be .035. Given the wide range of coefficients estimated, it is unlikely that such a credit will significantly alter the benefits of conservation. It may only if the <u>perceived</u> gains are greater than they turn out to be.

4.4. POLICY IMPLICATIONS

It appears that the major difference between adopters and nonadopters is a sense of effectiveness. They both believe that energy will continue to be a chronic problem, and they themselves are responsible for acting. If this finding is supported by other research efforts, then public policy should be directed to the lower portion of the sequential choice model shown in Fig. 4.1. That is, advertising campaigns should focus on the economic issues by trying to better illustrate the savings that can be anticipated. Advertising directed at creating a sense of problem is not likely to yield much in the way of results.

Another finding which should alter policy-makers' conception of the conservation issue is the wide variation in insulation's effectiveness. If these results stand up over time, the implication is that much of this valuable resource is currently being wasted. It is either being applied to homes that do not need it, or being installed in a fashion which renders it useless. One way to improve the overall effectiveness of conservation measures is to routinize the process. One institution which could be involved in this process is the savings and loan companies. The following proposal to involve them grew out of the findings just presented.

4.4.1 <u>Incorporating Utility Payments into the Loan Formula</u>

In processing a mortgage application, banks (savings and loan associations) routinely compute the principal, interest, insurance, and property tax payments that an individual must make each month. This is called PITI. If the PITI is less than some accepted fraction of the prospective buyer's adjusted income, then the loan is normally granted. True, banks will often ask for information concerning the

TABLE 4.4 Payback period for different assumption regarding price and discount rate.

Effectiveness of Insulation in Reducing Natural Gas Consumption (hundred cubic feet/ dollar/month)	Number of Years Assumptions with Regard to Price and Discount Rate		
	No Discounting No Price Change*	Discounting-9% Price Increase-13%	Discounting-9% No Price Increase
0	∞	∞	∞
.02	21	15	∞
.05	8	7	∞
.10	4	3.8	7
.20	2	2	2.5

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*Base price of $.20/hundred cubic feet.

[1] The discount rate of 9 percent was developed assuming an opportunity cost of 12 percent and an average tax bracket of 25 percent. In this regard, it is interesting to note energy savings are <u>not</u> taxable.

home's energy use; however, such information is not integral to the qualification decision. Since utility costs have climbed so dramatically over the past five years, I see no reason for pretending that they are less important than PITI. In fact, in the Northeast where high-priced imported oil is the primary source of fuel, heating costs often exceed PITI. It may be argued that utility payments are a discretionary expenditure whereas PITI is fixed. However, heating costs are not arbitrarily variable, either in Massachusetts or in Colorado. They may fluctuate depending upon a resident's tolerance for the cold. But even so, the variation in energy use is still quite narrow.

The proposal put forth as a result of the research presented above begins with the prospective home buyer. In either seeking a new mortgage or assuming the current one, the buyer would have to earn approximately four times the combined principal, interest, insurance, tax, and utility payments. If he (she) does not qualify, then the bank would determine the utility savings that could be achieved by either insulating, caulking, or undertaking any one of a number of other adjustments. Determining the effectiveness of different conservation practices would not be an easy task, but it could be done through an energy audit much like that currently performed by the Public Service Company of Colorado. It is quite possible that utility costs could be reduced enough to warrent the increased principal and interest payments required to retrofit the structure.

As a result of this procedure, the bank would provide the buyer with a series of options involving the potential trade-offs between utility payments and the cost of implementing energy-saving practices. At that point the decision is left to the home buyer. If he (she) qualified for the loan using the PITIU formula, then he (she) may opt to ignore the suggestions. However, if the PITIU payments exceed some proportion of his/her income, then the selection of one of the energy-saving measures may reduce U more than the increase in PI needed to pay for it. The trade-off in this latter instance becomes visible and relatively straightforward to understand.

This procedure also enjoys a number of other advantages:

1. It routinizes the task of conservation. This leads to a better data base and a more efficient means of disseminating information. It is easier for a loan officer sitting in front of a computer terminal to determine the cost and effectiveness of the various conservation options than a home buyer (owner) haphazardly searching through the "Yellow Pages".

2. The mechanism could be used to allocate energy subsidies. This winter $1.2 billion will be disseminated to the poor and elderly to help supplement incomes. For the most part, these monies will be used to pay for higher heating costs and very little will be devoted to conservation. As a result, such subsidies will become a permanent fixture in the federal budget, and the incentive to conserve will have deteriorated.

4.4.2 Implementing the Proposal

Implementing the proposal requires the cooperation of a disparate group of institutions which have not traditionally communicated with one another. This means that new linkages will have to be forged. It can be expected that both the energy distribution companies and the banks will at first balk at the proposal. However, this resistance may disintegrate when each begins to realize the mutual advantages: the banks gain mortgage security while the Public Service Company accomplishes its well-touted goal of conservation.

The plan will not be made operational overnight; it may take the better part of five years to gather the requisite data, establish procedures, and test the system. An integral step in this direction would be the development of computational routines which could integrate information from all sources. For example, the results from the energy audit must be combined with current interest rates and tax legislation (credits, tax bracket of the individual, etc.) in order to determine the net benefits of conservation. Energy demand models, such as the ones discussed elsewhere in this report, would go a long way in establishing the required base for an evaluation of the credit worthiness of a prospective customer.

5. AN INTERINDUSTRY MODEL FOR THE STUDY OF WEATHER AND ENERGY RELATED SOCIO-ECONOMIC EFFECTS

The purpose of this study is to provide a detailed description of the economy of Greeley in order to develop a means for projecting future economic conditions. The effects of atmospheric variability on space heating energy requirements and socioeconomic reaction to both weather and weather-related policy may then be analyzed. The method of analysis used to accomplish both goals is known as input-output. Specifically, the input-output approach utilizes the following base data:

1. An industry-by-industry sales and purchases distribution, measured in dollars and obtained from direct survey in Greeley.
2. A measurement of the extent to which each industry purchases labor, raw materials, and processed goods within the Greeley region as opposed to imports from outside the region.
3. Employment on an industry-by-industry basis in Greeley obtained from confidential files of the Colorado Department of Employment.

In addition to the information provided directly by the base data, the input-output model will be used to: (1) Generate provisional forecasts of future economic activity, and (2) Estimate industry-by-industry space heating fuel requirements to the year 2003. These provisional forecasts are based partly upon expectations for growth held by government and the key industrial sectors which currently have the greatest economic influence in Greeley. Specifically, the effects of temperature variation on space heating energy requirements, by sector, will be incorporated in the input-output model.

5.1 WHY AN INPUT-OUTPUT MODEL?

Economists and regional scientists generally agree that the inter-industry or input-output model provides the most effective means to describe and analyze a region's economy. The input-output technique is unique in that it simultaneously accounts for all components of the regional economy so that growth in each sector is consistent with that in all other sectors. The method is practical since it can be applied to the analysis of almost every facet of the regional economy and thus a new model need not be developed each time a new phenomenon is to be studied. Input-output models are more flexible and versatile than is commonly recognized. Although a linear model may seem overly simplistic, in fact, the limits of its application are set mainly by the inventiveness of the researcher and the availability of data. Computerization of the input-output model allows analysts to study alternative scenarios quickly in response to fast-changing resource development. However, the economic base model is an often used alternative. Its main advantage is that it is inexpensive to construct. Therefore, this report begins with an exposition of both the economic base model and the input-output technique and also contains a discussion of the advantages of the input-output method over the economic base model. The discussion concludes with a justification for the use of primary survey-based data rather than secondary information sources in constructing the model.

The economic base model is similar in concept to the well-known Keynesian model which is the basis for national income policy analysis. Generally, however, data which are appropriate to construct income accounts for regions are not available. The base model thus is a very simplified Keynesian model. Usually proxy data such as employment are used to construct a ratio of total economic activity to "basic" economic activity for a region. It can be shown that this ratio roughly approximates the economic multiplier known as an export multiplier in the Keynesian model.

The economic base technique has many limitations. Two deficiencies stand out. First, the base model only shows the multiplier effects of changes in aggregate exports, i.e., changes in sales outside the region by the basic sector. (A related problem concerns the definition of what is basic and what is nonbasic.) In contrast, the input-output model clearly delineates each component in each industry which is basic (or part of final demand in I-O terminology). By disaggregating each industries purchases and sales, the I-O model allows a higher degree of accuracy in the estimation of multiplier effects.

A second deficiency in the base method is that it fails to achieve consistency in its forecasts. While the I-O model requires, through its basic structure, that the output from each industry is just sufficient to satisfy demand, no such requirement is imposed by the base model at the industry level. Consequently, while total income may be correctly identified by a base model, little can be said about its components. This limitation is very serious for practical applications. Predictions of aggregate output or income for a region are very seldom sufficient, nor are they very accurate. Since exports by all industries are aggregated to find the base model multiplier, the predictions made with the multiplier implicitly assume that all industry exports continue to rise in proportion to the initial export levels. Practical application of regional forecasting almost always requires the study of changes in particular export sectors and one may also wish to analyze changes in export mix, investment change or changes in government purchases. The base model supplies only a very rough and ready estimate of the impact of such changes.

The final and most telling weakness of the base method is that it fails to provide predictions of output change on an industry-by-industry basis. Conversely, the I-O method can supply predictions for each industry and for local government sectors as well. Only the I-O model has the ability to supply information useful to measure changes in local services, both public and private, and the accompanying public finance requirements and fiscal problems associated with economic change. In particular, the industry-by-industry forecasts provided by the I-O model allow forecasts of numerous other variables closely associated with industry output, e.g., employment, energy use, pollution, population change, etc. Several other unresolved problems with the base method, both conceptual and empirical, are discussed by Isard et al., 1960; Pfouts, 1960 and Richardson, 1972.

From time to time, attempts are made to short-cut the survey process which is required to develop the table of transactions for the input-output model. The adjustment of national input-output models is unlikely to serve these purposes. This is not to say that the generation of non-survey multipliers is ruled out in all cases. The degree of importance and time allowed for the analysis must determine the effort expended to achieve acceptable results. In such cases, however, the considered judgement of local regional economists might suffice as well. Perhaps the worst danger from the proliferation of low quality input-output models arises from their indiscriminate use by persons neither familiar with their limitations nor aware of the economic nature of the regions which they may be responsible for analyzing.

Our own rather extensive experience with small region-survey based input-output models leads us to conclude that, for our purposes, the kind of detail provided by non-survey models, is inadequate for local impact analysis. See reports by Gray and McKean (1974; 1975a, b; 1976), Gray et al. (1975; 1976; 1977a, b, c, d; 1979), McKean et al. (1977a, b), McKean and Weber (1978, 1979), McKean (1979), for appreciation of the background and expertise we have in the area of input-output modelling. In particular, the numerous local service sectors, local government sectors, and sectors peculiar to a region often dominate the economy of a small study area. None of these sectors can be estimated by non-survey techniques. The few sectors which might be estimated from national models can usually be surveyed at little added cost.

Our review of comparisons of survey and non-survey input-output models would seem to indicate that non-survey models should not be used for making forecasts which might have important policy implications. The degree of error inherent even in survey-based models makes their application to very long-run projections suspect at best. Introduction of added errors through non-survey techniques may make such models unusable.

At a time when increasing pressures are placed on agencies faced with the responsibility of managing resources, it is important that the best possible information be available to justify decisions and also that those affected respect the quality of information which is used.

Again, the purpose of this study is to analyze the relationship among the economic sectors of the Greeley economy in north-central Colorado and to relate economic activity in this regional economy to pressures exerted on the region's energy resources used for space heating. In satisfying this purpose, five specific objectives will be met: 1) estimation of the interdependent economic structure of the Greeley economy; 2) projections of the future output of sectors within the economy and the resulting estimation of the direct and indirect impact of assumed output changes on the sectors of the regional economy; 3) delineation of the estimated space heating energy resource requirements necessary to support current levels of economic activity; 4) estimation of the impact of expanding economic activity upon future resource requirements; and 5) analysis of alternative meteorological conditions, e.g., average temperature, for alternative futures. The input-output model, or interindustry analysis, is best suited to achieve these objectives.

5.2 DESCRIPTION OF THE INPUT-OUTPUT MODEL

The technique particularly adapted to the study of resource use in a regional economy is the interindustry production model popularized by W.W. Leontief*. The strength of this model (often termed the input-output model) lies in its capability not only to describe the interdependence existing among sectors of an economy but also in the capacity to demonstrate, sector by sector, the total consequences of any number of development scenarios.

An input-output model empirically illustrates the interdependent economic structure of the study region. This model provides an account of transactions for each sector of the economy, a calculation of the input requirements of these sectors and a measurement of the effects of growth in demand for the outputs of each sector. Essentially, the model is a system of double entry bookkeeping such that annual sales and purchases by each sector to and from all other sectors are accounted for and measured.

The model consists of two major components--those transactions which are identified as intermediate transactions and those which are termed final. Intermediate transactions consist of the purchase and sale of intermediate goods (i.e., those which are subject to further local processing). Final transactions include all purchases and sales from or to sectors which are external to the model (i.e., to sectors not identified as intermediate or producing sectors). Such transactions would include, for example, sales from intermediate sectors to exogenous investment or governments, and other exports and purchases by intermediate sectors from outside governments or in the form of imports from outside the region.

The model is driven by the final demand sectors. Thus, if it is assumed that sales to state or federal government, investment, or export by any particular sector are going to change, the model estimates the impacts of this change on the entire economy. These impacts, whether measured in terms of employment, income, or the value of production, provide consistent estimates which mutually and simultaneously satisfy all requirements for intermediate and final production. Once the essentials of the model have been identified and the basic empirical description of economic transactions developed, forecasting with the analytical technique requires only the specification of appropriate changes in final demand.

The input-output technique provides two forecasting tools: (1) multipliers and (2) development scenarios. A multiplier indicates how much business activity in sales dollars, units of energy input, employment, water use, etc., is generated by a given industry within the region for each dollar of sales to final demand. Final demand is defined as sales to state or federal governments, investments, and exports outside of the region. A multiplier will be large for an industry which purchases a large part of its inputs from within the local economy. This is because the money which it earns from its sales will be spent again in the region. The important "basic" or driving exporting industries will usually be characterized by large multipliers.

Several types of multipliers may be calculated. The business multiplier, just discussed shows the total business spending within the region per dollar of additional sales to final demand by a given industry. A space heating multiplier shows the total added cubic feet of gas used per month in the region per dollar of additional sales to final demand by a given industry. An income multiplier shows the increase of personal income per dollar of additional sales to final demand by a given industry. The multipliers may all include direct, indirect, and induced effects. This means that if a "basic" industry expands its sales to, say, exports by $1,000, it may spend $600 directly on locally produced goods. The producers of these local goods are then indirectly required to purchase some local goods and services themselves in order to meet this additional demand, and so on. The induced impact refers to the assumption that labor hired directly will respend a fixed proportion of its added income stimulating further expansion of the regional economy. Thus, both local producers and local labor are assumed to respend locally part of their increased incomes which resulted from the increased exports by the "basic" industry. The total effect is reflected in the multiplier.[1]

The second forecasting tool provided by the input-output technique is the projection of future business activity by sector or development scenarios. In addition to the projection of dollar sales for each sector, variables which may be assumed to rise proportionately with production may also be estimated. Employment, water use, population, and energy use are examples of variables which may be projected in this manner.

Projections of future economic activity are derived from the input-output model by focusing on the "basic" or driving industries. Examination of the size of the multipliers and the size and expected growth of the basic industries reveals the key sectors. Estimates of expected export growth in these basic sectors must be obtained in order to drive the input-output model. Scenarios for growth in these sectors might be constructed from information obtained from personal interviews with representatives of major firms in each sector. Government growth estimates are often available directly from the relevant government agencies. The expected growth estimates for the basic industry and government sectors are introduced into the input-output model to generate new, consistent estimates of the value of sales for each industry. A more detailed explanation of I-O techniques may be found in Richardson, 1972 or in many of our reports listed in the reference section. In Appendix 5A our modelling techniques are given in detail.

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* Recent Nobel Prize recipient in Economics.

[1] The "induced" household spending effect can be removed, if desired, by shifting the household sector out of processing into final demand so that household purchases are assumed to be exogenous.

5.3 SOURCES OF INFORMATION FOR THE GREELEY I-O MODEL

5.3.1 Questionnaire Design and Use

Previous experience with questionnaires employed to obtain primary information for interindustry models has shown that a questionnaire, alone, should not be used in the pursuit of the primary data. The reason behind this is that no firm accounts for expenditure and revenue patterns on an SIC (Standard Industrial Classification) basis, the language ultimately employed in an interindustry model. Rather, a firm's books are designed around process or product activities. The use of a questionnaire, either by mail or by interview, presupposes adequate translation from a firm's accounting language into SIC codes. The typical entrepreneur or manager does not ordinarily work with SIC descriptions, a rather precise and technical language.

Accordingly, all interviews were conducted in a basic accounting language tailored to the individual firms involved and we translated the information to SIC classification. Thus, the sample questionnaire form shown in Appendix 5D represents the format for the final translation by the researcher.

Not all interviews could, however, be conducted as planned. It was discovered, for example, that some firms wished to refer for legal advice while others did not want to reveal information in the form desired. Even though primary data were not solicited through the mail, it was necessary to design a questionnaire for use both as an interview focal point and as an item that could be left with an interviewed firm.

The questionnaire included a cover sheet used to briefly explain the nature of the research and to solicit information on the nature of the firm's product lines, the number of employees, and level of capacity utilization. Outlay patterns, both of a cash flow and a noncash flow nature, were the concern of the second sheet. Information on sales distribution was solicited on the third sheet. Sales and outlay patterns were disaggregated by economic sector and regionalized according to location (1) within Greeley city limits, and (2) outside Greeley.

5.3.2 Conduct of the Survey and Processing the Data

Interview schedules were arranged in advance by telephone. Every effort was made to gain an interview with the person who would have immediate authority to release information. The length of time spent on an individual interview varied from firm to firm. Some were conducted in less than an hour; some took place over several days. The total survey was conducted over a period of several months.

Information gathered on the outlay and sales patterns for any given enterprise were tabulated to conform to sector delineations and regional descriptions shown in Table 5.1. Care was exercised at this step to assure a balance between outlays and sales. Any anomalies were checked and corrected before proceeding further.

The next step was to aggregate questionnaire forms within a sector and to expand the information to represent gross flows. Typically, industry employment totals were used to expand survey data using the survey ratio of sales to employment. The gross flows identified in this manner provided the industry sales totals for the initial transactions statement. A complete description of the data sources used in this study is given in Appendix 5C.

TABLE 5.1 Economic sectors for the Greeley economy.

Endogenous Sections

Agri-Business

Food Processing

Manufacturing

Printing and Publishing
All Other Manufacturing

Services

Transportation (excluding railroads)
Communication
Electricity
Natural Gas
Water and Sanitation
Hotels and Motels
Finance, Insurance and Real Estate
Health Services (doctors, hospitals and nursing homes)
All Other Services (includes Postal Service)

Trade

Wholesale
Restaurants
All Other Retail

Local Government Services

Public Grade and High Schools
Other Local Government Services
University (State)

Investment Creating

Construction (residential, commercial)

Final Consumers

Households

Exogenous Sections

Investment (varies by sector)

Exports (varies by sector)

5.3.3 Selection of the Base Year

Other than a consumer price index for the Denver metropolitan area, there is no price index constructed specifically for Colorado. This lack effectively removes one criterion (relatively stable prices) from consideration when selecting a base year for Colorado economic studies. The 1978 base was selected for the following reasons.

Interviewing for the Greeley interindustry study was planned to begin in April 1979. Calendar year 1978 was the most recently completed accounting cycle for most firms; thus the information from this cycle would be, qualitatively speaking, foremost in the command of the interviewees. Also, in a rapidly developing economy, such as Greeley, it is important to utilize current data in describing the interdependent economic structure.

The survey included business firms, government agencies, schools, and non-profit institutions. Whereas over 60 manufacturers are located in Greeley, less than half this number have over 20 employees. All large firms were contacted.

5.4 FINAL DEMAND PROJECTION

In addition to the survey of business and government, previously discussed, to determine the interdependent economic structure of the Greeley economy, a second survey must also be conducted to determine the projected growth of final demand. The input-output technique for projecting the economic growth of a region requires knowledge of certain future exports, federal government, and investment spending for the region. These exogenously determined variables drive the endogenous processing sector of the economy. Not all of business and government need be queried regarding future growth plans -- only those industries and government agencies which make up a significant part of the Greeley economy and whose future growth is capable of some volatility are important. For example, neither the post office nor the university need be surveyed, even though they are a part of government. The post office does not grow exogenously; it is included as part of the endogenous processing sector since it reacts to demands by other processors and does not initiate growth. The university cannot initiate growth, according to guidelines set down by the state government which "cap" enrollments at all major Colorado Universities. The relative importance of exports to each of the sectors in the Greeley economy is shown in Table 5.2. Wholesale, food processing, health services and tourism-related sectors appear to provide much of the driving force for the Greeley economy.

TABLE 5.2 Export share of total output by sector, Greeley, Colorado, 1978 (percent).

Sector	Export Share
Food Processing	84.6
Printing and Publishing	13.2
Manufacturing N.E.C.	60.3
Construction (79.1% to Investment Including Export)	
Transportation (Excluding Railroads)	6.6
Communication	17.3
Electricity* (Exports Excluded From Model)	--
Natural Gas* (Exports Excluded From Model)	--
Water and Sanitation	24.3
Wholesale	89.4
Retail N.E.C.	16.3
Restaurants	44.1
Hotels-Motels	48.9
FIRE (Finance, Insurance, Real Estate)	24.1
Health Services	69.5
Services N.E.C.	--
Schools	0
College	44.6
Local Government (Sales Taxes, also 2.8% to Investment)	23.1 + 2.8%
Households	16.1

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*Energy sectors do not include sales outside Greeley in order to match Greeley space heating energy use with sales.

The survey of expected growth for the exogenous sector of the economy should cover the years 1980 to 2000. Past a twenty year span, it would be expected that significant changes in technology and in trading patterns among producers would weaken the predictive accuracy of an input-output model, especially in a rapidly developing economy such as that of Greeley.

Once the expected growth of the final demand sector has been estimated, the input-output model will be used to simulate economic growth of the region to the year 2003. Sector by sector projections of sales and employment, as well as projections of the payments among sectors (such as payments from each sector to households) can be calculated on an annual basis.

5.5 INCORPORATION OF SPACE HEATING REQUIREMENTS

The input-output model can address resource use when that use is related to output or sales volume of each economic sector. Space heating requirements are known for various types of buildings in Greeley from our physical modelling results. The space heating requirements for 1978 by economic sector per dollar of output and by average temperature are shown in Table 5.3. The energy requirements are shown in cubic feet of natural gas per month per dollar of output. The growth scenarios assume that space heating requirements rise proportionately with the value of output produced in each industry. However, each industry will have its own unique relationship between output and heating input. Since industries will not grow uniformly, the space heating requirements for Greeley could not have been projected through simple extrapolation. Only a projection technique which takes account of the interdependent nature of the economy, such as input-output, can provide accurate forecasts of energy requirements in the future.

With the incorporation of space heating requirements into the input-output model, the baseline projections to the year 2003 can now also include space heating requirements.

5.6 INPUT-OUTPUT ANALYSIS OF GREELEY

The results of the descriptive analysis of the Greeley economy are presented in this section. The discussion contained herein includes: the description of the economy; an analysis of the nature and magnitude of economic interdependence among processing sectors; the various business activity and income multipliers; and an analysis of space heating energy use in the region.

The description and analysis of the economy hinges on three major components of the interindustry model. These are: the gross flows or transactions table; the table of direct production requirements; and the table of direct plus indirect production requirements. These tables are discussed and interpreted in turn. Because of possible violation of disclosure laws a predicted gross flows table for 1983 is shown rather than the survey-based 1978 table.

5.6.1 The Transactions Table

The first essential component of any interindustry study is the collection and tabulation of data which serve to describe the flows of commodities from each supplying sector to each purchasing sector. These flows are typically expressed in terms of the dollar value of transactions occurring in a specific period of time, normally one year. The information is arrayed in tabular form with the suppliers (selling sectors) listed at the left of the table and the purchasing sectors listed at the top. The information in this table, termed the transactions table, does two things simultaneously: it identifies the estimated annual dollar value of sales by each sector to each of the other sectors (thus, the distribution of each sector's output), and it identifies the purchases of ingredients of production by each sector from each of the other sectors (the distribution of purchases). In essence, the information contained in the transactions table represents a double-entry system of bookkeeping in which every sale is simultaneously described as a purchase. Thus, the system deliberately double-counts. (Please refer to Appendix 5B to find the transactions tables which are described in the following discussion.)

The rows and columns of Table 5B.1 (Appendix 5B) which are numbered 1-19, identify the processing, or

TABLE 5.3 Physical input resource vectors.

	Sector	Monthly consumption Cu. Ft. Natural Gas per $ of Sales				
		14.1°	17.3°	29.7°	34.0°	40.8°
1.	Food Processing	.02135	.02059	.01526	.01505	.01434
2.	Printing and Publishing	.51729	.49969	.37439	.37121	.35543
3.	Manufacturing N.E.C.	.11300	.10895	.08103	.08004	.07610
4.	Construction	.40223	.38869	.29103	.28852	.27632
5.	Transportation	1.86854	1.81146	1.38038	1.37853	1.34082
6.	Communication	.13622	.13154	.09854	.09770	.09357
7.	Electricity	.02389	.02316	.01737	.01716	.01642
8.	Natural Gas	.03180	.03082	.02311	.02283	.02185
9.	Water and Sanitation	.39287	.37948	.28423	.28186	.26998
10.	Wholesale	.11160	.10758	.08134	.08095	.07820
11.	Retail	.41609	.40298	.30522	.30394	.29437
12.	Restaurants	.21799	.21131	.16090	.16055	.15609
13.	Hotels-Motels	4.33571	4.22657	3.28292	3.30249	3.27580
14.	FIRE	.22560	.21786	.16324	.16183	.15498
15.	Health Services	.23068	.22436	.17308	.17387	.17047
16.	Services N.E.C.	.35395	.34246	.25863	.25729	.24822
17.	Schools	.80762	.78735	.61213	.61620	.61110
18.	College	.63770	.61969	.47766	.48036	.46795
19.	Local Government	.94306	.91193	.68666	.68210	.65667
20.	Households	.85354	.82188	.60822	.59961	.56786

intermediate demand sectors. Row and column 20 represents subtotals of activities within the processing sector. This portion of the table plus the household sector (sector 21) describes, in dollars terms, the flow of goods and services necessary to satisfy intermediate demands. Final demands, i.e., demands for goods and services that will not be processed further within the region, are identified in columns 22-24. Rows 22-24 identify the final payments sector. Final payments then include federal and state taxes, profits or losses, net inventory depletions and payments for goods and services imported from outside Greeley. The last row and column of Table 5B.1 (Appendix 5B) contain, respectively, total outlay (purchases) and total output (sales) for each sector of the Greeley economy.

The total distribution of the output of each sector, according to the sectors in which the output is sold, may be readily discerned by reading across the rows of Table 5B.1 (Appendix 5B). The bill of purchases by each sector is found by reading down any column of the table. These column entries show the allocation of purchases by cost component.

Other information can be obtained directly from the transactions table. The household row represents wages paid subject to withholding. This row shows household income. Similarly, sector by sector contributions to taxes may be directly obtained from rows 19 and 22.

Whereas these items, obtained directly from the transactions table, are useful as initial indicators of the relative importance of each sector in the regional economy, the important question of interdependence is not addressed. In order to do so, it is first necessary to isolate the direct production relationships existing in the economy.

5.6.2 Direct Production Requirements

The direct production requirements, or coefficients, represent the second major component of the interindustry analysis. These direct requirements are presented in Table 5.4. Computation of the direct production requirements is quite simple, given the transactions table, and requires only that each column entry of the transactions table be divided by the respective column total. The resulting coefficients describe the direct purchases necessary from each supplier (at the left of the table) in order for the purchasing sector (at the head of the column) to produce one dollar's worth of output. The coefficients then are interpreted as the direct requirements per dollar of output produced by each sector.

These direct impacts identify only a portion of the total economic impacts that would accompany a change in final demands for the output of a given sector. There are additional, or indirect, impacts which can be quite important. Assessment of all direct and indirect impacts of these exogenous (final demand) changes is made possible through the third analytical component of interindustry analysis. This component is the table of direct plus indirect production requirements.

5.6.3 Direct Plus Indirect Impacts

The concept of interdependence can be fairly easily established with a brief example. Suppose that the export demand for health services increases. There will be immediate, or direct, responses of the following type: health service production will have to increase. In order for health service to increase, inputs must be obtained from sectors such as printing and publishing, transportation, communication, utilities, power, retail and labor. These are direct impacts. As these other industries increase their output to meet the increasing requirements in the health service sector, their own requirements for productive ingredients increase, e.g. services, labor, petroleum and natural gas, and even health services. The chain of events goes on. The total impacts are readily estimated through the input-output framework.

Before proceeding to a discussion of Table 5.5, a few comments regarding the treatment of households are in order. Households may be treated as either a part of the processing sector of the economy or as a part of the final demand component. In the first instance, households are treated in precisely the same manner as

TABLE 5.4 Greeley direct production requirements.*

Technical Coefficients

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	.005433	.001669	.001034	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	PRINT-PUB	.000532	.000455	.002624	.013941	.002061	.001797	.000842	.001541	.000864	.000441
3	MFG NEC	.000616	.001669	.027873	.013876	0.000000	.000240	.002632	.000140	0.000000	0.000000
4	CONST	.013918	.001669	.002346	.160482	.002679	.001438	.002526	0.000000	.015119	0.000000
5	TRANSPORT	.009760	0.000000	.009423	.000013	.000824	.000779	.000105	.000280	0.000000	.016044
6	COMMUNICAT	.004733	.002892	.002465	.000734	.016073	.001258	.000842	.001401	.001512	.001330
7	ELECTRICTY	.006735	.006068	.005169	.000013	.005358	.005691	0.000000	.001121	.019870	.000897
8	NAT GAS	.006637	.001517	.003340	.003381	.011745	.000719	.000105	.000140	.000648	.000829
9	WATER-SAN	.000476	.002882	.000835	.011937	.001030	.000419	.000105	.000140	0.000000	.000164
10	WHOLESALE	.007925	.030340	.007237	.049790	0.000000	0.000000	0.000000	0.000000	.024622	0.000000
11	RETAIL	.009284	.027002	.012644	.016916	.162374	.015035	.003158	.005183	.010583	0.000000
12	RESTAURANT	.002310	0.000000	.000119	.000013	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
13	HOTEL-MOT	0.000000	0.000000	.001034	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
14	FIRE	.012490	.086165	.032604	.091889	.096229	.180424	.047053	.031797	.176458	.002563
15	HEALTH SER	0.000000	0.000000	.000954	.001376	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	SERV NEC	.002394	.049150	.020835	.019772	.023079	.002875	.003263	.008264	.081641	.008818
17	SCHOOLS	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
18	COLLEGES	.000028	.000455	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	LOCAL GOVT	.002142	.000910	.004095	.018842	.008448	.075177	.053895	.055750	.030454	.004117
20	HOUSEHOLDS	.120211	.391232	.363459	.152385	.591181	.372230	.101474	.129850	.118143	.099737
21	FED-ST GOV	.016033	.022603	.034274	.031407	.049866	.102013	.043684	.026754	.006479	.005986
22	PROFIT DEP	.073037	.145176	.121352	.063705	.027612	.134779	.101053	.090769	.436717	.023247
23	IMPORTS	.705304	.228155	.346282	.349528	.001442	.105128	.639263	.646869	.076890	.835827

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 HOUSEHOLDS
1	FOOD PROC	0.000000	.328447	0.000000	0.000000	0.000000	0.000000	.011617	0.000000	.000851	.002321
2	PRINT-PUB	.009456	.002791	.004745	.008473	.002687	.003492	.000581	.003624	.007570	.001448
3	MFG NEC	0.000000	0.000000	0.000000	0.000000	0.000000	.002153	.000968	0.000000	.001063	.017816
4	CONST	.000714	.000247	.033215	.001746	.000092	.002357	0.000000	.002841	.006677	.003961
5	TRANSPORT	.000551	0.000000	.000593	.000714	.001285	.004975	.010003	.001855	.001021	.001538
6	COMMUNICAT	.004467	.034795	.045077	.008572	.006659	.005295	.005034	.011539	.006804	.019333
7	ELECTRICTY	.007876	.010138	.030249	.002183	.003854	.005674	.015295	.014032	.006677	.010465
8	NAT GAS	.001485	.004910	.013049	.001161	.002412	.013093	.012778	.012582	.005954	.009040
9	WATER-SAN	.001020	.002013	.016014	.000347	.000878	.000989	.003356	.001797	.004806	.003988
10	WHOLESALE	.030609	0.000000	.110320	.000268	.005519	.029765	.003356	.007161	.008548	0.000000
11	RETAIL	.001403	.050585	.040332	.008185	.014327	.023073	.027364	.001247	.019563	.410686
12	RESTAURANT	.000004	0.000000	0.000000	.004236	0.000000	.001251	.000194	0.000000	.000255	.033611
13	HOTEL-MOT	0.000000	0.000000	0.000000	.000198	0.000000	0.000000	.000194	0.000000	.012801	.001133
14	FIRE	.007614	.005758	.148873	.009624	.035248	.033577	.064795	0.000000	.016118	.118469
15	HEALTH SER	0.000000	0.000000	0.000000	0.000000	.020160	0.000000	.000065	.002580	.011738	.047076
16	SERV NEC	.021992	.033240	.011862	.029476	.020121	.024586	.009681	.014902	.023901	.037998
17	SCHOOLS	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	.001276	.314706	0.000000
18	COLLEGES	0.000000	0.000000	0.000000	0.000000	0.000000	.000058	.002194	0.000000	.000128	.003780
19	LOCAL GOVT	.006667	.005723	.017200	.005199	.008691	.015450	.002065	0.000000	.010249	.014382
20	HOUSEHOLDS	.089895	.191282	.282918	.134265	.277907	.251738	.683833	.787406	.355023	.003392
21	FED-ST GOV	.020659	.031262	.024318	.040995	.018207	.040647	0.000000	.063578	.017862	.179384
22	PROFIT DEP	.040603	.144583	.199288	.307561	.436281	.371672	.001162	.013771	.140384	.037641
23	IMPORTS	.755074	.154227	.021945	.436796	.145672	.170153	.145466	.059809	.027303	.042538

* Each column represents a distribution of input requirements by the sector shown at the column heading.

TABLE 5.5 Greeley direct plus indirect production requirements.*

Technical Coefficients

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	1.0086	.0088	.0077	.0043	.0106	.0079	.0027	.0031	.0037	.0019
2	PRINT-PUB	.0024	1.0055	.0069	.0204	.0105	.0082	.0031	.0039	.0053	.0016
3	MFG NEC	.0040	.0112	1.0375	.0225	.0142	.0103	.0060	.0040	.0049	.0026
4	CONST	.0179	.0057	.0062	1.1939	.0086	.0062	.0047	.0019	.0205	.0010
5	TRANSPORT	.0105	.0024	.0114	.0024	1.0035	.0029	.0010	.0012	.0019	.0165
6	COMMUNICAT	.0094	.0167	.0150	.0098	.0368	1.0169	.0061	.0074	.0099	.0051
7	ELECTRICTY	.0097	.0149	.0133	.0061	.0193	.0157	1.0036	.0053	.0251	.0033
8	NAT GAS	.0089	.0082	.0094	.0083	.0213	.0080	.0028	1.0033	.0052	.0028
9	WATER-SAN	.0016	.0055	.0033	.0160	.0051	.0036	.0014	.0015	1.0018	.0009
10	WHOLESALE	.0121	.0413	.0167	.0670	.0187	.0107	.0040	.0046	.0331	1.0027
11	RETAIL	.0811	.2393	.2115	.1441	.4811	.2402	.0767	.0924	.1138	.0599
12	RESTAURANT	.0081	.0177	.0163	.0104	.0264	.0189	.0061	.0071	.0089	.0047
13	HOTEL-MOT	.0003	.0008	.0018	.0008	.0013	.0018	.0010	.0010	.0008	.0003
14	FIRE	.0401	.1601	.1019	.1580	.2083	.2599	.0743	.0635	.2190	.0238
15	HEALTH SER	.0081	.0243	.0237	.0159	.0366	.0264	.0089	.0105	.0117	.0066
16	SERV NEC	.0138	.0834	.0511	.0486	.0748	.0419	.0166	.0231	.1051	.0176
17	SCHOOLS	.0025	.0048	.0053	.0101	.0098	.0285	.0187	.0195	.0129	.0025
18	COLLEGES	.0007	.0024	.0018	.0011	.0029	.0021	.0007	.0008	.0009	.0005
19	LOCAL GOVT	.0080	.0154	.0170	.0322	.0311	.0906	.0593	.0619	.0410	.0080
20	HOUSEHOLDS	.1653	.5011	.4670	.2872	.7542	.5268	.1699	.2025	.2333	.1357

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 HOUSEHOLDS
1	FOOD PROC	.0019	.3351	.0065	.0040	.0051	.0053	.0234	.0130	.0148	.0160
2	PRINT-PUB	.0108	.0065	.0110	.0103	.0061	.0070	.0079	.0109	.0144	.0086
3	MFG NEC	.0026	.0065	.0090	.0036	.0068	.0087	.0167	.0176	.0152	.0217
4	CONST	.0019	.0083	.0435	.0035	.0027	.0054	.0059	.0095	.0136	.0073
5	TRANSPORT	.0016	.0046	.0042	.0015	.0027	.0068	.0129	.0049	.0069	.0034
6	COMMUNICAT	.0082	.0453	.0584	.0138	.0164	.0147	.0270	.0351	.0280	.0288
7	ELECTRICTY	.0104	.0186	.0392	.0057	.0102	.0119	.0294	.0292	.0244	.0184
8	NAT GAS	.0035	.0116	.0193	.0039	.0071	.0178	.0229	.0236	.0193	.0133
9	WATER-SAN	.0018	.0041	.0190	.0014	.0028	.0029	.0076	.0065	.0100	.0057
10	WHOLESALE	.0340	.0113	.1226	.0050	.0129	.0375	.0186	.0233	.0258	.0187
11	RETAIL	1.0582	.1917	.2300	.0873	.1668	.1681	.3806	.3954	.3342	.4862
12	RESTAURANT	.0046	1.0120	.0159	.0107	.0125	.0131	.0292	.0322	.0253	.0398
13	HOTEL-MOT	.0003	.0006	1.0010	.0006	.0007	.0007	.0015	.0014	.0141	.0017
14	FIRE	.0296	.0657	.2314	1.0395	.0892	.0857	.1850	.1336	.1460	.1587
15	HEALTH SER	.0065	.0158	.0217	.0090	1.0381	.0166	.0406	.0481	.0471	.0562
16	SERV NEC	.0316	.0565	.0484	.0424	.0439	1.0480	.0617	.0700	.0735	.0664
17	SCHOOLS	.0036	.0061	.0117	.0036	.0060	.0083	1.0078	.0091	.3247	.0086
18	COLLEGES	.0005	.0013	.0017	.0007	.0014	.0014	.0054	1.0036	.0036	.0044
19	LOCAL GOVT	.0114	.0195	.0373	.0113	.0192	.0264	.0249	.0250	1.0319	.0273
20	HOUSEHOLDS	.1320	.3226	.4405	.1846	.3595	.3395	.8362	.9383	.7220	1.1616

* Each cell shows the added purchases by all sectors from the sector row heading when the sector at the column head expands sales to exports by $1.

any other production sector. The estimate of the direct and indirect production impacts of a change in final demand include the induced production impacts which derive from increased household incomes and increased consumption. In the latter, with households a component in final demand, the induced impacts of successive rounds of consumer spending are omitted. For purposes of this report, the discussion of economic interdependencies and the subsequent business and income multiplier analysis is based upon the model which includes households as a member of the processing sector of the economy.

The direct plus indirect coefficients, shown in Table 5.5, are interpreted as the production required or generated in all sectors of the economy in order to sustain the delivery of one dollar's worth of output to final demand by any single sector. It should be carefully noted that these coefficients reflect production generated per dollar of final demand (exports) as opposed to requirements per dollar of output. This, of course, reflects the fact that the model is driven by changes in final demand.

5.6.4 Business Multipliers

The column sums of the direct plus indirect requirements table are termed business activity (or production) multipliers. They identify the total value of production in the region which results from a dollar's worth of output delivered to final demand. Table 5.6 presents the business multipliers. These estimates indicate that the greatest business activity generated per dollar of delivery to final demand is the local government sector. The business multiplier for this sector is 2.93 which indicates that, as the "final demand" for city and county government services increases by $1, a total production of $2.93 is generated in the Greeley economy. Other sectors of the economy which have relatively large business multipliers are: College, 2.88; transport, 2.81; education, 2.79; hotels-motels, 2.40; and communication, 2.36. These sectors show the greatest degree of interdependence with other sectors of the regional economy.

TABLE 5.6 Business multipliers for the Greeley economy.*

	Sector	Multiplier
1.	Food Processing	1.421
2.	Printing and Publishing	2.195
3.	Manufacturing N.E.C.	2.049
4.	Construction	2.074
5.	Transportation	2.814
6.	Communication	2.355
7.	Electricity	1.476
8.	Natural Gas	1.529
9.	Water and Sanitation	1.871
10.	Wholesale	1.305
11.	Retail	1.362
12.	Restaurants	2.160
13.	Hotel-Motel	2.395
14.	FIRE	1.452
15.	Health Services	1.829
16.	Services N.E.C.	1.843
17.	Schools	2.788
18.	Colleges	2.879
19.	Local Government	2.932
20.	Households	2.213

These sectors will generate the greatest business activity per added dollar of output delivered to final demand. In using the business multipliers, the argument should be stated in terms of the impacts of an equal dollar increase in final demands. That is, for an equal increase (in dollar terms) in final demands, local government will generate more business activity in the local economy than will any other sector. However, a large exogenous increase in local government may be less likely to occur than would a large increase in some other sector (which indirectly changes requirements for local government services).

5.6.5 Income Multipliers

Other multiplier effects can also be estimated from the interindustry model. For example, there are income multipliers which relate to changes in income paid to the household sector. The following discussion presents what are termed the Type I and Type II income multipliers.

The Type I and Type II income multipliers are estimated ratios: Type I is the ratio of the direct plus indirect income to the direct income paid households; Type II is the ratio of direct plus indirect plus induced income to direct income. Thus, while the business activity multipliers are related to changes in sales to final demand, the income multipliers are related to changes in income paid to the household sector. The Type I multiplier describes the direct plus indirect income increases emanating from an additional dollar of direct income paid to households. The Type II multiplier takes into account not only the direct plus indirect changes in income, but also the induced income increases generated by additional consumer spending. Accordingly, the Type II income multiplier identifies the direct plus indirect plus induced income generated by an additional dollar of income paid directly to households. The income multipliers for Greeley are shown in Table 5.7.

TABLE 5.7 Income multipliers for Greeley, Colorado.*

	Sector	Type I	Type II
1.	Food Production	1.183627	1.384795
2.	Printing and Publishing	1.102639	1.290043
3.	Manufacturing N.E.C.	1.106276	1.294298
4.	Construction	1.622492	1.898249
5.	Transportation	1.098364	1.285041
6.	Communication	1.218380	1.425455
7.	Electricity	1.441722	1.686765
8.	Natural Gas	1.342420	1.570576
9.	Water and Sanitation	1.700169	1.989128
10.	Wholesale	1.171084	1.370120
11.	Retail	1.264149	1.479002
12.	Restaurants	1.451984	1.698762
13.	Hotel-Motel	1.340325	1.568125
14.	FIRE	1.183352	1.384473
15.	Health Services	1.113677	1.302956
16.	Services N.E.C.	1.160938	1.368250
17.	Schools	1.052702	1.231618
18.	Colleges	1.035858	1.200211
19.	Local Government	1.750771	2.048330

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* Change in dollars of total transactions in Greeley per dollar of change in exports by the sector indicated.

* Change in total Household income in Greeley per dollar change in salaries and wages paid by the sector indicated.

5.7 SPACE HEATING ENERGY USE MULTIPLIERS

Estimates of total and sector-by-sector space heating energy use are useful from a purely descriptive point of view. However, the model also allows the analysis of direct and indirect energy use which parallels the previous discussion of direct and indirect production. The purpose of such analysis is to isolate the effect of economic interdependence on space heating energy requirements. The specific question to be addressed is that of determining the likely impact of expanding final demand in any or all processing sectors on Greeley space heating energy demand. The key element in the assessment is the derivation of the direct plus indirect space heating energy requirements per dollar of output delivered to final demand.

The procedure is really quite simple once the direct energy requirements and the table of direct plus indirect production requirements have been obtained. The matrix of direct and indirect production coefficients is premultiplied by a diagonal matrix consisting of the direct energy requirements per dollar of output delivered to final demand by each sector. The resulting matrix for the Greeley economy is shown in Table 5.8. This table shows the energy requirements at a temperature of 14.1°F. Similar tables were constructed for each temperature level. The importance of considering indirect as well as direct energy requirements in the planning perspective can be readily seen by comparing Table 5.3 and 5.9. Consider, for example, the direct space heating energy requirements for schools with an average temperature of 14.1°. The direct requirements are .81 cu. ft. of gas per month for each dollar of output. However, as the final demand for the output of the school sector expands by one dollar, there is a total direct plus indirect monthly gas requirement of 1.86 cu. ft. developed throughout the economy. The indirect impact (1.86 - .81 = 1.05) exceeds the direct requirement because the significant interdependencies within and between schools and other sectors are more important. Applying only the direct energy requirement to assumed increases in deliveries to final demand can obviously result in an understatement of space heating energy use.

5.8 PROJECTIONS OF SPACE HEATING ENERGY USE IN GREELEY

The final product of the Greeley input-output model space heating energy analysis is the sector-by-sector projections of space heating energy requirements for specific average monthly temperatures. These estimates are made by utilizing the space heating energy requirements per dollar as presented in Table 5.3 and the projected output in dollars by sector as shown in Appendix 5B. On the lower half of the projected Greeley transactions tables are shown the projected space heating energy requirements by sector for five average monthly temperatures.

TABLE 5.8 Greeley direct plus indirect space heating gas requirements at 14.1°F.

	1. Food Prod.	2. Print-Pub.	3. Mfg. N.E.C.	4. Const.	5. Transport.	6. Communicat.	7. Electricity	8. Nat. Gas	9. Water-San.	10. Wholesale
1. Food Production	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Printing & Publishing	0.00	0.52	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
3. Manufacturing N.E.C.	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Construction	0.01	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.01	0.00
5. Transportation	0.02	0.00	0.02	0.00	1.88	0.01	0.00	0.00	0.00	0.03
6. Communication	0.00	0.00	0.00	0.00	0.01	0.14	0.00	0.00	0.00	0.00
7. Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
8. Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
9. Water and Sanitation	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.39	0.00
10. Wholesale	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.11
11. Retail	0.04	0.10	0.09	0.06	0.21	0.10	0.03	0.04	0.05	0.03
12. Restaurants	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
13. Hotel-Motel	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00
14. Fire	0.01	0.04	0.02	0.04	0.05	0.06	0.02	0.01	0.05	0.01
15. Health Services	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00
16. Services N.E.C.	0.01	0.03	0.02	0.02	0.03	0.02	0.01	0.01	0.04	0.01
17. Schools	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.00
18. Colleges	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19. Local Government	0.01	0.02	0.02	0.03	0.03	0.09	0.06	0.06	0.04	0.01
20. Households	0.14	0.43	0.40	0.25	0.65	0.45	0.15	0.17	0.20	0.12

	11 Retail	12 Restaurant	13 Hotel-Motel	14 Fire	15 Health Ser.	16 Serv. N.E.C.	17 Schools	18 Colleges	19 Local Govt.	20 Households
1. Food Production	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Printing & Publishing	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
3. Manufacturing N.E.C.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Construction	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00
5. Transportation	0.00	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01
6. Communication	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7. Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8. Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9. Water and Sanitation	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10. Wholesale	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11. Retail	0.44	0.08	0.10	0.04	0.07	0.07	0.17	0.17	0.15	0.21
12. Restaurants	0.00	0.22	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
13. Hotel-Motel	0.00	0.00	4.34	0.00	0.00	0.00	0.01	0.01	0.06	0.01
14. Fire	0.01	0.02	0.05	0.23	0.02	0.02	0.04	0.03	0.03	0.04
15. Health Services	0.00	0.00	0.01	0.00	0.24	0.00	0.01	0.01	0.01	0.01
16. Services N.E.C.	0.01	0.02	0.02	0.02	0.02	0.37	0.02	0.03	0.03	0.02
17. Schools	0.00	0.01	0.01	0.00	0.00	0.01	0.81	0.01	0.26	0.01
18. Colleges	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.00
19. Local Government	0.01	0.02	0.04	0.01	0.02	0.03	0.02	0.02	0.97	0.03
20. Households	0.11	0.28	0.38	0.16	0.31	0.29	0.72	0.81	0.62	1.00

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* Each cell shows the added cu. ft. of gas purchased by the sector at the left when the sector at the column head expands sales to exports by $1 when average temperature is 14.1°F. Similar tables were constructed for average temperatures of 17.3°, 29.7°, 34.0° and 40.8°.

TABLE 5.9 Specific industry growth economic natural gas multipliers.*

	Sector	Direct Plus Indirect Gas Requirement				
		14.1°	17.3°	29.7°	34.0°	40.8°
1.	Food Processing	0.26	0.25	0.19	0.19	0.18
2.	Printing and Publishing	1.16	1.13	0.85	0.84	0.80
3.	Manufacturing N.E.C.	0.72	0.70	0.52	0.52	0.49
4.	Construction	0.92	0.89	0.67	0.66	0.63
5.	Transportation	2.87	2.80	2.11	2.11	2.03
6.	Communication	0.91	0.89	0.66	0.66	0.63
7.	Electricity	0.31	0.30	0.23	0.23	0.22
8.	Natural Gas	0.36	0.35	0.26	0.26	0.25
9.	Water and Sanitation	0.81	0.78	0.59	0.58	0.56
10.	Wholesale	0.31	0.30	0.23	0.23	0.22
11.	Retail	0.60	0.59	0.44	0.44	0.42
12.	Restaurants	0.67	0.66	0.49	0.49	0.47
13.	Hotels-Motels	5.00	4.88	3.77	3.78	3.73
14.	FIRE	0.48	0.46	0.35	0.34	0.33
15.	Health Services	0.70	0.68	0.51	0.51	0.49
16.	Services N.E.C.	0.82	0.80	0.60	0.59	0.57
17.	Schools	1.84	1.80	1.37	1.36	1.33
18.	College	1.75	1.71	1.29	1.28	1.23
19.	Local Government	2.17	2.11	1.59	1.58	1.52
20.	Households	1.34	1.32	0.98	0.97	0.93

* Additional cubic feet of gas per month required by the total Greeley economy for a $1 increase in sales to export by the sector indicated. Obtained by summing the columns of Table 5.8 and similar tables for each of the five temperature levels.

In Table 5.10 the projected energy requirements for space heating, summed over all economic sectors, are presented for extremely cold and warm weather situations. The Greeley transactions tables, Appendix 5B, show projected interindustry transactions for the years, 1983, 1988, 1993, 1998 and 2003. In order to publish the industry detail desired, it was not possible to show transactions for 1978. To do so, might violate disclosure laws and would also violate the confidence of those taking part in the industry survey. In order to prohibit "working backwards" to find the 1978 control totals by industry, we also cannot reveal the particular scenario of export growth which was used to generate the various future projected transaction tables. The scenario used was fairly consistant with recent history and is presented as a feasible (but not necessarily the best) prediction of future growth trends in Greeley. A great deal more study of individual industries' future growth potentials would be required to obtain the "best" futures projection.

Neither time nor resources allows such a detailed study of expected future exports at this time. Nevertheless, the projections presented here are suggestive of the type of forecast possible using an input-output technique.

The projected use of natural gas for space heating assumes that no substitution of other fuels, insulation or other devices occurs over the forecast period. A more sophisticated projection could include adjustments for these phenomena.

One interesting outcome of the projections concerns the growth of energy requirements for space heating. Whereas the projection scenario assumed constant rates of change of exports over time, the business activity generated increases at an increasing rate (see Table 5.11). Evidently the sectors which are most stimulated by the export growth are above average in their interdependence with other sectors.

TABLE 5.10 Projected extreme weather space heating gas use in Greeley, 1978-2003.*

Year	Gas Consumption at 14.1°F (1,000 cu. ft. per month)	Gas Consumption at 40.8°F (1,000 cu. ft. per month)
1978	677,939	463,841
1983	911,900	624,479
1988	1,249,673	856,495
1993	1,784,169	1,223,823
1998	2,679,766	1,839,445
2003	4,277,926	2,937,699

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* Assuming continued economic growth and no substitution or technological change in the use of natural gas for space heating. Taken from the tables in Appendix 5B.

TABLE 5.11 Effect of industry mix on gas use for space heating.**

Period	Growth in $ Transactions*	Growth in Gas Used for Space Heating (at 14.1°F)
1983/1978	37%	35%
1988/1983	41%	37%
1993/1988	47%	43%
1998/1993	56%	50%
2003/1998	66%	60%

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* Five-year growth rates; an annual average growth rate to achieve 35% in 5 years would be about 6 percent. By the end of the period the annual growth rate is projected at 10 percent for space heating energy use.

** Calculated from Table in Appendix 5B and Table 5.10

Thus, the change in industry mix over time results in ever increasing amounts of transactions to generate the same proportional increase of exports. In like manner, the consumption of natural gas for space heating rises at an ever increasing rate. Scarcity, rising prices and factor substitution may prevent this from actually happening. However, it does suggest that continued growth along recent trends may result in rapid expansion in the processing sector in Greeley and concommitant increases in space heating energy requirements.

5.9 DEPENDENCE OF THE GREELEY ECONOMY ON NATURAL GAS SUPPLIES

For most industries, an interruption of gas service results in the use of far more expensive backup energy sources, such as coal, oil, propane or electricity. The additional costs may result in industry losses and reduced business activity. Marginal firms may be forced to suspend operations. Furthermore, backup fuel supplies may be inadequate if an extended period of gas shortage should occur. Severe reduction of industrial production might then ensue. The Greeley economy is strongly biased towards industries which depend mainly upon energy for space heating. Warehousing (part of transportation), education, wholesale and retail trade, services and government now dominate the economy. These sectors, plus households, require energy mainly for space heating. Although current expenditures for energy are relatively low (see Table 5.12), the marginal cost of energy required for future growth may greatly exceed the average cost. The local economy could be severely impacted by natural gas shortages if projected trends in economic growth continue unchecked.

Conservation of space heating energy affecting a 30% reduction in energy use, while necessary, may not provide a lasting solution. Reference to Table 5.11 shows that gas consumption will rise from an annual growth rate of 6% to over 10% within 20 years. A 30% conservation would free up enough gas to allow three added years of growth if a lid were imposed on gas use in 1993. Clearly, conservation will not provide a total solution.

The input-output model can provide some indicators of the sectors which are likely to be most affected by the costs of switching to alternative fuels and to suffer impacts caused by shortages of inputs from other sectors and/or by loss of markets when customers are impacted by gas shortages.

Certain of the sectors are more important to employment in Greeley than others because they have more interdependence with the rest of the Greeley economy. One measure of this interdependence is the employment multiplier. The multipliers shown in Table 5.13 indicate that education, hotels-motels, local government, and transportation provide the most employment stimulus per dollar of exports. Unfortunately, these are also among the largest space heating energy users in the city. (Note: a considerable amount of food processing and federal government business activity lies just outside the city limits and was excluded from the processing portion of the model.) Table 5.9 shows that the space heating gas multipliers are highest for hotel-motel, local government, transportation and schools. There is evidence hat food processing requires high energy inputs lthough the portion included in the model (inside the city limits) does not reflect this general tendency. A further indicator of susceptibility to energy shortages lies in the projected growth trends for each

TABLE 5.12 Percent of total costs allocated for natural gas by industry, 1978.

	Sector	Natural Gas Expense as a % of Total Expense*
1.	Food Processing	0.66
2.	Printing and Publishing	0.15
3.	Manufacturing N.E.C.	0.33
4.	Construction	0.34
5.	Transportation	1.17
6.	Communication	0.07
7.	Electricity	0.01
8.	Natural Gas	0.01
9.	Water and Sanitation	0.06
10.	Wholesale	0.08
11.	Retail	0.15
12.	Restaurants	0.49
13.	Hotels-Motels	1.30
14.	FIRE	0.11
15.	Health Services	0.24
16.	Services N.E.C.	1.31
17.	Schools	1.28
18.	College	1.26
19.	Local Government	0.60
20.	Households	0.90

* Total expense includes taxes, rent, interest, profit and savings, as well as all direct costs. The I-O accounts are not margined, thus the trade sectors expense includes total costs of goods sold.

TABLE 5.13 Employment multipliers in the Greeley economy.

	Sector	Direct Requirement[1]	Indirect Requirement[2]	Multiplier[3]
1.	Food Processing	6	6	12
2.	Printing and Publishing	37	13	50
3.	Manufacturing N.E.C.	32	13	45
4.	Construction	13	15	28
5.	Transportation	50	20	70
6.	Communication	22	19	41
7.	Electricity	12	8	20
8.	Natural Gas	9	9	18
9.	Water and Sanitation	6	14	20
10.	Wholesale	7	4	11
11.	Retail	17	5	22
12.	Restaurants	52	13	65
13.	Hotels-Motels	62	17	79
14.	FIRE	11	6	17
15.	Health Services	29	10	39
16.	Services N.E.C.	39	11	50
17.	Schools	89	19	108
18.	College	82	19	101
19.	Local Government	42	47	89
20.	Households	1	20	21
21	Federal-State Government	1	-	-

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[1] Direct employment by the sector indicated per million dollars of sales.

[2] Employment induced throughout the Greeley economy due to a one million dollar increase in sales to final demand by the sector indicated.

[3] Direct employment plus employment induced throughout the Greeley economy for a one million dollar increase in sales to final demand by the sector indicated.

industry as shown in Table 5.14. Very rapid growth is projected for employment (growth of output is proportional) in the manufacturing sector. Very rapid growth is also expected in health services. The extremely rapid growth in manufacturing indicates a change in the basic structure of the economy which is currently dominated by trade and services.

Sectors which experience wide variations in natural gas use because of temperature change are more likely to experience unexpected shortfalls or unpredictable operating cost variations during the peak gas consumption periods. Peaking requirements for the city will expand if those industries with temperature sensitivite energy use expand more rapidly than the total economy. Table 5.15 shows the relative degree of sensitivity of gas consumption to temperature by sector. Households, food processing, manufacturing, utilities, financial services and local government all show above average peaking due to temperature variation. The high projected growth for manufacturing (see Table 5.14) may imply an increase in peak loads on gas service.

From the standpoint of social planning, the single most important variable is probably employment. Both short-term disruption and longer run cost inflation tendencies are indicated for energy intensive sectors. The relationship of employment and energy shortfall is an important one. Table 5.16 provides an indication of the relative sensitivity of employment in Greeley (both direct and indirect) by sector to a shortfall of natural gas directly required by the sector. From this standpoint, natural gas services , electric services, food processing, manufacturing and communciation show the strongest vulnerability of employment to gas shortages.

Table 5.17 provides a summary of the indicators of vulnerability to natural gas shortages. It is interesting to note that no single sector is critical with regard to all of the indicators. However, the manufacturing sectors with their extremely high projected growth also show high peaking to temperature variation and high employment impacts. Perhaps the stability of the local economy will be adversely affected by a change toward manufacturing vis-a-vis trade and services. Health services is another sector with well above average growth expectations. Unlike manufacturing however, health services is already a significant part of the Greeley economy. Although growing less rapidly than manufacturing, health services, because of its larger base size, nearly equals manufacturing in employment by 2003. These two sectors alone, account for about 90,000 workers in 2003 (see Table 5.14). The rapid expansion of health service industries appears less troubled by instability and growth problems due to energy shortages. Table 5.17 shows that health services has little vulnerability except in the case of the dependence of employment to gas inputs. Overall, health services appears to be one of the better choices for high growth in the economy of Greeley.

5.10 FUTURE APPLICATION OF THE MULTIPLIERS

Projections of the economy and of space heating requirements may be accomplished without added computer processing by simply making use of the business multipliers, employment multipliers and natural gas for space heating multipliers presented earlier. For example, if one had reason to expect an expansion of exports by the hotel and motel sector of say, $1,000,000 the business multiplier of 2.4 would lead one to expect total business activity to be stimulated (by this one change in exports) by the total amount of $2,450,000. The natural gas for space heating multiplier of 5.01 would indicate that gas consumption for space heating would rise by about 5,010,000 cu. ft. per month.[1] In like manner, an employment increase of 79 workers would be predicted. If a great deal of expansion is expected in sectors such as hotel-motel, transportation or local government, natural gas use will rise much more rapidly than business activity. Any desired scenario of export change can be projected by simply performing the steps shown above. Since the model is linear, the effects of each separate change in exports can be cumulated to find the total projected change in natural gas use from concurrent export changes in several sectors. Thus, the table of business multipliers, the employment multipliers and the table of space heating natural gas multipliers can be useful for researchers and planners in the future.

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[1] If only the direct requirement for gas by hotel-motel had been considered, the forecast would only be for an additional 4,335,710 cu. ft. per month.

TABLE 5.14 Greeley projected potential employment by sector (full time equivalent workers).

Sector		1983	1988	1993	1998	2003	Ratio 2003 to 1983 Employment
1.	Food Processing	598	786	1036	1376	1845	3.09
2.	Printing and Publishing	323	445	635	949	1503	4.65
3.	Manufacturing N.E.C.	1638	3549	8081	18952	45199	27.59
4.	Construction	1301	1705	2240	2956	3929	3.02
5.	Transportation	336	486	730	1159	1963	5.84
6.	Communication	495	676	957	1419	2229	6.63
7.	Electricity	149	206	297	455	745	5.00
8.	Natural Gas	88	120	173	262	426	4.84
9.	Water and Sanitation	37	50	69	99	149	4.03
10.	Wholesale	1312	1836	2580	3644	5187	3.95
11.	Retail	5090	6861	9585	14024	21751	4.27
12.	Restaurants	1926	2590	3564	5057	7479	3.88
13.	Hotels-Motels	153	231	358	570	936	6.12
14.	FIRE	1464	1998	2829	4199	6613	4.52
15.	Health Services	3814	6867	12641	23640	44710	11.72
16.	Services N.E.C.	1804	2518	3685	5715	9478	5.25
17.	Schools	1842	2485	3401	4750	6826	3.71
18.	Colleges	3363	4076	5044	6373	8225	2.45
19.	Local Government	1321	1799	2523	3675	5626	4.26
20.	Households	316	427	601	890	1403	4.44
21	Federal-State Government	207	277	371	497	665	3.21

TABLE 5.15 Sensitivity of sector space heating energy requirements to temperature.

Sector	Percentage Increase in Natural Gas Use When Average Monthly Temperature Falls from 40.8F to 14.1F
1. Food Processing	49
2. Printing and Publishing	46
3. Manufacturing N.E.C.	48
4. Construction	46
5. Transportation	39
6. Communication	46
7. Electricity	46
8. Natural Gas	46
9. Water and Sanitation	46
10. Wholesale	43
11. Retail	41
12. Restaurants	40
13. Hotels-Motels	32
14. FIRE	46
15. Health Services	35
16. Services N.E.C.	43
17. Schools	32
18 Colleges	36
19. Local Government	44
20. Households	50
21 Federal-State Government	41

TABLE 5.16 Greeley employment vulnerability to gas shortages (full time equivalent workers).

Sector	Direct Plus Indirect Employment Loss Per Direct 1,000,000 Cu. Ft. Loss of Natural Gas	
	14.1°	40.8°
1. Food Processing	557	830
2. Printing and Publishing	96	140
3. Manufacturing N.E.C.	384	570
4. Construction	59	85
5. Transportation	48	52
6. Communication	296	431
7. Electricity	833	211
8. Natural Gas	563	819
9. Water and Sanitation	51	74
10. Wholesale	81	115
11. Retail	50	71
12. Restaurants	295	412
13. Hotels-Motels	18	24
14. FIRE	72	105
15. Health Services	163	220
16. Services N.E.C.	135	192
17. Schools	133	176
18 Colleges	158	215
19. Local Government	91	131
20. Households	21	32

TABLE 5.17 Relative vulnerability of sectors to gas shortages.

Sector	Input Cost Rise[1] or Shortages	Loss of[2] Customers	Employment[3] Vulnerability	Sensitivity to[4] Temp. Variation	Projected[5] Growth
1. Food Processing	L	L	VH	H	L
2. Printing and Publishing	M	H	M	H	L-M
3. Manufacturing N.E.C.	L	M	H	H	VH
4. Construction	L	H	L	H	L
5. Transportation	M-H	H	L	M	M
6. Communication	L	H	H	H	M
7. Electricity	L	H	VH	H	M
8. Natural Gas	L	H	VH	H	M
9. Water and Sanitation	L	H	L	H	L-M
10. Wholesale	L	L	M	H	L-M
11. Retail	L	H	L	M	L-M
12. Restaurants	L	M	M	M	L
13. Hotels-Motels	H	M	L	L	M
14. FIRE	L	H	M	H	M
15. Health Services	L	L	M	L	H
16. Services N.E.C.	L	H	M	H	M
17. Schools	M	H	M	L	L
18 Colleges	M	M	M	L	L
19. Local Government	M	H	M	H	L-M
20. Households	M	H	L	H	M

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[1] Based upon the relative size of the gas input multiplier. The larger the multiplier the greater the chance of supply interruption or price rise for inputs. Source: Table 4.

[2] Based upon the percentage of sales made within Greeley. The forward linkage indicates both a sensitivity to local business conditions and also the dependence of the Greeley economy on the sector indicated for inputs to other sectors.

[3] Based upon all adjusted employment multiplier on sales and the ratio of sales to gas input by industry. An indicator of how gas shortages will affect total employment when gas is restricted for a given sector.

[4] Ratio of gas required for space heating at 14.1F to that required at 40.8F. Source: Table 7.

[5] Ratio of projected employment for the year 2003 divided by projected employment for the year 1983.

KEY: L = Low, M = Medium, H = High, VH = Very High.

6. EXECUTIVE SUMMARY

6.1 RESEARCH TASKS:

The research efforts between January 1, 1978 and March 31, 1980 were concerned with

1. Causes of interannual atmospheric variability.
2. Effects of sea-surface temperature anomalies on planetary wave patterns.
3. Planetary wave patterns and regional weather anomalies.
4. Energy demand by a large metropolitan area.
5. Parameterized modelling approaches.
6. Non-stationary modelling aspects.
7. Modelling applications to user problems.
8. Economic impact.

Progress on items 1, 2 and 3 was reported extensively elsewhere (Reiter, 1979, Middleton, 1980, Ding and Reiter, 1980). The present report, which is also the final report for the above-mentioned grant period, concerns itself with items 4 through 8.

6.2 MODELLING OF ENERGY CONSUMPTION

The energy consumption by the city of Minneapolis, Minnesota, was modelled successfully for two winter seasons. A physical model and a statistical reference (regression) model were tuned during the evaluation period, 11/1/77 to 2/28/78, and then applied to the period of independent data (prediction period), 1/1/79 to 3/31/79. Statistical tests accept the null hypothesis that the residual time series (observed minus computed energy consumptions) are random. The performance indices, expressed as daily absolute errors, were 6.26% and 5.54% for the physical and statistical reference models, respectively, over the time period 12/1/77-2/28/78. Applications of these two models to the period 1/1/79-3/31/79 yielded daily absolute errors of 5.39% and 5.94%.

Energy use in the city of Cheyenne, Wyoming, was reexamined using newly acquired energy consumption data for 1975-76. Since meteorological data were avaiable for that season only from the airport station of the National Weather Service, urban distributions of meteorological elements derived from our special network operative during the 1976-77 winter had to be used to generate local meteorological model input data for 1975-76. Application of the adaptive identification framework rejected the null hypothesis that the sequence of unexplained energy consumption values were random, when the model developed for the 1975-76 season was applied to 1976-77. Reexamination of our input data revealed that during 1976-77 the use of processing gas by an interruptible customer was subtracted from the total daily gas consumption in Cheyenne, using wrong line pressure values. A redesign of the physical model for Cheyenne yielded the conclusion that building modules tested for Greeley were interchangable with those representing Cheyenne.

Preliminary model applications to the 1978-79 winter season in Greeley, Colorado, provide firm indications that the energy use patterns of this community have changed significantly during the past two years, mainly due to the addition of new structures. For a final model run to check for the effectiveness of energy conservation measures we have t await a forthcoming, updated building census.

A comparison between the energy uses in these three communities revealed that the per capita energy use as a function of average daily temperature is significantly less in Minneapolis than in Greeley and Cheyenne, due to more conservative building practices that have prevailed for many years in the colder northern climate.

Application of the physical model to census block areas permits a detailed evaluation of the geographic distribution of energy demand within a city. In Minneapolis the city region has been subdivided into 127 such areas. A predominant energy use for space heating in the downtown core areas became apparent. Application of model outputs to the planning of alternative energy systems can be advocated.

Preliminary model development for the cooling season, applied to several buildings in Ft. Collins, indicated midday wet bulb temperature to be a more important parameter than dry bulb temperature. Surprisingly, solar radiation was rejected as significant input to the model. However, operating schedules for building occupancy proved to be a parameter of consequence. Inefficiencies of a dual-duct air conditioning system could be pointed out.

6.3 ENERGY MODEL INPUT DATA

The generation of an urban heat island, and the simultaneous reduction in wind speed can affect local energy demand by as much as 20%. It was necessary, therefore, to monitor in detail the local distribution of meteorological parameters with the aid of a station network specially installed in Minneapolis. Nevertheless, a considerable amount of data massaging was required to interpolate for missing data. The mean heat-island intensity (urban-rural temperature difference) was about 2°C during the abnormally cold monitoring period in early 1979. Extreme heat island intensities of 7°C were observed on occasion, but were probably still underestimated. The effects of anthropogenic heat on the formation of the urban heat island could be demonstrated quite clearly. Under light-wind conditions cold-air drainage lends some importance even to relatively minor tropographic details.

The acquisition of building census data for Minneapolis was a formidable task. Only 13% of the total number of heated structures had any use pattern information that could be extracted from the assessor's computerized files. Use information could be supplemented for approximately 4500 buildings, by addresses, from the Yellow Pages telephone directory. 1200 structures, occupied by interruptible customers, were removed from our census files, including 20 downtown buildings linked to a central heating system not supplied by the utility company that provided our data. Our final census file contained 105,722 buildings. The city was divided into 127 census tracts. Missing size or structural data were substituted by using the average values for such parameters obtained for the remainder of the buildings of the same type within the respective census tract.

A comparison of building census data from M neapolis with similar data from Greeley and Cheye shows relatively larger percentages of residential structures, but relatively higher energy use for space heating by commercial buildings in Minneapolis than in the other two cities.

A further complication arose from the fact that daily natural gas send-out data were not available for the Minneapolis city proper, but for a much larger area for which, on the other hand, no detailed building census could be obtained. The average ratio between monthly gas consumption within the city limits and in the wider area (both sets of values were available for the Minnesota Gas Company) was used as a weighting factor to arrive at daily send-out information for the city of Minneapolis.

6.4 THE DECISON TO CONSERVE: INSULATION AS A TEST CASE.

It is all too often presumed that economic factors are the prime motivators for conservation. From our investigation it appears, however, that homeowners have not made full use of the conservation options open to them. It was assumed that decisions to retrofit and conserve are made, following a model of "bounded rationality", i.e. prescribing that man is basically reasonable, but is subject to a series of self-imposed or external constraints. Our investigation seriously questioned the premise that an equation objectively yielding the net present value of an energy conservation device stands at the core of an individual's decision-making process. Two sets of families, those who had insulated their homes in the last five years and those who had not, were questioned along the points of a "decision tree". To this purpose a detailed questionnaire was developed. A roster of adopters and nonadopters was obtained through the aid of a reputable, local insulating firm in Greeley, Colorado.

Results of our study indicate that adopters are generally more inclined towards conservation (recycling) than nonadopters and also favor the development of alternative energy sources. Both groups, however, match in their anticipation of higher energy prices, in their considering future planning important, and in their belief that insulation eventually will pay off. Nonadopters tend to doubt the effectiveness of insulation in reducing monthly expenditures for energy.

The payback period of the cost of insulation was estimated for those families in our sample who had opted for retrofitting. The distressing result emerged, that in many instances positive effects were minimal and insulation was wasted.

Conservation attitudes could be enhanced significantly if economic factors were laid out clearly, and were advertised in an understandable and convincing way. Waste of insulation material should be avoided.

It would further promote conservation attitudes if the cost of utilities (U) were calculated into loan applications which presently are concerned with PITI (principal, interest, taxes, insurance) as a certain percentage of income. If PITIU were considered instead, reduction in U by captial investment for conservation might more than offset increases in PI.

As a result of this procedure, the bank would provide the buyer with a series of options involving the potential trade-offs between utility payments and the cost of implementing energy-saving practices. At that point the decision is left to the home buyer. If he (she) qualified for the loan using the PITIU formula, then he (she) may opt to ignore the suggestions. However, if the PITIU payments exceed some proportion of his/her income, then the selection of one of the energy-saving measures may reduce U more than the increase in PI needed to pay for it. The trade-off in this latter instance becomes visible and relatively straightforward to understand.

This procedure also enjoys a number of other advantages:

It routinizes the task of conservation. This leads to a better data base and a more efficient means of disseminating information. It is easier for a loan officer sitting in front of a computer terminal to determine the cost and effectiveness of the various conservation options than for a home buyer (owner) haphazardly searching through the "Yellow Pages".

The mechanism could be used to allocate energy subsidies. This winter $1.2 billion will be disseminated to the poor and elderly to help supplement incomes. For the most part, these monies will be used to pay for higher heating costs and very little will be devoted to conservation. As a result, such subsidies will become a permanent fixture in the federal budget, and the incentive to conserve will have deteriorated.

Implementing the proposal requires the cooperation of a disparate group of institutions which have not traditionally communicated with one another. This means that new linkages will have to be forged. It can be expected that both the energy distribution companies and the banks will at first balk at the proposal. However, this resistance may disintegrate when each begins to realize the mutual advantages: the banks gain mortgage security while the Public Service Company accomplishes its well-touted goal of conservation.

6.5 AN INTERINDUSTRY MODEL FOR THE STUDY OF WEATHER AND ENERGY RELATED SOCIOECONOMIC EFFECTS.

A regional input-output (I-O) model has been developed for Greeley, Colorado, to arrive at local economic multipliers and to study certain development scenarios. Special attention was given in this model to energy requirements for space heating under expanding economic activity and under varying meteorological conditions.

Data were collected by questionnaries which served as focal points for interviews and could be left for further consideration with the interviewed firm. Information was solicited on the nature of the firm's product lines, the number of employees, the level of capacity utilization, cash flow and non-cash flow outlay patterns, and sales distribution. Sales and outlay patterns were disaggregated by economic sector and regionalized according to location within and outside Greeley city limits.

Since space heating requirements are known for various types of buildings in Greeley from our physical energy demand modelling results, these requirements could be obtained for 1978 by economic sector as cubic feet of natural gas per dollar of output per month and for average temperatures. Hotels and motels showed the largest natural gas use for space heating per dollar of output, followed by transportation (including warehousing) and local government. Business multipliers (i.e. the production in each sector of the economy generated by an increase of 1 dollar in the final demand on each sector) are largest for the local government (2.93) and for the university (2.88). They are at 1.53 for natural gas and 1.48 for electricity.

Multipliers for space heating energy use were developed for each economic sector in Greeley. These multipliers relate the effect of increased demands by increased dollar output in one sector to the reverberating effects in other sectors. For instance, the direct space heating requirements in schools are 0.81 cu. ft. of gas per month for each dollar of output at a temperature of 14.1°F. If the final demand for output for the school expanded by one dollar, there would be a total direct plus indirect monthly gas requirement of 1.86 cu. ft. developed throughout the economy. The indirect impact (1.86-0.81 = 1.05) in this case exceeds the direct requirement because of the important interdependencies between schools and other sectors of the economy. Applying only the direct energy requirement to assumed increases in deliveries to final demand can obviously result in an understatement of space-heating energy use. Similar multiplyers can, and should be applied to projections of future energy needs for space heating. If this is done, the demand for energy is anticipated to rise at an ever increasing rate. Scarcity, rising prices and factor substitution will, most likely, become severely limiting factors. With annual growth rates for space heating energy demand projected to rise from 6% in the 1980's to 10% by the year 2000, it is clear that even a 30% reduction in heating energy by conservation will buy only three added years.

By computing employment multipliers, the I-0 model is capable of assessing which economic sectors will be hardest hit by energy curtailments and by switching to more expensive alternate fuels. Employment multipliers in Greeley are highest for the education, hotels-motels, local government and transportation sectors, meaning that in these sectors the most employment is stimulated per dollar of exports. Unfortunately, these sectors are also among the largest space heating energy users in the city and therefore are expected to suffer considerably from energy shortages and price increases. The model provided estimates of the sensitivity to temperature changes of natural gas use in various sectors of the Greeley economy. Households, food processing, manufacturing, utilities, financial services and local government all show above average sensitivity and therefore are main contributors to peak-load problems in energy generation and transmission. Notably for the manufacturing sector a rapid growth has been projected for the next few years. This growth might compound some of these peak load problems.

A final model application concerns itself with an estimate of the relative sensitivity of employment in various economic sectors to shortfalls of natural gas required directly or indirectly in these sectors. Vulnerability was computed to be highest in the sectors encompassing restaurants, electric services, manufacturing and services. Education and health services also showed a strong linkage between employment and gas input.

The manufacturing sector is singled out as having extremely high projected growth, its energy demand being strongly sensitive to temperature variations, and also having a high impact on employment. The present and projected trend in Greeley away from trade and services towards manufacturing forebodes an adverse effect on the region's economic stability in view of an uncertain energy future. Health serivces, another industry of rapid growth, are foreseen to suffer less from problems generated by energy shortages.

The appendices, numbered according to the chapters to which they pertain, contain more detailed computational information.

Note: Appendices are numbered according the the chapter to which they pertain.

APPENDIX 2A

MODELLING OF ENERGY CONSUMPTION FOR SPACE HEATING BY A COMMUNITY USING THE GMDH APPROACH[1]

Abstract

This paper describes an alternative method for modelling the energy consumption for space heating of a community by using the grouped method of data handling (GMDH) approach to construct the necessary descriptions. First, a weather cause-effect description is trained and tested to represent the deterministic part of the underlying process of energy consumption. The residual (which is the difference between the observed energy consumption and the estimated value from the weather cause-effect description) time series is then considered as a realization of the stochastic part of the underlying process. A description of this residual time series is synthesized as a class of the Kolmogorov-Gabor polynomial, which is a general type of auto-regressive generating function. The result is comparable to the more elaborate physical model of energy consumption developed at Colorado State University but takes much less computer time and effort for implementation.

2A.1. BACKGROUND

The energy crunch has been threatening the maintenance of our style and quality of life since the Arabian oil embargo in 1973. As the supply of fossil fuels become scarce and new sources of energy are not yet ready to be used economically or safely, the energy situation steadily becomes worse. Two major sectors of energy consumption, residential and commercial, used 31% of the total energy consumed in this country in 1972. Of this amount, two thirds were consumed for space heating on an annual average basis (F.E.A., 1975).

In the winter of 1976-77 people in the eastern United States experienced a very difficult time obtaining enough heating fuel and paying for their escalating fuel bills affected by the combination of severe weather and the shortage of energy (Reiter et al., 1978).

No doubt, a comprehensive energy policy is necessary before the imbalance of supply and demand of energy causes a drastic dislocation in our way of life. The concern for this has been evident by the extensive discussions and publications at all levels, for example, the discussion of energy problems by leaders of different nations at the international conference in Tokyo in June 1979. To have our energy policy encompass the details of all phases of the energy situation, the decision-makers and energy planners not only have to consider various scenarios of energy demands from all sectors but also have to visualize the possible changes of energy use patterns and their effects due to the variability of some of the uncontrollable factors. Weather-dependent energy use in space heating our buildings introduces such variability into energy demand.

This paper reports a method of analysis and prediction of energy demand by a community for space heating as a function of weather parameters. It is the result of an ongoing research project at Colorado State University.

In previous reports (Reiter et al., 1976 and 1978; Johnson, 1978) a physical modelling approach was presented which aggregates the energy consumption by individual buildings into an estimated daily total value for an entire community. Even though the physical model has been developed through the simplification of using only 52 typical building modules to calculate the heat gain/loss with respect to the change in weather conditions, the amount of input data required is very large. Besides the bihourly weather data which are used as the forcing input to the model, the model also requires the a priori compiled data set of building characteristics which must be attained by a detailed census or by stratified sampling within certain accuracy limits (Starr, 1978). Sometimes considerable efforts have to be expended to obtain a usable set of building characteristics from the raw data as, for instance, contained in assessors' files.

A community is a complex system of growth and development; it is nonstationary and, no matter how complete our current data base is, a description of the community may become obsolete with time if there is no mechanism provided to continuously trace or detect changes. It is this reasoning which has led to the development of a second modelling method which alleviates the dependency of intensive building information. This method can also be used as a tool to construct a preliminary model before a comprehensive, sophisticated physical model can be derived. The straightforward manner of this procedure makes it attractive for the investigation of other energy consumption estimations from different sectors using either on-line forecasting or brief-time operation on a system with observable input-output measurements.

2A.2 FORMULATION

The fundamental hypothesis of our approach is that the energy consumption for space heating of a community is a process which can be separated into two components, namely the deterministic and the stochastic. The responses of both are continuous and bounded. In addition, the stochastic component is quasi-stationary. The process of the deterministic component is viewed as a result of the operation through an open-loop system representing the major routine behavior of a steady community. The output of this open loop system, reflecting the average energy consumption of a community, will be a response function determined by a low order Kolmogorov-Gabor polynomial in terms of the average daily meteorological variables, i.e. temperature, wind speed and solar radiation. The description of such a process is called a weather cause-effect description.

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[1] Paper presented at the IEEE International Conference on Cybernetics and Society, Oct. 7-10, 1979, Denver, Colorado.

On the other hand, the stochastic component is considered to be a process resulting from a feedback mechanism interacting, not only with the current and the past weather conditions, but also with the finite memory of its own output trend and the fluctuations of random factors and noise. The realization of this process is assumed to be observable from the residual time series, where the residual is defined as the difference between the daily observed energy consumption and the deterministic component computed from the cause-effect description. A general autoregressive generating function may then be formed as a class of the Kolmogorov-Gabor polynomial to approximate an unknown stochastic process which generates the residual time series. This approximation will, henceforth, be called the time series description.

The formulation of the energy consumption process can now be expressed as

Energy consumption = deterministic component

+ stochastic component

= weather cause-effect description

+ time series description.

Both descriptions will be constructed and optimized by the GMDH algorithm (Leong, 1975) presented in the next section.

The compensation produced by the time series description to reduce errors (residual) produced by the cause-effect description has shown an efficient and promising way to model the energy consumption for space heating, even if the community is experiencing a slow change.

2A.3 THE GMDH ALGORITHM

The original version of the grouped method of data handling (GMDH) was proposed by Ivakhnenko in 1968. It is a self-organized learning algorithm for numerically modelling a complex multi-input single-output nonlinear system based on the multi-layer perceptron concept introduced by Rosenblatt in 1952.

Assuming the input variables to be X_1, X_2 ..., X_S, and the output response variable to be Y, then $G[\cdot]$ is called a Complete Description (CD) of the Kolmogorov-Gabor polynomial of m^{th} order if it includes all the input variables in the form:

$$Y = G_m[X_1, X_2, \ldots, X_S]$$

$$= a_0 + \sum_{i=1}^{S} a_i X_i + \sum_{i_1=1}^{S} \sum_{i_2=1}^{S} a_{i_1, i_2} X_{i_1} X_{i_1} \qquad \text{(A2.1)}$$

$$+ \ldots + \sum_{i_1=1}^{S} \sum_{i_2=1}^{S} \cdots \sum_{i_m}^{S} a_{i_1 \ldots i_m} X_{i_1} X_{i_2} \cdots X_{i_m}.$$

A function is said to be a Partial Description (PD) if the variables of the PD constitute only a subset of all of the input variables of the system.

The essence of the GMDH is the assumption that the response function, with respect to all the input variables, is bounded and continuous. Thus a complete system description (CD) can be approximated by a Kolmogorov-Gabor polynomial. Instead of searching for a best complete description of all variables at once, the GMDH solves a set of partial polynomials called perceptrons (or PDs) with two variables each through a multilayered perceptron scheme. The least squares method is used to evaluate the coefficients of each perceptron. The entire set of perceptrons of a current layer is then compared with heuristic criteria so that the best perceptrons will be combined at the next higher layer, and those with negative contribution to the minimum mean squared error are rejected. A new layer of perceptrons will then be formed (by treating the perceptron of the previous layer as new variables) until a best perceptron, with mean squared error attaining a specified accuracy, is found.

A flow chart of GMDH is presented in Fig. 2A.1 to show the essential organization of the scheme. The descriptions below should be read in conjunction with this conceptual flow chart.

Step 1. Separate data into training and testing sets;

Step 2. Select variables, two at a time, for all possible combinations;

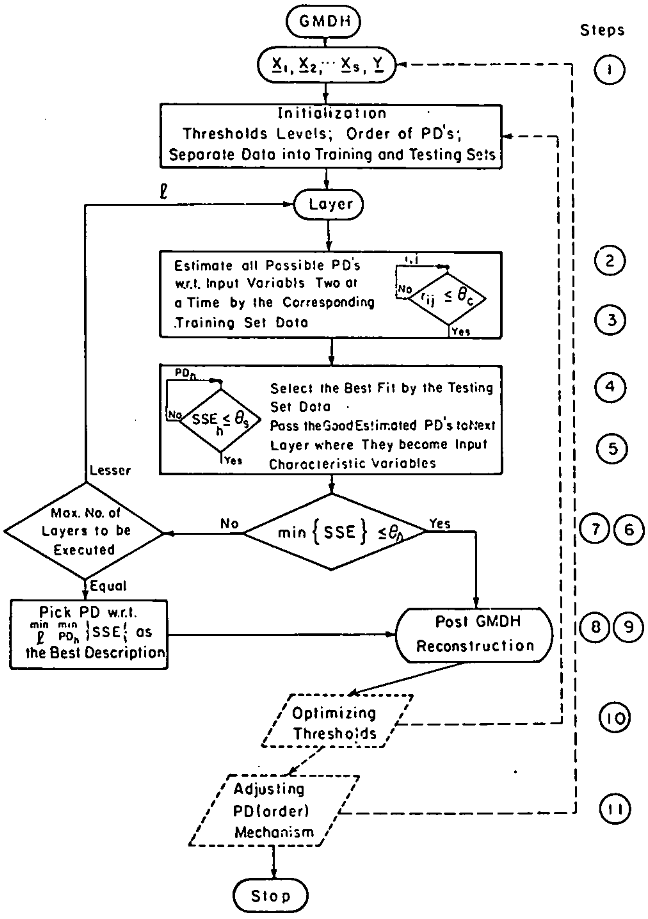


Fig. 2A.1 The GMDH flow diagram.

Step 3. Generate a PD as a bivariate polynomial in terms of two selected variables of given order with the use of training data on the basis of the least squares technique;

Step 4. Using data from the testing set, compute the mean squared error (MSE) for each PD generated in Step 3;

Step 5. Sift the "good" PD whose MSE is less than the sifting threshold θ from all generated PDs in the current layer. The sifted PDs will be treated as new independent variables for the next layer, their corresponding estimated values becoming the input data for the next layer;

Step 6. Check whether the minimum MSE among all generated PDs of this layer is less than the accuracy threshold θ_A. If yes, the corresponding PD becomes the "best" description. The scheme continues at Step 9;

Step 7. Check whether the current layer number is less than the preassigned maximum layer number. If yes, enter next layer loop at Step 3;

Step 8. When Step 7 is false, pick the PD whose MSE is the smallest min {MSE} among all the layers as the best description, that is, the MSE of the best description is corresponding to the value given by

$$\underset{\text{All Layers}}{\text{Minimum}} \left\{ \underset{\text{All PDs}}{\text{Minimum}} \left[\text{MSE(PD, layer)} \right] \right\}$$

Step 9. Reconstruct the complete description and stop. Starting at the layer corresponding to the best PD, the scheme traces back through the relationships between variables and PDs from the higher to the lower layers until the original variables are obtained;

Step 10. If no satisfactory result is obtained from the above procedure, adjust or optimize the threshold levels by steepest descent technique and then enter loop at Step 1;

Step 11. If no satisfactory result is obtained the from above procedure, adjust the polynomial regression order or the significance test level in generating the PDs, then enter loop at Step 1.

In this fashion, the complete description constructed by the GMDH is a "best" Kolmogorov-Gabor polynomial in the sense of minimum mean squared error under the given threshold values. It accomplishes the following:

1. Stops at an appropriate order where the remainder of the polynomial is negligible.
2. Retains only the variables/terms which are most significant in correlation with the response variables.
3. Is capable of estimating the coefficients of all the significant terms, even when the number of observed data points is relatively small.
4. Avoids the situation of converting a large or ill-conditioned matrix, which is one of the prevailing pitfalls in solving large-scale complex systems.

The current status of the GMDH package at Colorado State University consists of three parts. Part I is basically the same as the original algorithm proposed by Ivakhnenko which can be used to generate a best set of perceptrons of multilayer structure from input/output data. Part II is used to formulate a parsimonious perceptron tree form with respect to the desired partial description of any pre-specified layer which may be equal to, or less than, the maximum number of layers from Part I. The parsimonious tree form can be used directly for simulation or estimation, or by Part III with little human supervision. Part III is an iterative perceptron estimation with respect to a specific input when Part II fails to produce uniformly convergent estimates from lower to higher layers. This amplifies the uses of the perceptrons in each layer to minimize the rare effect of a single extreme or bad element being observed in an input vector. Such an extension of regrouping of the perceptrons of different layers to reformulate a more homogeneous response surface at each layer based on the posteriori information is especially important during the course of change of a system which might result in consistant overestimation or underestimation of the output and thus signifies that the previously evaluated model no longer fits the current system.

2A.4 CAUSE-EFFECT DESCRIPTION EVALUATION

As the name suggests, this procedure is designed to find a description to represent the vital causes in terms of the weather variables and their main effects on the energy consumption of a community. Incorporating the uses of the GMDH we first devise a set of K discrete states to represent the conditional response under a given weather state where each state has an equal chance of occurrence. The K states are defined as follows: Let an empirical cumulative distribution function (cdf), denoted as $F_N(Y)$, of the daily energy consumption be computed from N data points over a period $[t_1, t_2]$. For a given integer, $K > 0$, the $F_N(Y)$ can be subdivided into K portions such that each portion defines an equal probability, 1/K. The daily energy consumption response (or the observed output data) of the community is said to be in the k^{th} state of output if the value falls in the k^{th} portion, for $k = 1, 2, \ldots, K$. All the data points contained in the k^{th} portion can be thought of as a sample drawn from an unknown conditional population of the k^{th} state of output, with conditional probability distribution function (pdf) $F(Y_k)$. All the concurrent daily weather records (or the observed input data) corresponding to the k^{th} state of output are described as a sample drawn from an unknown joint conditional population of the k^{th} state of input, with joint conditional pdf $F(\underline{X}_k)$.*

Figure 2A.2 illustrates an empirical cdf of daily energy consumption for Cheyenne, Wyoming which is partitioned across the range of energy variation into 10 K-states, with each state representing an equal probability of 1/K, or 10%. Based on past experience, the following weather parameters and their combinations are defined as the input variables for the description evaluation.

X_1 = daily average temperature,

X_2 = daily minimum temperature,

X_3 = daily maximum temperature,

X_4 = daily average wind speed,

X_5 = daily minimum wind speed,

X_6 = daily maximum wind speed,

X_7 = daily average solar radiation,

X_8 = daily average temperature times daily average solar radiation,

X_9 = daily average temperature times daily average wind speed,

X_{10} = daily average solar radiation times daily wind speed,

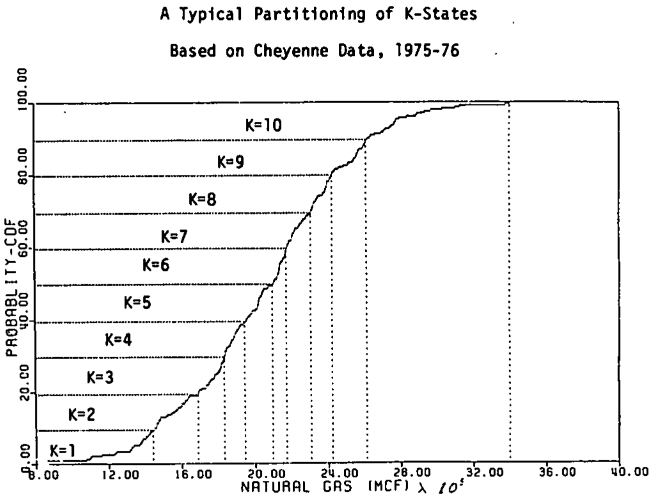
X_{11} = square of the wind speed,

X_{12} = square of the daily solar radiation.

Also we denote θ as the output or response for the k^{th} state of daily energy consumption.

Once the boundaries of the 10 K-states have been established, as shown in Fig. 2A.2, a reverse cross-mapping is performed on the twelve input variables, X_1, through X_{12}, such that for each observed energy consumption, θ, in the k^{th} state, the corresponding input variables are grouped into the k^{th} state of input. Having developed the K states of input and output samples, various statistics may be derived to characterize the relationship between, or within, the input and output states. The statistics of most interest to our subsequent application are the means and the medians of each state sample. The set of the K state means is then used as the training data set while the set of K state medians becomes the testing data set, or vice versa, for the GMDH algorithm to identify the cause-effect description.

It should be noted that in Fig. 2A.2 the width of the energy variation within each state is different and that the states close to the center of the cdf are thinner than those near the tails of the cdf. This means that during the evaluation by the GMDH of the relationship between the output (energy consumption) and the input (X_1 through X_{12}) states, more weight will be put on the values which had been observed more frequently than those which were only rarely observed.


A Typical Partitioning of K-States

Based on Cheyenne Data, 1975-76

Fig. 2A.2 The 10 K-states partitioned from the empirical probability distribution function of energy consumption in Cheyenne, Wyoming based on the period 11/2/75 to 3/31/76.

In practice, there is only a limited number of states that can be formed through the available data to characterize the average behavior of the system. It is our opinion that the response function is best approximated by a low order Kolmogorov-Gabor polynomial.

The following sequences of minimum mean squared errors of consecutive layers, MSE $[G_\theta]$, are the results of the GMDH run by setting the partial description to order 1.

Layer number:	1	2	3	4	5
MSE $[G_\theta]$ of training:	460000	371107	331164	317417	292507
MSE $[G_\theta]$ of testing:	769857	668071	647642	610428	616250

Even though the description could be improved under the MSE $[G_\theta]$ with respect to the training data set from layer 4 to layer 5, it did not reduce the MSE $[G_\theta]$ with respect to the testing data set. The final GMDH was, therefore, stopped at layer 4. The weather cause-effect description was then obtained as the set of partial descriptions given by

1^{st} layer:

$$\theta_1^{(1)} = 03458.9 - 421.24X_2 - 1.0053X_{12}$$

$$\theta_2^{(1)} = 36053.8 - 374.12X_3 + 71.098X_4$$

$$\theta_3^{(1)} = 37003.0 - 379.66X_3 - 11.714X_5$$

$$\theta_4^{(1)} = 33703.5 - 370.15X_3 + 198.17X_6$$

2^{nd} layer:

$$\theta_1^{(2)} = -181.163 + .353860\theta_1^{(1)} + .655080\theta_3^{(1)}$$

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* Even though the output states are partitioned into K portions exclusively, the K input state samples are almost never exclusive sets such that the data points may belong to more than one input state population or, in other words, any two adjacent input state populations have overlapping pdf tails.

$$\theta_2^{(2)} = -198.06 + .361070\theta_1^{(1)} + .648710\theta_2^{(1)}$$

$$\theta_3^{(2)} = -248.662 + .334940\theta_1^{(1)} + .677340\theta_4^{(1)}$$

3rd layer:

$$\theta_1^{(3)} = 85.5154 - .716490\theta_1^{(2)} + 1.71220\theta_3^{(2)}$$

$$\theta_2^{(3)} = 104.857 - 1.06900\theta_2^{(2)} + 2.06380\theta_3^{(2)}$$

4th layer:

$$\theta^{(4)} = 26.130 - 2.42790\theta_1^{(3)} + 3.42660\theta_2^{(3)} \tag{A2.2}$$

where the notation $\theta_i^{(L)}$ should be read as i^{th} response function evaluated at L^{th} layer.

A linear function, $\theta^{(4)}$, can be obtained in terms of X_2, X_3, X_4, X_5, X_6, and X_{12} if the equations of the lower layer are substituted into the higher layer. It is interesting to note that the GMDH did not pick up the average daily temperature (X_1) or its combinations (X_8 and X_9), but put more weight on the daily maximum and minimum temperature. This could be a reflection of the fact that the extreme temperatures may cause people to change the thermostat setting and therefore change the energy consumed.

The "deterministic" component of the daily energy consumption is then readily computed by substituting the original daily weather conditions in to the above cause-effect description. In Fig. 2A.3 the light solid line with the "Δ" symbol at each data point represents the deterministic estimation of the energy consumption over the period 11/1/75-3/31/76, which is the same data set used for obtaining the K states to train and test the description. The deterministic estimation was also applied to another period, 1/1/77-3/21/77 (see Fig. 2A.4). Even though the data from the 1977-period were not used to evaluate the cause-effect description, we can see from Fig. 2A.4 that the prediction agrees well with the major features of the observed energy consumption data, symbolized by "0". The results of each period were then compared with the observed energy consumption to obtain the daily residual time series which are plotted in light solid lines at the bottom of each figure. These become the data base for our time series description evaluation.

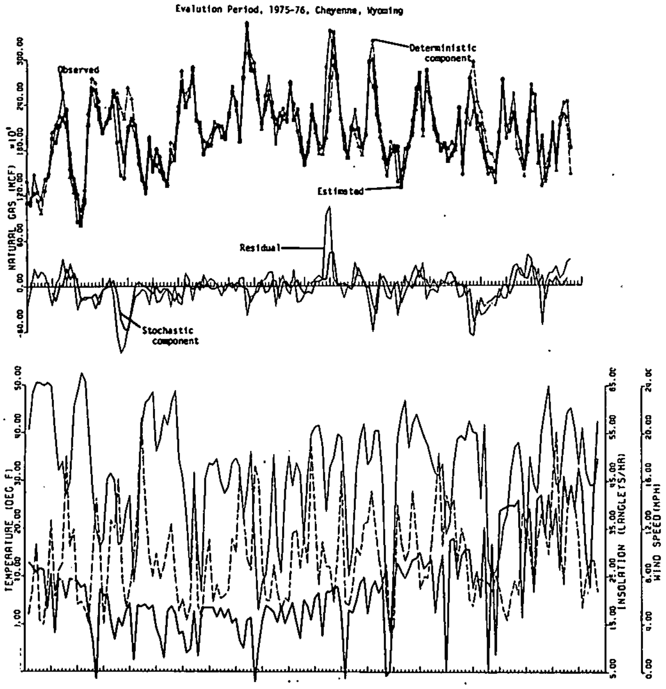

Fig. 2A.3 Energy consumption, in cubic feet of natural gas, and weather for Cheyenne, Wyoming during the period 11/1/75 to 3/31/76.

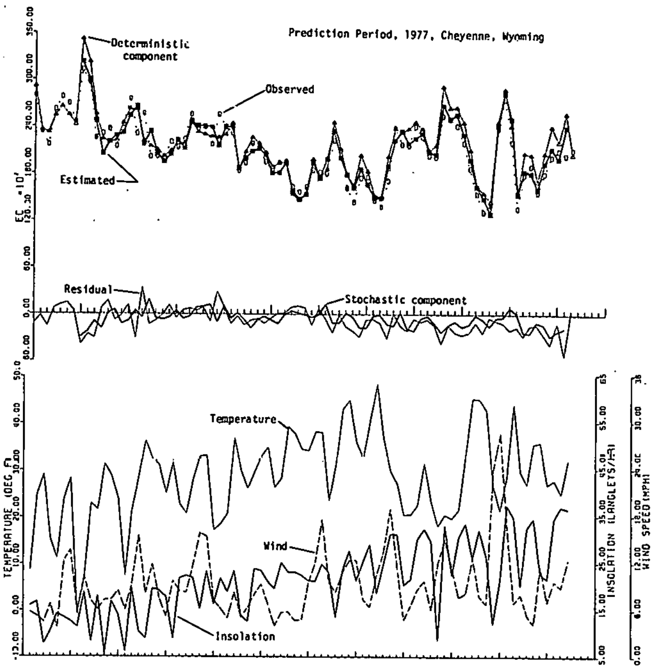

Fig. 2A.4 Same as Fig. 2A.3, except for the period 1/1/77 to 3/21/77.

2A.5. PROCEDURE OF TIME SERIES DESCRIPTION

Let $\tilde{Y}(t)$ be the residual of the observed energy consumption, $Y(t)$, subtracted from the estimated deterministic component, $\hat{\theta}(t)$, which was computed from the cause-effect descriptions. Then a complete description of the residual $\tilde{Y}(t)$ for V input variates $X_1(t)$, $X_2(t)$, ..., $X_V(t)$, with finite discrete time memory of L can be expressed as the m^{th} order Kolmogorov-Gabor polynomial:

$$\tilde{Y}(t) = G_m[X_1(t-\tau), \ldots, X_V(t-\tau)] \quad \tau=0, 1, \ldots, L$$

$$= g_0 + \sum_{v=1}^{V} \sum_{\tau=0}^{L} g_v(\tau)\, X_v(t-\tau) +$$

$$+ \sum_{v_1=1}^{V} \sum_{v_2=1}^{V} \sum_{\tau_1=0}^{L} \sum_{\tau_2=0}^{L} g_{v_1 v_2}(\tau_1,\tau_2) X_{v_1}(t-\tau_1) X_{v_2}(t-\tau_2) +$$

$$+ \ldots + \tag{A2.3}$$

$$+ \sum_{v_1=1}^{V} \cdots \sum_{v_m=1}^{V} \sum_{\tau_1=0}^{L} \cdots \sum_{\tau_m=0}^{L} g_{v_1 \ldots v_m}(\tau_1 \ldots \tau_m) \cdot$$

$$\cdot X_{v_1}(t-\tau_1) \ldots X_{v_m}(t-\tau_m) + w(t)$$

where the g's are weighting coefficients and w(t) is a term signifying independent white noise, for $t \in [t_1, t_N]$ and $t_1 \geq L$.

We note here that when order m is equal to one, the Kolmogorov-Gabor polynomial is equivalent to the well known autoregressive time series model (Box and Jenkins, 1976).

Without loss of generality, the variables associated with the time delay in Equ. (A2.3) can be renamed and treated as new input variables. $\breve{Y}(t)$ can then be rewritten in a simplified form as

$$\breve{Y}(t) = G_m[X_1(t), \ldots, X_V(t),\ X_{V+1}(t), \ldots, X_{V(L)}(t),$$

$$X_{V(L)+1}(t), \ldots, X_{V(L+1)}(t)]$$

$$= \beta_o + \sum_i \beta_i X_i(t) + \sum_i \sum_j \beta_{ij} X_i(t) X_j(t) + \ldots + \tag{A2.4}$$

$$+ \sum_{i_1} \cdots \sum_{i_m} \beta_{i_1 \ldots i_m} X_{i_1}(t) \ldots X_{i_m}(t) + w(t)$$

where each summation runs from 1 to V(L+1) and the β's are weighting coefficients.

This general type of autoregressive formulation provides the flexibility: 1) to select as many descriptive input variables as desired; and 2) to construct linear and nonlinear input variables to account for possible higher order effects.

From our analysis the following defined variables revealed the most significant cross- or auto-correlation coefficients, thus they are used as candidates for the input variates to the GMDH algorithm for construction of a time series description:

$X_1(t)$ = T(t), the daily average temperature at date t;

$X_2(t)$ = ∇T, the past temperature change, i.e. T(t)-T(t-1);

$X_3(t)$ = ΔT, the future temperature change, i.e. T(t+1)-T(t);

$X_4(t)$ = W(t), the daily average wind speed;

$X_5(t)$ = S(t), the daily average solar radiation;

$X_6(t)$ = Y(t-1), the observed energy consumption of lag 1;

$X_7(t)$ = $\hat{\theta}(t)$, the estimated energy consumption based on the cause-effect description;

$X_8(t)$ = $\breve{Y}(t-7)$, the residual of lag 7;

$X_9(t)$ = $\breve{Y}(t-6)$, the residual of lag 6;

$$\vdots$$

$X_{14}(t)$ = $\breve{Y}(t-1)$, the residual of lag 1;

$\breve{Y}(t)$ = $Y(t) - \hat{\theta}(t)$, residual response (output) at date t.

For the arrangement of the training and testing data sets from a time series the authors recommned that the given sequence should be wholly used as a training set unless it has been proved unreliable. Then, on the basis of a Markov event assumption, the most recently observed data of the same sequence, for example, the last cycle of fluctuations, or 10% of the total observations with respect to the latest arrival time, should be used as the testing set. There is no difference if the first section of the sequence is used as training and the rest as testing, or in reverse, if the system is truly stationary. The recommendation that the whole data set should be used as the training data set, however, will most likely yield a better evaluation of a time series. This is simply because any cut-off from the training sequence will mean a reduction in the amount of information available for evaluation.

A typical time series description, as identified by the GMDH for the Cheyenne residual energy consumption over the period 11/1/1975-3/1/1976, is given as the following set of partial descriptions:

Layer 1:

$$Y^{(1)}_1(t) = 624.60 + .29534X_6(t) - .33370X_7(t)$$
$$Y^{(1)}_2(t) = -114.77 - .00102X_{13}(t) + .55156X_{14}(t)$$
$$Y^{(1)}_3(t) = 38.365 - .00734X_8(t) + .55522X_{14}(t)$$
$$Y^{(1)}_4(t) = -792.49 + 30.599X_5(t) + .55110X_{14}(t)$$
$$Y^{(1)}_5(t) = -1304.2 + 121.18X_4(t) + .53160X_{14}(t)$$
$$Y^{(1)}_6(t) = 2787.7 - .14828X_7(t) + .54604X_{14}(t)$$

Layer 2:

$$Y^{(2)}_1(t) = 102.88 + .58681Y^{(1)}_1(t) + .77388Y^{(1)}_4(t)$$
$$Y^{(2)}_2(t) = 125.93 + .65838Y^{(1)}_1(t) + .78311Y^{(1)}_2(t)$$
$$Y^{(2)}_2(t) = 127.55 + .66227Y^{(1)}_1(t) + .78492Y^{(1)}_3(t)$$
$$Y^{(2)}_4(t) = 71.360 + .44605Y^{(1)}_1(t) + .80412Y^{(1)}_6(t)$$
$$Y^{(2)}_5(t) = 135.86 + .66452Y^{(1)}_1(t) + .81181Y^{(1)}_5(t)$$

Layer 3:

$$Y^{(3)}_1(t) = 5.1559 + .18693Y^{(2)}_4(t) + .83113Y^{(2)}_5(t)$$
$$Y^{(3)}_2(t) = -6.2252 - .33980Y^{(2)}_3(t) + 1.3179Y^{(2)}_5(t)$$
$$Y^{(3)}_3(t) = -7.3237 - .38967Y^{(2)}_2(t) + 1.3639Y^{(2)}_5(t)$$
$$Y^{(3)}_4(t) = -8.5671 - .36367Y^{(2)}_1(t) + 1.3336Y^{(2)}_5(t)$$

Layer 4:

$$Y^{(4)}_1(t) = 1.2278 + .40248Y^{(3)}_1(t) + .60182Y^{(3)}_4(t)$$
$$Y^{(4)}_2(t) = -1.3205 - 5.5698Y^{(3)}_2(t) + 6{,}5652Y^{(3)}_3(t)$$

Layer 5:

$$\hat{Y}(t) = .95475 + .48561Y_1^{(4)}(t) + .51773Y_2^{(4)} \qquad \text{(A2.5)}$$

plus an independent noise term w(t) with a mean of -71.0608 and a variance of 4135752.3

The estimated residual time series corresponding to the above description for the period 11/1/75-3/31/76 is shown as the heavy solid curve at the center in Fig. 2A.3. The predicted residual time series for the period 1/1/77-3/21/77 is shown in the center of Fig. 2A.4.

2A.6 PERFORMANCE INDICES

As soon as the stochastic component, or the residual energy consumption has been estimated, the total estimation of daily energy consumption can be computed by adjusting the estimated deterministic component with the estimated stochastic component. The curves with symbol "*" shown in Figs. 2A.3 and 2A.4 represent the final daily energy consumption estimations and predictions corresponding the 1975-76 and 1977 periods, respectively.

Two performance indicies are computed to measure the merit of the model in comparison to its estimates with the actual observations. The daily absolute error (ABS error) performance index is defined to be the average daily absolute error divided by the mean daily energy consumption. The daily root mean square error (RMS error) performance index is defined to be the square root of the mean square error divided by the mean daily energy consumption.

The ABS error corresponding to the 1975-76 estimation period is 7.36% whereas the RMS error is 9.79%. The errors corresponding to the 1977 prediction period are 5.9% for ABS error and 7.3% for RMS error. It is surprising to note that the performance indices of the prediction period are better than those of the model evaluation period. This may be interpreted in two ways: 1) The weather information of 1977 was more accurate because a network of weather stations had been set up around the city, whereas there was only one source of weather information before 1977; 2) The people of Cheyenne were more conservative in energy use in 1977 compared with the previous year (possibly the result of an insulation retrofit campaign conducted by the utility company).

It may be noted that if the cause-effect descriptions perfectly represented the real system, the time series description would have a white noise response. On the other hand, if the time series does represent the persistent fluctuation pattern due to changing the level of response or input with respect to the finite past observations (finite memory), the time series description will act as a compensator to reduce the error and drive the model closer to the true state. The estimated time series shown in Figs. 2A.3 and 2A.4 closely follow the residual time series pattern. However, the model error does not seem improved significantly. For example the ABS error of the estimated deterministic component is 6.7% whereas the final ABS error of the predicted energy consumption is 5.9% during the prediction period. This indicates that the residual time series only represent a small fraction of the total energy consumption.

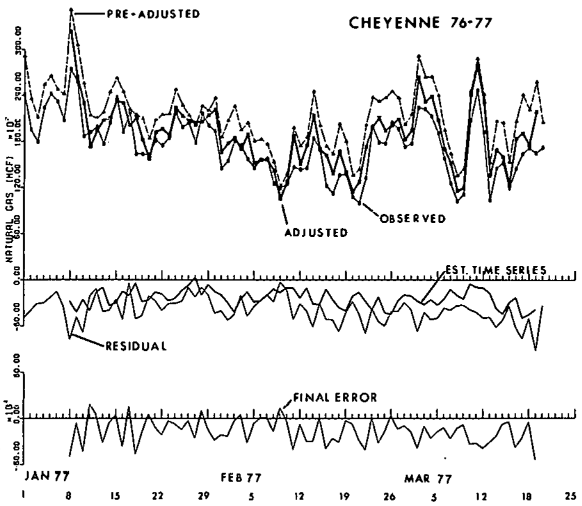

Fig. 2A.5 Energy consumption prediction of the statistical reference model during the 1976-77 heating season, in thousands of cubic feet of natural gas, for Cheyenne, Wyoming. Both pre-adjusted (without the time series description) and the adjusted (which includes the time series description) model results were presented. Note that this model is identified from the 1975-76 evaluation period data only. The middle curve shows the predicted time series which is used to adjust the model results. The residual curve is the observed minus the preadjusted consumption. The final error curve is the observed minus the adjusted consumption.

It is interesting to note that in Fig. 2A.5 the role played by the time series description is much more significant and the ABS error of the estimated deterministic component is reduced from 22.6% to a final ABS error of 11.2% for the total energy consumption prediction. The descriptions being used for Fig. 2A.5 are exactly the same as for Fig. 2A.4 and Fig. 2A.3 which are expressed by Eqn. 2A.2 and Eqn. 2A.5. The only difference is the values of the observed energy consumption were systematically varied from the real values.*

2A.7 COMPARISON AND CONCLUSION

The GMDH procedure was also applied to the energy consumption prediction in Greeley, Colorado over the periods of 12/1/75-2/29/76 and 12/1/76-3/31/77. The first data set was used for identifying the descriptions and the second data set was used to demonstrate the ability of prediction. The results are comparable with those from the more elaborate physical model. All the details of applying the physical model to Cheyenne and Greeley were reported by Reiter et al., 1976, 1978 and 1979. Table 2A.1 shows the comparison of the use of these models for both cities.

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* When the Cheyenne, Wyoming energy consumption data were first received, it was necessary to subtract the large interruptible customer usages from the total amount of metered natural gas. This result in the total city usage has been reported as the observed energy consumption. The daily energy values for the 1977 winter which were first received from the local utility company were given for two different base pressures. This was not noticed when the data were first processed and therefore incorrect amounts were subtracted from the metered natural gas, resulting in an erroneous data set.

TABLE 2A.1 Comparison of performance indices between the GMDH and the physical modelling approaches applied to two cities.

Model Error	ABS%	RMS%	ABS%	RMS%
	Greeley, Colo.		Cheyenne, Wyo.	
Evaluation Period:	12/2/75-2/29/76		11/1/75-3/31/76	
GMDH	6.01	7.52	7.36	9.79
Physical	4.54	5.78	9.77	14.06
Prediction Period:	12/1/76-3/31/77		1/1/77-3/21/77	
GMDH	9.33	11.56	5.9	7.3
Physical	6.04	7.79	6.1	7.5

The physical model was very precise in the determination of energy consumption for Greeley but not quite as good for Cheyenne. This is because the building information collected for Greeley was done by detailed census, whereas for Cheyenne it was compiled by statistical sampling. Since the GMDH procedure proposed here does not depend on the building information, it is free from the inherent sampling error of the building data and it has outperformed the physical model in the case of Cheyenne. We also conclude that this procedure can be implemented easier and requires less computer time, but it can not do the kind of simulation the physical model can, such as assess the effects of a change of insulation, a switching of fuel use, etc.

APPENDIX 2B

STATISTICAL INFORMATION FOR THE MINNEAPOLIS MODEL DEVELOPMENT

This appendix contains 9 sets of graphs and related statistics from intermediate analyses developed in the course of identifying the Minneapolis energy consumption model for the 1977-78 and 1978-79 heating seasons. Each of the 9 sets contains a condensation of information derived for a particular data sequence. The analyses are arranged so as to illustrate how a model is improved from one stage of development to another and how the physical modelling procedure differs from the reference modelling procedure.

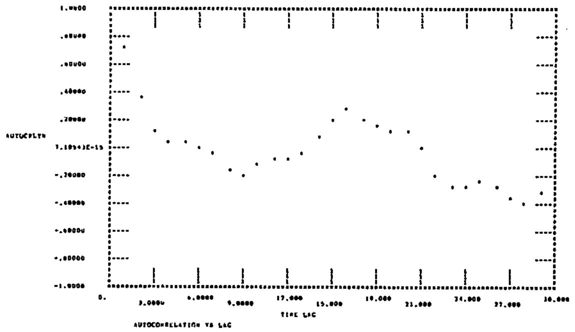
The four stages of model development represented below are: daily energy consumption estimates without time series adjustment, residuals from energy consumption estimates without time series adjustment, energy consumption estimates with time series adjustments, and residuals from energy consumption estimates with time series adjustments.

The first data set, 2B.1, shows raw data for the observed daily energy consumption during the 1977-78 and 1978-79 evaluation periods. The next four sets, 2B.2 through 2B.5, are results of the four stages of energy consumption data analysis for the physical and reference models over the 1977-78 evaluation period. The last four sets, 2B.6 through 2B.9, are similar to 2B.2 through 2B.5, except for the 1978-79 evaluation period.

2B.1 Statistics for observed energy consumption sequence in Minneapolis, Minnesota during 1977-78 and 1978-79 heating seasons.

Evaluation Period
12/1/77-2/28/78

Autocorrelation

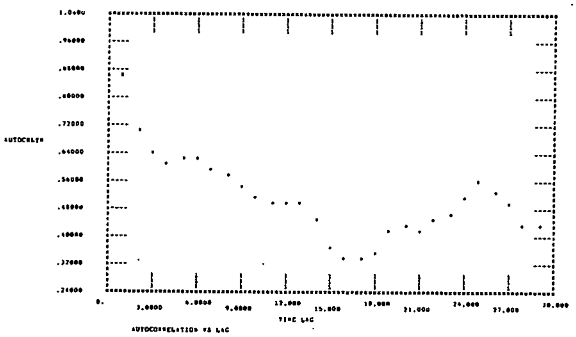


```
BASIC STATISTICS

        NUMBER OF OBSERVED DATA =           90
        MEAN                    =     150676.8889
        COEFF. OF VARIATION     =           .1785
             STANDARD DEVIATION =      26902.3572
             SAMPLE VARIANCE    =  723736821.0436
             3RD CENTRAL MOMENT =        .1121E+13
             4TH CENTRAL MOMENT =        .13494139E+19
        MEDIAN OF THE SAMPLE    =     149662.5000
        LOWER EXTREME     ..    =      87578.0000
        .25-QUANTILE      ..    =     130714.0000
        .75-QUANTILE      ..    =     169252.0000
        UPPER EXTREME     ..    =     211034.0000
```

```
H I S T O G R A M
-----------------

VMU 150676.88889      SIGMA  26752.48214      SKEW

-------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20..
-------------------------------------------------------
  1   .8758E+05   .9375E+05      2 **
  2   .9375E+05   .9992E+05      0
  3   .9992E+05   .1061E+06      3 ***
  4   .1061E+06   .1123E+06      3 ***
  5   .1123E+06   .1184E+06      1 *
  6   .1184E+06   .1246E+06      6 ******
  7   .1246E+06   .1308E+06      8 ********
  8   .1308E+06   .1370E+06      8 ********
  9   .1370E+06   .1431E+06      3 ***
 10   .1431E+06   .1493E+06     10 **********
 11   .1493E+06   .1555E+06      9 *********
 12   .1555E+06   .1617E+06      7 *******
 13   .1617E+06   .1678E+06      7 *******
 14   .1678E+06   .1740E+06      5 *****
 15   .1740E+06   .1802E+06      4 ****
 16   .1802E+06   .1863E+06      5 *****
 17   .1863E+06   .1925E+06      3 ***
 18   .1925E+06   .1987E+06      3 ***
 19   .1987E+06   .2049E+06      0
 20   .2049E+06   .2110E+06      3 ***
-------------------------------------------------------
```

Prediction Period
1/1/79-3/31/79

Autocorrelation



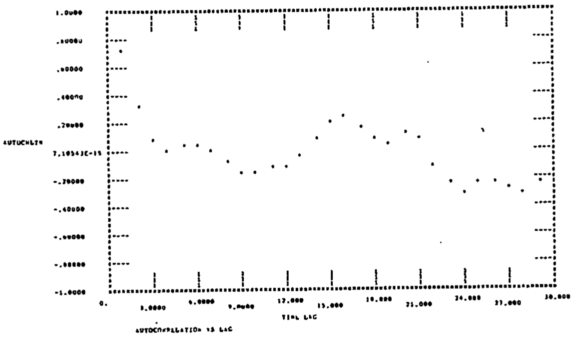
```
BASIC STATISTICS

        NUMBER OF OBSERVED DATA =           90
        MEAN                    =     147762.4444
        COEFF. OF VARIATION     =           .2388
             STANDARD DEVIATION =      35280.4415
             SAMPLE VARIANCE    = 1244709550.2271
             3RD CENTRAL MOMENT =        .4316E+13
             4TH CENTRAL MOMENT =        .28117995E+19
        MEDIAN OF THE SAMPLE    =     143983.0000
        LOWER EXTREME     ..    =      82954.0000
        .25-QUANTILE      ..    =     118767.0000
        .75-QUANTILE      ..    =     176978.0000
        UPPER EXTREME     ..    =     211097.0000
```

```
H I S T O G R A M
-----------------

VMU 147762.44444      SIGMA  35083.89152      SKEW

-------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20..
-------------------------------------------------------
  1   .8295E+05   .8936E+05      3 ***
  2   .8936E+05   .9577E+05      1 *
  3   .9577E+05   .1022E+06      5 *****
  4   .1022E+06   .1086E+06      3 ***
  5   .1086E+06   .1150E+06      7 *******
  6   .1150E+06   .1214E+06      5 *****
  7   .1214E+06   .1278E+06     10 **********
  8   .1278E+06   .1342E+06      5 *****
  9   .1342E+06   .1406E+06      4 ****
 10   .1406E+06   .1470E+06      4 ****
 11   .1470E+06   .1534E+06      2 **
 12   .1534E+06   .1598E+06      3 ***
 13   .1598E+06   .1662E+06      7 *******
 14   .1662E+06   .1727E+06      2 **
 15   .1727E+06   .1791E+06      8 ********
 16   .1791E+06   .1855E+06      3 ***
 17   .1855E+06   .1919E+06      5 *****
 18   .1919E+06   .1983E+06      7 *******
 19   .1983E+06   .2047E+06      2 **
 20   .2047E+06   .2111E+06      4 ****
-------------------------------------------------------
```

2B.2 Comparative statistics for the computed energy consumption sequences of the physical and reference models for the 1977-78 heating season <u>without</u> the time series adjustment.

Preadjusted Physical
(Evaluation Period: 12/1/77-2/28/78)

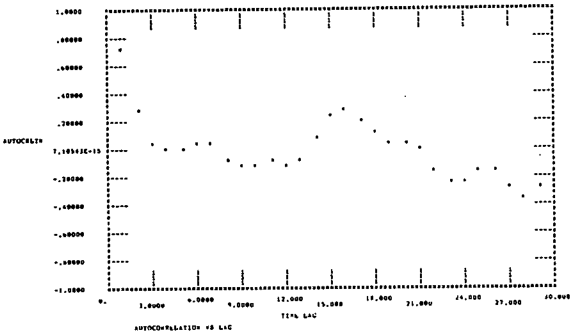
Autocorrelation



```
-----------------------------------------------------------
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =               90
          MEAN                    =          154515.3333
          COEFF. OF VARIATION     =                .1344
                STANDARD DEVIATION =          20771.7333
                SAMPLE VARIANCE    =      431464904.6291
                3RD CENTRAL MOMENT =            .6644E+12
                4TH CENTRAL MOMENT =        .52509298E+18
          MEDIAN OF THE SAMPLE    =          152065.5000
          LOWER EXTREME    ..     =          104329.0000
          .25-QUANTILE     ..     =          141017.0000
          .75-QUANTILE     ..     =          169581.0000
          UPPER EXTREME    ..     =          207608.0000


H I S T O G R A M
-----------------

VMU 154515.33333      SIGMA  20656.01245       SKEW

------------------------------------------------------------
               RANGE              FREQ.1...5...10...15...20...
------------------------------------------------------------
  1  .1043E+06  .1095E+06     1 *
  2  .1095E+06  .1147E+06     2 **
  3  .1147E+06  .1198E+06     1 *
  4  .1198E+06  .1250E+06     4 ****
  5  .1250E+06  .1301E+06     2 **
  6  .1301E+06  .1353E+06     3 ***
  7  .1353E+06  .1405E+06     9 *********
  8  .1405E+06  .1456E+06     7 *******
  9  .1456E+06  .1508E+06    15 ***************
 10  .1508E+06  .1560E+06     6 ******
 11  .1560E+06  .1611E+06     7 *******
 12  .1611E+06  .1663E+06     8 ********
 13  .1663E+06  .1715E+06     5 *****
 14  .1715E+06  .1766E+06     7 *******
 15  .1766E+06  .1818E+06     4 ****
 16  .1818E+06  .1870E+06     3 ***
 17  .1870E+06  .1921E+06     3 ***
 18  .1921E+06  .1973E+06     1 *
 19  .1973E+06  .2024E+06     1 *
 20  .2024E+06  .2076E+06     1 *
------------------------------------------------------------
```

Preadjusted Reference
(Evaluation Period: 12/1/77-2/28/78)

Autocorrelation

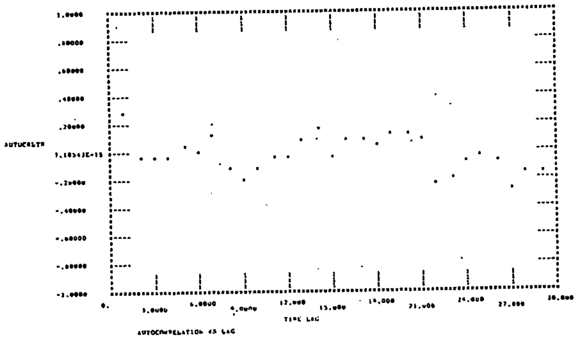


```
-----------------------------------------------------------
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =               90
          MEAN                    =          149609.2094
          CUEFF. OF VARIATION     =                .1806
                STANDARD DEVIATION =          27025.5548
                SAMPLE VARIANCE    =      730380610.0704
                3RD CENTRAL MOMENT =            .2990E+13
                4TH CENTRAL MOMENT =        .12463088E+19
          MEDIAN OF THE SAMPLE    =          150406.9918
          LOWER EXTREME    ..     =           95091.6666
          .25-QUANTILE     ..     =          129039.0345
          .75-QUANTILE     ..     =          166632.9621
          UPPER EXTREME    ..     =          207533.0393


H I S T O G R A M
-----------------

VMU 149609.20936      SIGMA  26874.99339       SKEW

------------------------------------------------------------
               RANGE              FREQ.1...5...10...15...20...
------------------------------------------------------------
  1  .9509E+05  .1007E+06     3 ***
  2  .1007E+06  .1063E+06     1 *
  3  .1063E+06  .1120E+06     4 ****
  4  .1120E+06  .1176E+06     3 ***
  5  .1176E+06  .1232E+06     3 ***
  6  .1232E+06  .1288E+06     8 ********
  7  .1288E+06  .1344E+06     9 *********
  8  .1344E+06  .1401E+06     6 ******
  9  .1401E+06  .1457E+06     4 ****
 10  .1457E+06  .1513E+06     5 *****
 11  .1513E+06  .1569E+06     5 *****
 12  .1569E+06  .1626E+06    10 **********
 13  .1626E+06  .1682E+06     9 *********
 14  .1682E+06  .1738E+06     4 ****
 15  .1738E+06  .1794E+06     3 ***
 16  .1794E+06  .1850E+06     2 **
 17  .1850E+06  .1907E+06     4 ****
 18  .1907E+06  .1963E+06     2 **
 19  .1963E+06  .2019E+06     0
 20  .2019E+06  .2075E+06     5 *****
------------------------------------------------------------
```

2B.3 Comparative statistics for the residual sequence of the physical and reference models for the 1977-78 heating season <u>without</u> the time series adjustment.

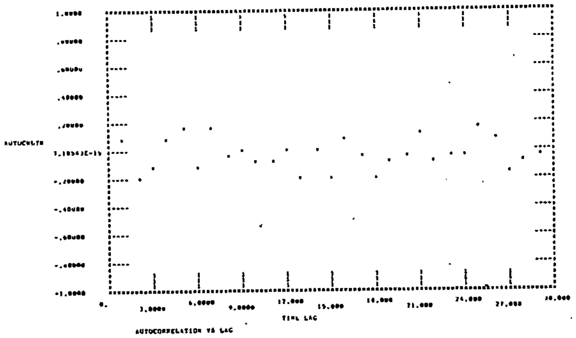
Preadjusted Physical
(Evaluation Period: 12/1/77-2/28/78)

Autocorrelation



Preadjusted Reference
(Evaluation Period: 12/1/77-2/28/78)

Autocorrelation



2B. 3 (Continued)

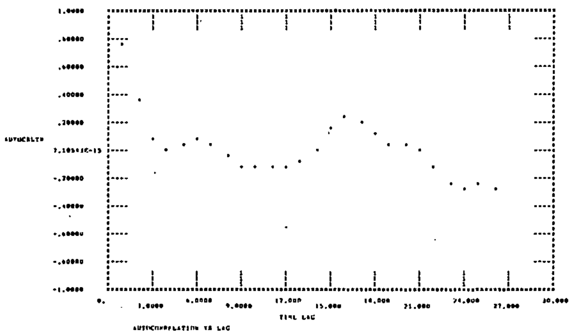
```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =          90
          MEAN                    =  -3838.4444
          COEFF. OF VARIATION     =     -2.7787
               STANDARD DEVIATION =  10665.8691
               SAMPLE VARIANCE    = 113760763.5306
               3RD CENTRAL MOMENT =   .7428E+12
               4TH CENTRAL MOMENT =   .38710148E+17
          MEDIAN OF THE SAMPLE    =  -5508.0000
          LOWER EXTREME     ..    = -22064.0000
          .25-QUANTILE      ..    = -11786.0000
          .75-QUANTILE      ..    =   3567.0000
          UPPER EXTREME     ..    =  27592.0000

H I S T O G R A M
-----------------

VMU  -3838.44444     SIGMA  10606.44875     SKEW

-----------------------------------------------------------
              RANGE            FREQ.1...5...10...15...20...
-----------------------------------------------------------
  1 -.2206E+05 -.1958E+05    3 ***
  2 -.1958E+05 -.1710E+05    6 ******
  3 -.1710E+05 -.1462E+05    4 ****
  4 -.1462E+05 -.1213E+05    9 *********
  5 -.1213E+05 -9650.       10 **********
  6 -9650.     -7167.        5 *****
  7 -7167.     -4684.       11 ***********
  8 -4684.     -2202.        8 ********
  9 -2202.      281.2        3 ***
 10  281.2      2764.        7 *******
 11  2764.      5247.        8 ********
 12  5247.      7730.        3 ***
 13  7730.      .1021E+05    3 ***
 14  .1021E+05  .1270E+05    3 ***
 15  .1270E+05  .1518E+05    3 ***
 16  .1518E+05  .1766E+05    0
 17  .1766E+05  .2014E+05    2 **
 18  .2014E+05  .2263E+05    0
 19  .2263E+05  .2511E+05    1 *
 20  .2511E+05  .2759E+05    1 *
-----------------------------------------------------------
```

```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =          90
          MEAN                    =   1067.6795
          COEFF. OF VARIATION     =      9.8897
               STANDARD DEVIATION =  10559.0312
               SAMPLE VARIANCE    = 111493138.9121
               3RD CENTRAL MOMENT =   .6185E+11
               4TH CENTRAL MOMENT =   .37545206E+17
          MEDIAN OF THE SAMPLE    =   1871.0512
          LOWER EXTREME     ..    = -24188.8336
          .25-QUANTILE      ..    =  -6730.7705
          .75-QUANTILE      ..    =   8013.2598
          UPPER EXTREME     ..    =  29718.9655

H I S T O G R A M
-----------------

VMU   1067.67953     SIGMA  10500.20601      SKEW

-----------------------------------------------------------
              RANGE            FREQ.1...5...10...15...20...
-----------------------------------------------------------
  1 -.2419E+05 -.2149E+05    1 *
  2 -.2149E+05 -.1880E+05    3 ***
  3 -.1880E+05 -.1610E+05    2 **
  4 -.1610E+05 -.1341E+05    2 **
  5 -.1341E+05 -.1071E+05    4 ****
  6 -.1071E+05 -8016.        4 ****
  7 -8016.     -5321.        9 *********
  8 -5321.     -2626.        6 ******
  9 -2626.      69.68       10 **********
 10  69.68      2765.       11 ***********
 11  2765.      5460.        8 ********
 12  5460.      8156.        8 ********
 13  8156.      .1085E+05    8 ********
 14  .1085E+05  .1355E+05    4 ****
 15  .1355E+05  .1624E+05    4 ****
 16  .1624E+05  .1894E+05    2 **
 17  .1894E+05  .2163E+05    2 **
 18  .2163E+05  .2433E+05    0
 19  .2433E+05  .2702E+05    0
 20  .2702E+05  .2972E+05    2 **
-----------------------------------------------------------
```

2B.4 Comparative statistics for the computed energy consumption sequences of the physical and reference models for the 1977-78 heating season <u>with</u> the time series adjustment.

Adjusted Physical
(Evaluation Period: 12/1/77-2/28/78)

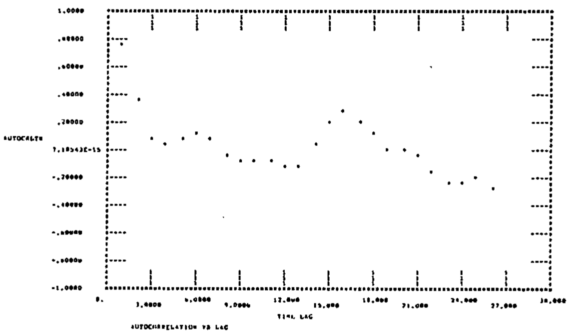
Autocorrelation



```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =          82
          MEAN                    = 150493.8010
          COEFF. OF VARIATION     =       .1747
               STANDARD DEVIATION =  26286.7002
               SAMPLE VARIANCE    = 690990609.6114
               3RD CENTRAL MOMENT =  -.1557E+13
               4TH CENTRAL MOMENT =   .14634177E+19
          MEDIAN OF THE SAMPLE    = 149393.0789
          LOWER EXTREME     ..    =  86459.0876
          .25-QUANTILE      ..    = 137011.7259
          .75-QUANTILE      ..    = 167932.3239
          UPPER EXTREME     ..    = 214796.5653
```

Adjusted Reference
(Evaluation Period: 12/1/77-1/31/78)
(Prediction Period: 2/1/78-2/28/78)

Autocorrelation



```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =          82
          MEAN                    = 151801.4562
          COEFF. OF VARIATION     =       .1756
               STANDARD DEVIATION =  26661.5869
               SAMPLE VARIANCE    = 710840217.0150
               3RD CENTRAL MOMENT =   .5013E+12
               4TH CENTRAL MOMENT =   .12615177E+19
          MEDIAN OF THE SAMPLE    = 151112.6425
          LOWER EXTREME     ..    =  96280.5546
          .25-QUANTILE      ..    = 131348.2545
          .75-QUANTILE      ..    = 170362.5275
          UPPER EXTREME     ..    = 211498.3790
```

2B.4 (Continued)

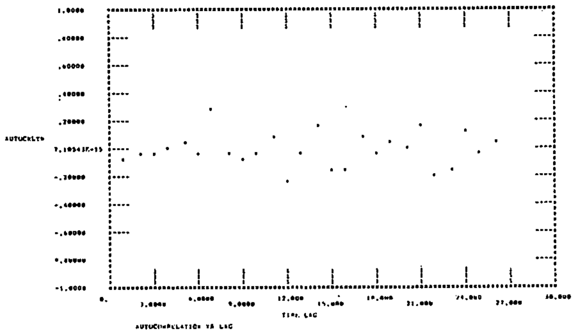
```
H I S T O G R A M
-----------------

VMU 150493.80098      SIGMA  26125.92381      SKEW

----------------------------------------------------------
                RANGE             FREQ.1...5...10...15...20...
----------------------------------------------------------
  1  .8646E+05   .9288E+05     2 **
  2  .9288E+05   .9929E+05     1 *
  3  .9929E+05   .1057E+06     1 *
  4  .1057E+06   .1121E+06     3 ***
  5  .1121E+06   .1185E+06     1 *
  6  .1185E+06   .1250E+06     3 ***
  7  .1250E+06   .1314E+06     6 ******
  8  .1314E+06   .1378E+06     6 ******
  9  .1378E+06   .1442E+06    11 ***********
 10  .1442E+06   .1506E+06     9 *********
 11  .1506E+06   .1570E+06     6 ******
 12  .1570E+06   .1635E+06     7 *******
 13  .1635E+06   .1699E+06     6 ******
 14  .1699E+06   .1763E+06     8 ********
 15  .1763E+06   .1827E+06     3 ***
 16  .1827E+06   .1891E+06     4 ****
 17  .1891E+06   .1955E+06     1 *
 18  .1955E+06   .2020E+06     1 *
 19  .2020E+06   .2084E+06     1 *
 20  .2084E+06   .2148E+06     2 **
----------------------------------------------------------
```

```
H I S T O G R A M
-----------------

VMU 151801.45617      SIGMA  26498.51758      SKEW

----------------------------------------------------------
                RANGE             FREQ.1...5...10...15...20...
----------------------------------------------------------
  1  .9628E+05   .1020E+06     2 **
  2  .1020E+06   .1078E+06     3 ***
  3  .1078E+06   .1136E+06     3 ***
  4  .1136E+06   .1193E+06     1 *
  5  .1193E+06   .1251E+06     2 **
  6  .1251E+06   .1308E+06     8 ********
  7  .1308E+06   .1366E+06     7 *******
  8  .1366E+06   .1424E+06     3 ***
  9  .1424E+06   .1481E+06     7 *******
 10  .1481E+06   .1539E+06     7 *******
 11  .1539E+06   .1597E+06     6 ******
 12  .1597E+06   .1654E+06     7 *******
 13  .1654E+06   .1712E+06     6 ******
 14  .1712E+06   .1769E+06     7 *******
 15  .1769E+06   .1827E+06     4 ****
 16  .1827E+06   .1885E+06     2 **
 17  .1885E+06   .1942E+06     3 ***
 18  .1942E+06   .2000E+06     0
 19  .2000E+06   .2057E+06     1 *
 20  .2057E+06   .2115E+06     3 ***
----------------------------------------------------------
```

2B.5 Comparative statistics for the residual sequences of the physical and reference models for the 1977-78 heating season with the time series adjustment.

Adjusted Physical
(Evaluation Period: 12/1/77-2/28/78)

Autocorrelation

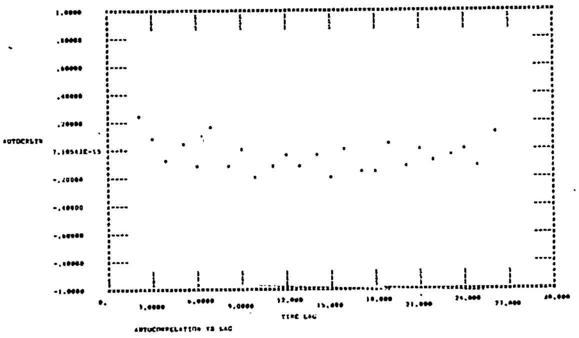


```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =             82
          MEAN                    =       203.6380
          COEFF. OF VARIATION     =        29.2411
              STANDARD DEVIATION  =      5954.6022
              SAMPLE VARIANCE     =  35457286.8782
              3RD CENTRAL MOMENT  =      .9230E+10
              4TH CENTRAL MOMENT  =      .35347365E+16
          MEDIAN OF THE SAMPLE    =      -105.5519
          LOWER EXTREME      ..   =    -15761.5713
          .25-QUANTILE       ..   =     -4014.7471
          .75-QUANTILE       ..   =      4504.9826
          UPPER EXTREME      ..   =     16515.6761
```

```
H I S T O G R A M
-----------------

VMU     203.63805      SIGMA   5918.18223      SKEW

----------------------------------------------------------
                RANGE             FREQ.1...5...10...15...20...
----------------------------------------------------------
  1 -.1576E+05 -.1415E+05      1 *
  2 -.1415E+05 -.1253E+05      0
  3 -.1253E+05 -.1092E+05      1 *
  4 -.1092E+05 -9306.          1 *
  5 -9306.     -7692.          2 **
  6 -7692.     -6078.          8 ********
  7 -6078.     -4465.          5 *****
  8 -4465.     -2851.          7 *******
  9 -2851.     -1237.         11 ***********
 10 -1237.      377.1          8 ********
 11  377.1      1991.          5 *****
 12  1991.      3605.          9 *********
 13  3605.      5219.          6 ******
 14  5219.      6833.          8 ********
 15  6833.      8446.          4 ****
 16  8446.      .1006E+05      2 **
 17  .1006E+05  .1167E+05      3 ***
 18  .1167E+05  .1329E+05      0
 19  .1329E+05  .1490E+05      0
 20  .1490E+05  .1652E+05      1 *
----------------------------------------------------------
```

Adjusted Reference
(Evaluation Period: 12/1/77-1/31/78)
(Prediction Period: 2/1/78-2/28/78)

Autocorrelation



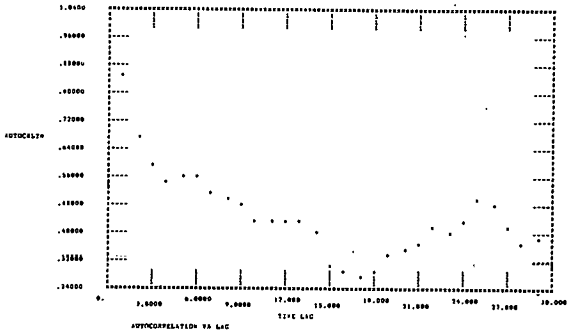
```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =             82
          MEAN                    =     -1104.0171
          COEFF. OF VARIATION     =        -5.8736
              STANDARD DEVIATION  =      6484.5409
              SAMPLE VARIANCE     =  42049270.8125
              3RD CENTRAL MOMENT  =     -.8808E+11
              4TH CENTRAL MOMENT  =      .54637145E+16
          MEDIAN OF THE SAMPLE    =      -716.8363
          LOWER EXTREME      ..   =    -19847.3790
          .25-QUANTILE       ..   =     -5126.9421
          .75-QUANTILE       ..   =      3340.0607
          UPPER EXTREME      ..   =     12048.6574
```

```
H I S T O G R A M
-----------------

VMU  -1104.01715      SIGMA   6444.87974      SKEW

----------------------------------------------------------
                RANGE             FREQ.1...5...10...15...20..
----------------------------------------------------------
  1 -.1985E+05 -.1825E+05      1 *
  2 -.1825E+05 -.1666E+05      0
  3 -.1666E+05 -.1506E+05      1 *
  4 -.1506E+05 -.1347E+05      2 **
  5 -.1347E+05 -.1187E+05      1 *
  6 -.1187E+05 -.1028E+05      0
  7 -.1028E+05 -8684.          4 ****
  8 -8684.     -7089.          6 ******
  9 -7089.     -5494.          3 ***
 10 -5494.     -3899.          7 *******
 11 -3899.     -2305.          8 ********
 12 -2305.     -709.8          8 ********
 13 -709.8      885.0         11 ***********
 14  885.0      2480.          4 ****
 15  2480.      4075.          9 *********
 16  4075.      5669.          6 ******
 17  5669.      7264.          3 ***
 18  7264.      8859.          4 ****
 19  8859.      .1045E+05      1 *
 20  .1045E+05  .1205E+05      3 ***
----------------------------------------------------------
```

2B.6 Comparative statistics for the predicted energy consumption sequence of the physical and reference models for the 1978-79 heating season <u>without</u> the time series adjustment.

Preadjusted Physical
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation

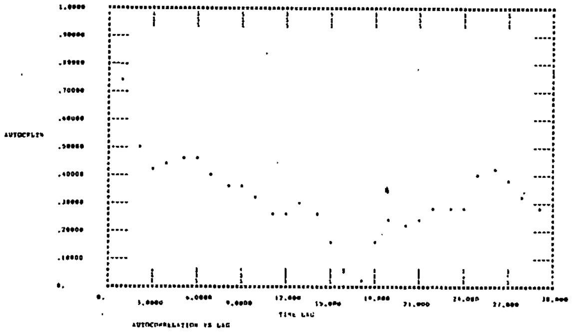


```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =            90
          MEAN                    =   149053.5909
          COEFF. OF VARIATION     =         .2599
               STANDARD DEVIATION =    38737.9367
               SAMPLE VARIANCE    = 1500627740.6745
               3RD CENTRAL MOMENT =      .3267E+13
               4TH CENTRAL MOMENT =   .45981498E+19
          MEDIAN OF THE SAMPLE    =   148204.4739
          LOWER EXTREME      ..   =    67262.9840
          .25-QUANTILE       ..   =   115830.2069
          .75-QUANTILE       ..   =   184327.7319
          UPPER EXTREME      ..   =   228261.8116
```

```
H I S T O G R A M
-----------------

VMU 149053.59090      SIGMA  38522.12480      SKEW

------------------------------------------------------------
               RANGE          FREQ.1...5...10...15...20...
------------------------------------------------------------
  1  .6726E+05  .7531E+05     2 **
  2  .7531E+05  .8336E+05     1 *
  3  .8336E+05  .9141E+05     1 *
  4  .9141E+05  .9946E+05     2 **
  5  .9946E+05  .1075E+06     7 *******
  6  .1075E+06  .1156E+06     9 *********
  7  .1156E+06  .1236E+06     8 ********
  8  .1236E+06  .1317E+06     3 ***
  9  .1317E+06  .1397E+06     6 ******
 10  .1397E+06  .1478E+06     6 ******
 11  .1478E+06  .1558E+06     6 ******
 12  .1558E+06  .1639E+06     5 *****
 13  .1639E+06  .1719E+06     5 *****
 14  .1719E+06  .1800E+06     6 ******
 15  .1800E+06  .1880E+06     6 ******
 16  .1880E+06  .1961E+06     6 ******
 17  .1961E+06  .2041E+06     3 ***
 18  .2041E+06  .2122E+06     4 ****
 19  .2122E+06  .2202E+06     2 **
 20  .2202E+06  .2283E+06     2 **
------------------------------------------------------------
```

Preadjusted Reference
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation



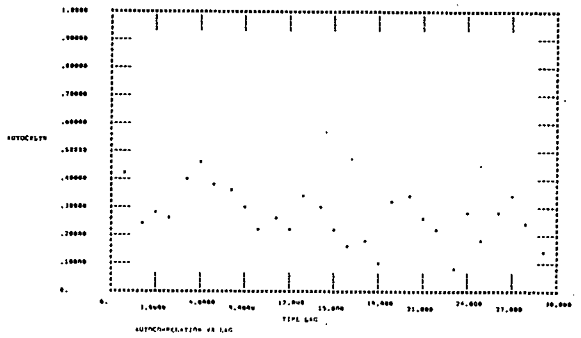
```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =            90
          MEAN                    =   144977.3222
          COEFF. OF VARIATION     =         .1874
               STANDARD DEVIATION =    27164.6037
               SAMPLE VARIANCE    =  737915694.7376
               3RD CENTRAL MOMENT =      .2067E+13
               4TH CENTRAL MOMENT =   .10419893E+19
          MEDIAN OF THE SAMPLE    =   144387.0000
          LOWER EXTREME      ..   =    93444.0000
          .25-QUANTILE       ..   =   124448.0000
          .75-QUANTILE       ..   =   167195.0000
          UPPER EXTREME      ..   =   196257.0000
```

```
H I S T O G R A M
-----------------

VMU 144977.32222      SIGMA  27013.26769      SKEW

------------------------------------------------------------
               RANGE          FREQ.1...5...10...15...20.
------------------------------------------------------------
  1  .9344E+05  .9858E+05     1 *
  2  .9858E+05  .1037E+06     4 ****
  3  .1037E+06  .1089E+06     5 *****
  4  .1089E+06  .1140E+06     2 **
  5  .1140E+06  .1191E+06     4 ****
  6  .1191E+06  .1243E+06     6 ******
  7  .1243E+06  .1294E+06     8 ********
  8  .1294E+06  .1346E+06    10 **********
  9  .1346E+06  .1397E+06     2 **
 10  .1397E+06  .1449E+06     3 ***
 11  .1449E+06  .1500E+06     6 ******
 12  .1500E+06  .1551E+06     5 *****
 13  .1551E+06  .1603E+06     2 **
 14  .1603E+06  .1654E+06     8 ********
 15  .1654E+06  .1706E+06     4 ****
 16  .1706E+06  .1757E+06     5 *****
 17  .1757E+06  .1808E+06     2 **
 18  .1808E+06  .1860E+06     7 *******
 19  .1860E+06  .1911E+06     2 **
 20  .1911E+06  .1963E+06     4 ****
------------------------------------------------------------
```

2B.7 Comparative statistics for the residual sequences of the physical and reference models for the 1978-79 heating season <u>without</u> the time series adjustment.

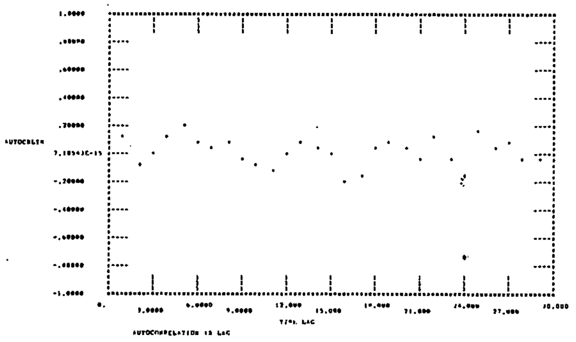
Preadjusted Physical
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation



Preadjusted Reference
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation



2B.7 (Continued)

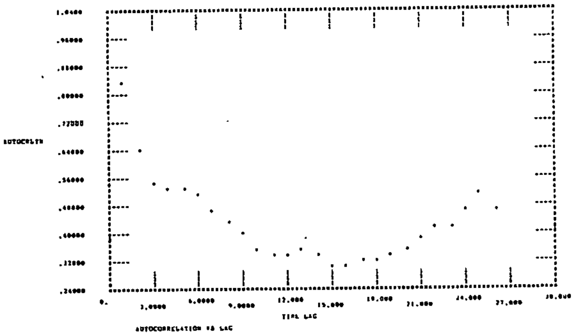
```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =           90
          MEAN                    =    2785.1222
          COEFF. OF VARIATION     =       4.3994
               STANDARD DEVIATION =   12252.7862
               SAMPLE VARIANCE    = 150130769.2096
               3RD CENTRAL MOMENT =     .3850E+12
               4TH CENTRAL MOMENT =  .67727057E+17
          MEDIAN OF THE SAMPLE    =    2951.0000
          LOWER EXTREME     ..    =  -24828.0000
          .25-QUANTILE      ..    =   -5843.0000
          .75-QUANTILE      ..    =   10861.0000
          UPPER EXTREME     ..    =   38904.0000

H I S T O G R A M
-----------------

VMU   2785.12222      SIGMA  12184.52500      SKEW

-----------------------------------------------------
              RANGE              FREQ.1...5...10...15...
-----------------------------------------------------
  1 -.2483E+05 -.2164E+05     2 **
  2 -.2164E+05 -.1845E+05     0
  3 -.1845E+05 -.1527E+05     4 ****
  4 -.1527E+05 -.1208E+05     4 ****
  5 -.1208E+05 -8895.         5 *****
  6 -8895.     -5708.         8 ********
  7 -5708.     -2522.         9 *********
  8 -2522.      664.8         6 ******
  9  664.8      3851.        10 **********
 10  3851.      7038.         9 *********
 11  7038.      .1022E+05     9 *********
 12  .1022E+05  .1341E+05     6 ******
 13  .1341E+05  .1660E+05     8 ********
 14  .1660E+05  .1978E+05     4 ****
 15  .1978E+05  .2297E+05     2 **
 16  .2297E+05  .2616E+05     1 *
 17  .2616E+05  .2934E+05     0
 18  .2934E+05  .3253E+05     2 **
 19  .3253E+05  .3572E+05     0
 20  .3572E+05  .3890E+05     1 *
-----------------------------------------------------
```

```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =           90
          MEAN                    =   -1291.1465
          COEFF. OF VARIATION     =     -11.1127
               STANDARD DEVIATION =   14348.0673
               SAMPLE VARIANCE    = 205867035.5142
               3RD CENTRAL MOMENT =    -.1137E+13
               4TH CENTRAL MOMENT =  .12153825E+18
          MEDIAN OF THE SAMPLE    =    -436.0227
          LOWER EXTREME     ..    =  -38132.0097
          .25-QUANTILE      ..    =   -9448.9505
          .75-QUANTILE      ..    =    9261.8207
          UPPER EXTREME     ..    =   33505.7749

H I S T O G R A M
-----------------

VMU  -1291.14646      SIGMA  14268.13316      SKEW

-----------------------------------------------------------
              RANGE              FREQ.1...5...10...15...20...
-----------------------------------------------------------
  1 -.3813E+05 -.3455E+05     1 *
  2 -.3455E+05 -.3097E+05     2 **
  3 -.3097E+05 -.2739E+05     3 ***
  4 -.2739E+05 -.2380E+05     1 *
  5 -.2380E+05 -.2022E+05     4 ****
  6 -.2022E+05 -.1664E+05     2 **
  7 -.1664E+05 -.1306E+05     5 *****
  8 -.1306E+05 -9477.         4 ****
  9 -9477.     -5895.         5 *****
 10 -5895.     -2313.        16 ****************
 11 -2313.      1269.         8 ********
 12  1269.      4851.         9 *********
 13  4851.      8433.         6 ******
 14  8433.      .1201E+05     5 *****
 15  .1201E+05  .1560E+05     8 ********
 16  .1560E+05  .1918E+05     7 *******
 17  .1918E+05  .2276E+05     3 ***
 18  .2276E+05  .2634E+05     0
 19  .2634E+05  .2992E+05     0
 20  .2992E+05  .3351E+05     1 *
-----------------------------------------------------------
```

2B.8 Comparative statistics for the predicted energy consumption sequences of the physical and reference models for the 1978-79 heating season with the time series adjustment.

Adjusted Physical
(Prediction Period: 1/1/79-3/31/79)

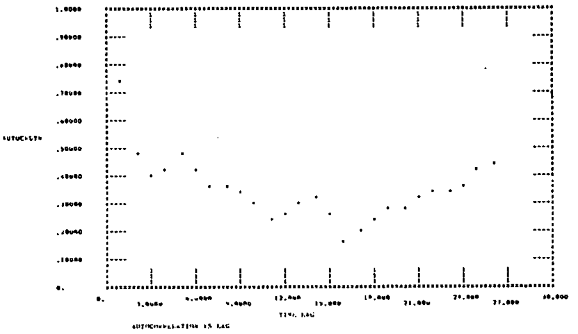
Autocorrelation



```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =            82
          MEAN                    =   138695.2179
          COEFF. OF VARIATION     =         .2316
               STANDARD DEVIATION =    32122.2937
               SAMPLE VARIANCE    = 1031841755.1645
               3RD CENTRAL MOMENT =      .4783E+13
               4TH CENTRAL MOMENT =   .22822549E+19
          MEDIAN OF THE SAMPLE    =   133897.8553
          LOWER EXTREME     ..    =    74535.6636
          .25-QUANTILE      ..    =   116583.4648
          .75-QUANTILE      ..    =   163224.0607
          UPPER EXTREME     ..    =   202517.1178
```

Adjusted Reference
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation



```
BASIC STATISTICS

          NUMBER OF OBSERVED DATA =            82
          MEAN                    =   143560.3918
          COEFF. OF VARIATION     =         .2445
               STANDARD DEVIATION =    35097.3786
               SAMPLE VARIANCE    = 1231825986.3303
               3RD CENTRAL MOMENT =      .4728E+13
               4TH CENTRAL MOMENT =   .31437436E+19
          MEDIAN OF THE SAMPLE    =   141402.1352
          LOWER EXTREME     ..    =    68246.1984
          .25-QUANTILE      ..    =   113879.9884
          .75-QUANTILE      ..    =   170889.9211
          UPPER EXTREME     ..    =   216521.2141
```

2B.8 (Continued)

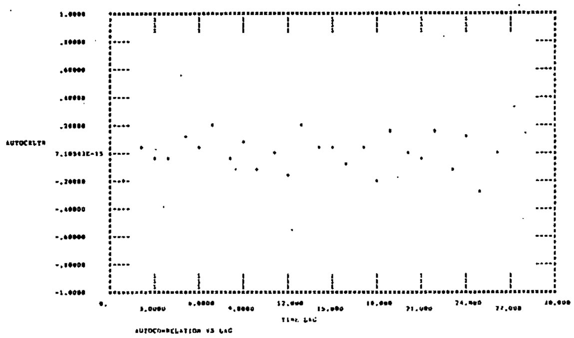
```
H I S T O G R A M
-----------------

VMU 138695.21790      SIGMA  31925.82527      SKEW

-----------------------------------------------------
               RANGE           FREQ.1...5...10...15...20...
-----------------------------------------------------
  1  .7454E+05  .8093E+05     2 **
  2  .8093E+05  .8733E+05     4 ****
  3  .8733E+05  .9373E+05     1 *
  4  .9373E+05  .1001E+06     0
  5  .1001E+06  .1065E+06     5 *****
  6  .1065E+06  .1129E+06     5 *****
  7  .1129E+06  .1193E+06     6 ******
  8  .1193E+06  .1257E+06    11 ***********
  9  .1257E+06  .1321E+06     6 ******
 10  .1321E+06  .1385E+06     4 ****
 11  .1385E+06  .1449E+06     6 ******
 12  .1449E+06  .1513E+06     3 ***
 13  .1513E+06  .1577E+06     3 ***
 14  .1577E+06  .1641E+06     7 *******
 15  .1641E+06  .1705E+06     3 ***
 16  .1705E+06  .1769E+06     3 ***
 17  .1769E+06  .1833E+06     3 ***
 18  .1833E+06  .1897E+06     5 *****
 19  .1897E+06  .1961E+06     2 **
 20  .1961E+06  .2025E+06     3 ***
-----------------------------------------------------
```

```
H I S T O G R A M
-----------------

VMU 143560.39185      SIGMA  34882.71374      SKEW

-----------------------------------------------------
               RANGE           FREQ.1...5...10...15...20...
-----------------------------------------------------
  1  .6825E+05  .7566E+05     1 *
  2  .7566E+05  .8307E+05     1 *
  3  .8307E+05  .9049E+05     2 **
  4  .9049E+05  .9790E+05     3 ***
  5  .9790E+05  .1053E+06     6 ******
  6  .1053E+06  .1127E+06     6 ******
  7  .1127E+06  .1201E+06     5 *****
  8  .1201E+06  .1276E+06     7 *******
  9  .1276E+06  .1350E+06     5 *****
 10  .1350E+06  .1424E+06     6 ******
 11  .1424E+06  .1498E+06     6 ******
 12  .1498E+06  .1572E+06     3 ***
 13  .1572E+06  .1646E+06     3 ***
 14  .1646E+06  .1720E+06     8 ********
 15  .1720E+06  .1795E+06     5 *****
 16  .1795E+06  .1869E+06     3 ***
 17  .1869E+06  .1943E+06     7 *******
 18  .1943E+06  .2017E+06     2 **
 19  .2017E+06  .2091E+06     1 *
 20  .2091E+06  .2165E+06     2 **
-----------------------------------------------------
```

2B.9 Comparative statistics for the residual sequences of the physical and reference models for the 1978-79 heating season with the time series adjustment.

Adjusted Physical
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation

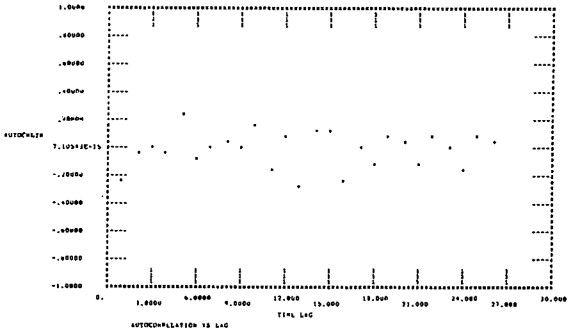


```
BASIC STATISTICS

        NUMBER OF OBSERVED DATA =              82
        MEAN                    =       5653.0016
        COEFF. OF VARIATION     =          1.3761
            STANDARD DEVIATION  =       7779.2197
            SAMPLE VARIANCE     =   60516258.6046
            3RD CENTRAL MOMENT  =       .3176E+11
            4TH CENTRAL MOMENT  =       .10523893E+17
        MEDIAN OF THE SAMPLE    =       5581.8950
        LOWER EXTREME     ..    =     -11815.8043
        .25-QUANTILE      ..    =        789.7139
        .75-QUANTILE      ..    =      10845.8555
        UPPER EXTREME     ..    =      25792.7545
```

```
H I S T O G R A M
-----------------

VMU    5653.00161      SIGMA   7731.63989      SKEW

-----------------------------------------------------
               RANGE           FREQ.1...5...10...15...20...
-----------------------------------------------------
  1 -.1182E+05 -9935.         2 **
  2 -9935.     -8055.         2 **
  3 -8055.     -6175.         1 *
  4 -6175.     -4294.         2 **
  5 -4294.     -2414.         7 *******
  6 -2414.     -533.2         4 ****
  7 -533.2      1347.         4 ****
  8  1347.      3228.         7 *******
  9  3228.      5108.        10 **********
 10  5108.      6988.         8 ********
 11  6988.      8869.         6 ******
 12  8869.      .1075E+05     8 ********
 13  .1075E+05  .1263E+05     6 ******
 14  .1263E+05  .1451E+05     6 ******
 15  .1451E+05  .1639E+05     3 ***
 16  .1639E+05  .1827E+05     1 *
 17  .1827E+05  .2015E+05     1 *
 18  .2015E+05  .2203E+05     2 **
 19  .2203E+05  .2391E+05     1 *
 20  .2391E+05  .2579E+05     1 *
-----------------------------------------------------
```

Adjusted Reference
(Prediction Period: 1/1/79-3/31/79)

Autocorrelation



```
BASIC STATISTICS

        NUMBER OF OBSERVED DATA =              82
        MEAN                    =        787.8277
        COEFF. OF VARIATION     =         14.4139
            STANDARD DEVIATION  =      11355.6788
            SAMPLE VARIANCE     =  128951441.9319
            3RD CENTRAL MOMENT  =      -.9726E+12
            4TH CENTRAL MOMENT  =       .70549954E+17
        MEDIAN OF THE SAMPLE    =       1756.3249
        LOWER EXTREME     ..    =     -37880.7315
        .25-QUANTILE      ..    =      -5832.4064
        .75-QUANTILE      ..    =       7550.8452
        UPPER EXTREME     ..    =      25753.0789
```

```
H I S T O G R A M
-----------------

VMU    787.82767      SIGMA  11286.22450      SKEW

-----------------------------------------------------
               RANGE           FREQ.1...5...10...15...20.
-----------------------------------------------------
  1 -.3788E+05 -.3470E+05     1 *
  2 -.3470E+05 -.3152E+05     1 *
  3 -.3152E+05 -.2834E+05     0
  4 -.2834E+05 -.2515E+05     0
  5 -.2515E+05 -.2197E+05     2 **
  6 -.2197E+05 -.1879E+05     1 *
  7 -.1879E+05 -.1561E+05     1 *
  8 -.1561E+05 -.1243E+05     1 *
  9 -.1243E+05 -9246.         3 ***
 10 -9246.     -6064.        10 **********
 11 -6064.     -2882.         8 ********
 12 -2882.      299.6        11 ***********
 13  299.6      3481.         9 *********
 14  3481.      6663.         9 *********
 15  6663.      9845.         8 ********
 16  9845.      .1303E+05     8 ********
 17  .1303E+05  .1621E+05     2 **
 18  .1621E+05  .1939E+05     3 ***
 19  .1939E+05  .2257E+05     3 ***
 20  .2257E+05  .2575E+05     1 *
-----------------------------------------------------
```

APPENDIX 2C

CHEYENNE INPUT-OUTPUT DATA FROM 1975-76 AND 1976-77

Daily Average Data

					Evaluation Period		Prediction Period	
Date	Temperature (°F)	Wind (MPH)	Isolation (Langleys/ 2 hours)	Observed Energy Consumption 10^3 Cu. Ft.	Reference Without Time Series 10^3 Cu. Ft.	Reference With Time Series 10^3 Cu. Ft.	Physical Without Time Series 10^3 Cu. Ft.	Physical With Time Series 10^3 Cu. Ft.
1/11/75	40.57	4.79	27.95	16375.00	15704.88		16090.50	
2/11/75	46.31	6.96	26.99	14420.00	13191.57		13576.00	
3/11/75	50.54	10.75	25.81	14287.00	12351.62		14138.70	
4/11/75	50.38	4.33	26.67	12440.00	12058.36		12877.50	
5/11/75	49.87	3.94	26.34	12182.00	10785.23		12626.50	
6/11/75	50.46	7.07	18.13	14155.00	13150.64		12953.70	
7/11/75	49.69	12.70	25.54	14710.00	13968.96		14678.70	
8/11/75	39.49	6.31	13.09	17808.00	18892.90	18465.98	16933.50	16696.75
9/11/75	31.94	8.43	24.50	21302.00	20110.84	18989.55	19876.20	18816.03
10/11/75	34.10	9.10	24.04	22330.00	20633.28	21422.26	20468.50	21493.70
11/11/75	27.11	18.07	20.28	25274.00	25264.28	26648.42	24177.70	24769.98
12/11/75	29.61	10.43	24.43	21353.00	21151.63	21086.91	22325.70	22714.56
13/11/75	45.72	11.99	24.13	17288.00	14441.48	14817.17	15527.90	16738.31
14/11/75	48.76	5.59	23.85	13236.00	13798.11	15376.64	13900.90	15934.91
15/11/75	52.59	5.89	22.49	8750.00	10843.57	10388.51	12038.30	12026.04
16/11/75	50.83	5.21	23.31	8474.00	12210.59	10064.63	11770.70	10033.00
17/11/75	39.84	4.07	16.97	13006.00	15426.35	11516.96	17240.30	13539.41
18/11/75	26.05	9.46	11.72	20560.00	21591.03	18665.19	22078.60	18833.73
19/11/75	20.07	14.55	3.44	25026.00	26052.06	24937.39	27488.40	25671.18
20/11/75	16.07	10.68	22.28	23109.00	26979.35	26031.94	26894.30	25634.51
21/11/75	17.71	4.01	20.84	22584.00	24795.12	21737.49	25195.50	22469.55
22/11/75	30.37	7.50	21.18	19645.00	20102.19	19029.16	20655.10	20030.87
23/11/75	31.65	12.73	15.70	20763.00	22462.27	22330.18	20948.60	20703.12
24/11/75	30.02	12.00	11.71	22329.00	23395.86	22609.68	22484.00	21501.73
25/11/75	16.41	16.17	16.32	22639.00	26647.75	25754.51	28522.30	26757.10
26/11/75	17.50	7.75	14.38	18518.00	25827.60	22842.99	26257.70	23186.76
27/11/75	23.69	5.43	17.68	14076.00	22894.13	17790.86	22392.90	17361.88
28/11/75	26.98	7.06	19.38	13459.00	22917.73	16711.26	22504.10	16236.44
29/11/75	6.60	9.56	7.31	19745.00	26832.24	19200.88	29717.10	21508.64
30/11/75	16.68	13.68	18.90	21182.00	26760.46	22337.54	27421.60	22762.38
1/12/75	40.84	21.29	18.60	19864.00	18784.91	17625.81	18881.10	17168.62
2/12/75	46.36	14.57	19.04	16173.00	14547.84	16259.63	15779.20	17180.01
3/12/75	47.14	10.00	18.00	14010.00	13293.02	14263.05	14769.00	15610.41
4/12/75	48.64	7.94	18.93	12334.00	13336.56	13417.05	13887.60	13984.43
5/12/75	36.14	9.92	14.17	17342.00	19430.93	17718.52	18934.20	16841.03
6/12/75	38.65	7.72	11.88	16895.00	16756.36	15440.88	17601.60	16482.43
7/12/75	43.86	8.85	7.80	16004.00	16833.11	17040.97	15699.70	16217.59
8/12/75	41.61	10.60	17.65	15221.00	16818.28	16323.69	16926.30	16376.84
9/12/75	46.45	12.45	16.60	14230.00	14196.24	13587.22	15345.60	14524.28
10/12/75	48.96	7.99	17.36	13248.00	13328.87	13111.31	13687.40	13525.29
11/12/75	34.60	5.07	12.83	16428.00	18936.82	18208.81	18444.50	16716.10
12/12/75	30.66	6.12	13.42	18651.00	18858.79	16398.23	20197.40	17824.40
13/12/75	22.72	4.30	8.87	21723.00	23365.14	23012.25	22380.70	21219.62
14/12/75	10.29	5.56	9.71	26081.00	27834.30	25376.49	27269.90	25009.71
15/12/75	30.49	16.73	17.74	25418.00	22026.91	21415.10	22797.30	23189.25
16/12/75	15.08	5.51	8.18	26024.00	25150.26	26065.96	25513.20	26552.77
17/12/75	6.72	4.53	18.36	27075.00	28773.04	28963.93	27950.30	27150.29
18/12/75	30.63	8.64	18.39	22644.00	22998.82	22926.34	20781.00	21084.06
19/12/75	33.74	11.15	18.47	20391.00	19353.01	19135.30	20212.40	20418.35
20/12/75	33.36	5.66	16.45	19227.00	17641.13	16069.29	19090.70	19764.87
21/12/75	34.68	7.35	16.34	18920.00	18633.10	19101.49	18921.40	19807.80
22/12/75	30.16	6.11	18.46	19856.00	19578.23	19503.50	20212.00	19942.57
23/12/75	27.28	6.36	16.22	21679.00	21103.78	20910.61	21384.70	20896.99
24/12/75	28.78	6.82	18.21	21215.00	21339.51	21333.23	20927.30	20928.60
25/12/75	33.76	11.19	15.08	19751.00	19113.17	19233.04	20267.70	20231.19
26/12/75	34.79	10.02	16.25	20196.00	19284.01	19570.75	19619.90	19901.14
27/12/75	33.08	16.52	11.63	22664.00	21270.10	22258.63	21553.90	22095.22

APPENDIX 2C (Continued)

Daily Average Data

Date	Temperature (°F)	Wind (MPH)	Isolation (Langleys/ 2 hours)	Observed Energy Consumption 10^3 Cu. Ft.	Evaluation Period: Reference Without Time Series 10^3 Cu. Ft.	Evaluation Period: Reference With Time Series 10^3 Cu. Ft.	Prediction Period: Physical Without Time Series 10^3 Cu. Ft.	Prediction Period: Physical With Time Series 10^3 Cu. Ft.
28/12/75	22.23	13.37	9.88	26313.00	24357.52	25045.68	25462.80	25841.88
29/12/75	27.89	9.53	15.83	23178.00	23178.89	24826.01	21975.70	23920.38
30/12/75	36.20	8.50	16.38	20138.00	18610.30	18485.19	18769.00	19539.03
31/12/75	15.69	17.31	2.88	26676.00	29234.73	30962.44	29195.60	28102.66
1/ 1/76	2.98	15.99	10.24	31017.00	32862.70	32436.72	35983.20	34656.22
2/ 1/76	8.89	8.72	15.78	29330.00	28426.72	27518.98	29223.00	28435.70
3/ 1/76	10.46	6.03	18.93	28353.00	27470.53	27616.04	26556.00	27180.14
4/ 1/76	19.00	5.97	18.33	25745.00	25563.96	26153.39	25263.30	26534.93
5/ 1/76	35.56	8.97	17.57	21339.00	16603.15	19077.40	19073.60	20716.25
6/ 1/76	16.48	6.70	15.30	25136.00	25541.59	27222.83	26964.00	26865.73
7/ 1/76	10.68	5.17	18.77	27661.00	28000.67	27199.14	26895.20	25577.17
8/ 1/76	27.66	6.22	15.06	24237.00	22574.65	21871.75	22197.60	22983.74
9/ 1/76	35.31	5.86	17.33	18840.00	18993.73	20271.36	18343.50	20115.39
10/ 1/76	28.81	11.55	19.59	22811.00	21583.43	21105.39	21610.80	20947.42
11/ 1/76	33.81	11.66	15.52	23431.00	20186.60	21499.02	21377.90	22815.19
12/ 1/76	31.61	8.67	11.94	21725.00	20626.15	22603.39	20480.40	22719.92
13/ 1/76	17.91	11.35	20.16	25962.00	26892.16	27818.05	28071.10	27468.42
14/ 1/76	30.90	9.11	18.82	24073.00	22469.79	21523.86	20752.10	21066.32
15/ 1/76	39.82	18.89	15.81	20445.00	18157.09	20678.79	19910.10	21790.07
16/ 1/76	41.30	12.95	20.55	17766.00	17624.40	19550.54	17444.00	19174.24
17/ 1/76	41.68	7.26	21.60	16003.00	16017.96	16063.64	15764.70	16111.98
18/ 1/76	37.23	10.93	12.43	18956.00	20015.46	19681.33	19809.30	19459.95
19/ 1/76	23.54	8.84	21.63	23905.00	23294.16	21797.99	23558.50	21913.62
20/ 1/76	32.83	8.79	21.68	21211.00	19871.92	20633.58	21062.00	22070.33
21/ 1/76	35.12	5.81	22.54	18843.00	18446.32	18953.29	18179.10	18964.79
22/ 1/76	39.90	9.91	22.79	16322.00	17490.74	17777.74	18247.10	18502.69
23/ 1/76	39.05	16.83	17.56	19501.00	18480.14	19465.64	18965.00	19351.70
24/ 1/76	25.68	5.76	3.57	23207.00	23025.74	23448.38	21942.80	21672.28
25/ 1/76	10.05	5.56	17.99	30308.00	28663.87	28359.92	28719.40	27601.02
26/ 1/76	15.82	7.30	17.29	27670.00	27597.79	28761.11	25834.60	27476.50
27/ 1/76	32.37	10.40	20.02	22012.00	21851.95	22062.45	21743.70	23236.24
28/ 1/76	35.98	9.74	23.60	18156.00	18030.40	18676.06	17865.10	18501.56
29/ 1/76	42.04	12.40	24.78	16943.00	16705.96	17092.23	17780.10	17874.15
30/ 1/76	33.31	12.54	17.13	20694.00	21074.13	21423.99	20613.40	19889.66
31/ 1/76	34.82	15.14	22.34	23253.00	20725.00	20833.01	19828.40	19934.34
1/ 2/76	40.49	12.40	24.16	19712.00	17266.55	19634.36	17671.60	20346.33
2/ 2/76	40.56	9.64	21.40	18544.00	16686.22	18313.44	17202.90	19008.70
3/ 2/76	30.44	7.36	23.54	20204.00	21340.99	21513.64	20599.50	20789.46
4/ 2/76	5.78	9.01	4.08	27408.00	29586.91	28127.90	30473.70	27195.58
5/ 2/76	-1.75	3.37	5.28	26379.00	31428.12	28490.33	30472.60	27717.95
6/ 2/76	12.41	3.65	23.68	24866.00	27123.73	23643.13	25575.40	22661.40
7/ 2/76	38.86	13.99	27.76	21328.00	16602.66	17364.38	18677.90	19298.30
8/ 2/76	43.57	10.93	26.06	16914.00	15404.39	17808.42	16209.00	18853.53
9/ 2/76	47.04	9.25	24.60	14583.00	15577.70	16677.07	14486.30	15841.01
10/ 2/76	36.90	10.15	26.43	17333.00	18779.42	17516.00	18731.20	17142.95
11/ 2/76	41.85	15.18	28.45	18457.00	17745.08	17419.74	17555.20	16680.06
12/ 2/76	44.03	11.44	28.75	13798.00	15634.72	16440.12	16127.30	16661.98
13/ 2/76	41.56	6.95	29.98	14487.00	15687.95	13934.74	16336.10	14636.76
14/ 2/76	39.29	7.98	26.49	18076.00	17354.07	16032.27	17172.30	16007.11
15/ 2/76	37.51	7.85	27.56	18299.00	17939.90	18108.05	17955.50	18415.18
16/ 2/76	34.42	10.62	28.69	21882.00	20033.87	20037.19	19751.40	19714.07
17/ 2/76	31.68	14.06	17.41	26098.00	21331.37	22710.19	21691.30	22686.25
18/ 2/76	31.19	16.32	25.06	27170.00	22555.40	26367.25	22657.30	25789.50
19/ 2/76	33.63	10.53	29.54	22916.00	19500.32	22966.98	20228.40	23676.66
20/ 2/76	18.78	14.78	5.00	25912.00	26122.84	27626.28	27297.40	28186.90
21/ 2/76	21.29	13.60	32.48	24365.00	24644.39	24819.69	25938.60	26122.91
22/ 2/76	33.82	14.43	32.94	20717.00	20033.76	20323.45	20992.70	22033.53
23/ 2/76	38.97	9.22	24.44	19159.00	19113.12	19645.24	17778.90	18823.95
24/ 2/76	39.56	17.08	29.36	18639.00	17901.44	18281.12	17975.30	18151.33

APPENDIX 2C (Continued)

Daily Average Data

Date	Temperature (°F)	Wind (MPH)	Isolation (Langleys/ 2 hours)	Observed Energy Consumption 10^3 Cu. Ft.	Evaluation Period		Prediction Period	
					Reference Without Time Series 10^3 Cu. Ft.	Reference With Time Series 10^3 Cu. Ft.	Physical Without Time Series 10^3 Cu. Ft.	Physical With Time Series 10^3 Cu. Ft.
25/ 2/76	38.51	10.61	30.59	18719.00	17743.39	18121.72	18259.30	18444.77
26/ 2/76	42.71	6.10	30.68	18138.00	16053.29	16493.64	15636.80	16358.19
27/ 2/76	40.27	5.50	22.52	18926.00	15912.66	16662.10	16477.10	17549.97
28/ 2/76	40.10	7.76	26.14	18346.00	18058.62	19660.71	16612.90	18563.31
29/ 2/76	26.24	7.76	20.53	22087.00	22610.98	22654.91	22186.10	21435.56
1/ 3/76	41.90	7.64	35.33	17112.00	16969.59	16484.95	15997.00	17037.69
2/ 3/76	13.74	7.43	5.72	25711.00	24960.90	24748.07	26648.80	24164.19
3/ 3/76	9.96	6.70	31.78	23873.00	27892.19	28037.33	27811.70	27203.96
4/ 3/76	11.20	8.09	8.53	26053.00	29205.92	26012.27	27969.00	24713.37
5/ 3/76	14.16	6.91	36.78	24964.00	26945.07	24737.64	26271.60	24218.79
6/ 3/76	20.58	5.25	39.23	21559.00	23958.15	22545.87	23307.20	22408.12
7/ 3/76	23.15	4.32	39.69	19538.00	22271.98	20201.35	22204.20	20682.70
8/ 3/76	31.94	6.37	40.01	17419.00	19742.99	17892.98	19708.50	18302.03
9/ 3/76	37.08	7.69	39.76	17348.00	18053.50	16424.40	18013.70	16531.00
10/ 3/76	38.16	6.45	41.07	16036.00	17742.69	16831.43	17340.10	16516.45
11/ 3/76	31.62	13.33	16.46	21983.00	24870.96	23332.72	21645.20	19477.28
12/ 3/76	15.31	12.71	34.47	27862.00	27539.49	25321.59	28195.70	25241.75
13/ 3/76	35.21	10.34	39.26	20891.00	20818.17	21361.74	19396.90	21504.57
14/ 3/76	29.40	6.71	22.57	20752.00	21097.26	20782.59	20775.40	20717.62
15/ 3/76	27.52	10.97	41.23	22014.00	22796.01	22423.41	22543.00	22090.44
16/ 3/76	40.12	13.26	42.16	18763.00	18487.25	18188.07	17886.70	18375.98
17/ 3/76	45.14	11.82	33.86	16237.00	15156.58	15897.64	15826.90	16342.36
18/ 3/76	50.05	9.86	42.19	13180.00	13693.06	14583.27	13450.40	14291.10
19/ 3/76	37.78	15.94	33.80	19270.00	20573.64	19834.41	19599.80	18045.64
20/ 3/76	29.32	20.14	39.47	25358.00	23030.40	22785.36	23794.90	22561.39
21/ 3/76	29.90	11.50	26.35	22161.00	20763.54	22769.28	21834.50	23926.46
22/ 3/76	39.03	7.34	46.05	16250.00	17600.70	18847.58	17275.60	
23/ 3/76	44.41	13.60	40.48	14314.00	16547.78	16192.51	16453.60	
24/ 3/76	45.40	15.50	44.27	13717.00	15413.78	14437.34	16176.00	
25/ 3/76	41.17	14.06	39.27	17735.00	18244.16	17025.35	18454.00	
26/ 3/76	33.52	11.27	47.85	19239.00	20245.61	19626.12	20272.70	
27/ 3/76	41.19	5.35	42.96	15403.00	16357.39	15877.40	15752.70	
28/ 3/76	31.84	8.00	29.60	19728.00	20475.62	18959.41	21129.00	
29/ 3/76	29.20	9.13	22.59	21694.00	21957.90	21172.43	21366.20	
30/ 3/76	29.24	9.48	43.43	22186.00	21725.94	21476.14	21993.60	
31/ 3/76	42.54	6.72	49.78	18954.00	16988.52		15632.00	
1/ 1/77	4.55	5.76	16.00	27946.00	28638.26		28046.70	
2/ 1/77	24.69	5.25	16.83	23349.00	23420.28		21354.70	
3/ 1/77	29.17	4.49	7.75	21649.00	20634.34		21058.20	
4/ 1/77	15.16	6.63	10.50	26179.00	26328.43		25982.10	
5/ 1/77	11.13	3.74	14.25	27767.00	26774.78		27052.30	
6/ 1/77	23.70	12.34	13.50	26933.00	25016.29		24278.30	
7/ 1/77	28.34	13.76	12.67	24600.00	24252.54		23764.40	
8/ 1/77	-.83	5.77	11.33	31271.00	33279.29	32269.64	31542.10	29632.34
9/ 1/77	6.49	10.40	19.00	29678.00	31854.69	30035.32	30066.60	29398.55
10/ 1/77	22.90	7.23	8.25	22554.00	24172.07	24700.47	24535.20	24727.92
11/ 1/77	21.56	6.13	18.17	23086.00	22985.55	20485.93	23121.20	21711.64
12/ 1/77	31.32	7.33	5.75	23713.00	21871.75	22068.15	20576.70	20929.71
13/ 1/77	28.83	7.36	17.00	21471.00	21107.56	22831.15	21144.30	22101.37
14/ 1/77	23.78	8.52	14.00	24266.00	24498.41	23196.65	24281.70	23831.54
15/ 1/77	7.33	6.06	6.08	27509.00	28455.75	25396.43	28894.60	27443.01
16/ 1/77	21.13	9.32	19.75	23066.00	26664.26	26646.21	23868.90	24257.50
17/ 1/77	28.53	15.63	10.42	25652.00	24267.05	21747.02	23929.00	22423.72
18/ 1/77	36.25	8.01	8.92	20160.00	20699.54	23427.41	18696.30	20627.60
19/ 1/77	32.42	11.94	19.67	20217.00	22131.71	20535.66	21331.80	20615.21
20/ 1/77	31.11	7.54	19.25	20141.00	20383.34	19510.05	20115.80	18629.29

APPENDIX 2C (Continued)

Daily Average Data

Date	Temperature (°F)	Wind (MPH)	Isolation (Langleys/ 2 hours)	Observed Energy Consumption 10^3 Cu. Ft.	Evaluation Period		Prediction Period	
					Reference Without Time Series 10^3 Cu. Ft.	Reference With Time Series 10^3 Cu. Ft.	Physical Without Time Series 10^3 Cu. Ft.	Physical With Time Series 10^3 Cu. Ft.
21/ 1/77	24.93	5.20	17.83	22038.00	22459.22	20460.96	22831.90	21877.97
22/ 1/77	31.63	9.82	8.92	21368.00	20959.69	22292.65	20524.30	20739.02
23/ 1/77	22.73	8.42	21.83	22378.00	24163.23	21280.35	23027.30	22711.92
24/ 1/77	20.66	8.30	22.42	25581.00	25840.17	24516.67	25477.60	24084.05
25/ 1/77	27.86	11.76	21.92	23754.00	22433.46	24153.41	22444.00	22667.96
26/ 1/77	32.66	15.94	15.25	23957.00	20681.74	24079.26	21821.00	22931.01
27/ 1/77	33.03	15.42	23.42	21771.00	21318.01	23970.15	21000.50	23101.89
28/ 1/77	17.08	7.30	16.25	25552.00	25690.66	21614.97	26318.30	25272.96
29/ 1/77	18.48	6.22	21.92	23951.00	23606.86	24074.57	24350.60	24304.90
30/ 1/77	20.70	4.97	18.83	23212.00	25628.78	23896.35	22695.60	22896.47
31/ 1/77	36.83	8.30	23.50	18381.00	18625.45	16730.93	19079.00	18965.17
1/ 2/77	29.90	5.08	13.92	19370.00	20254.68	20041.07	20038.30	19110.46
2/ 2/77	26.01	6.35	12.58	21866.00	22659.50	20851.10	22579.70	21118.00
3/ 2/77	29.38	8.03	23.92	21316.00	22094.90	21201.14	20755.00	20134.80
4/ 2/77	32.81	9.36	23.50	19543.00	20065.18	20442.78	21121.20	20814.80
5/ 2/77	34.83	6.82	21.17	18376.00	19064.96	16092.91	16536.20	16365.01
6/ 2/77	26.22	3.97	19.58	19446.00	20601.50	18133.76	20677.20	19498.66
7/ 2/77	28.21	5.70	25.25	19611.00	20832.26	19402.76	21438.50	20475.47
8/ 2/77	39.22	5.77	23.17	16347.00	15966.55	15811.97	16524.80	16285.73
9/ 2/77	37.68	4.69	23.17	15676.00	15745.38	14763.58	17455.50	16981.05
10/ 2/77	34.40	4.77	22.50	16324.00	17375.90	15369.82	18125.70	17036.60
11/ 2/77	34.08	9.47	21.33	16444.00	20431.30	19479.69	20161.00	18865.83
12/ 2/77	35.14	12.11	21.17	18215.00	20153.41	17407.12	18189.50	17326.18
13/ 2/77	37.93	17.64	24.92	18023.00	19471.89	19919.97	19024.80	18130.87
14/ 2/77	23.47	9.64	23.08	22217.00	23938.11	23476.99	24871.40	22829.47
15/ 2/77	30.88	8.32	13.58	21026.00	21332.41	20041.78	20752.30	20055.83
16/ 2/77	42.98	10.90	23.58	16194.00	16779.76	17954.56	17220.00	17626.63
17/ 2/77	44.92	12.36	27.75	14395.00	16470.42	16204.07	15951.90	15492.86
18/ 2/77	35.88	12.43	21.33	17472.00	19771.39	18636.68	20729.00	18482.12
19/ 2/77	32.52	7.41	25.33	17622.00	20449.56	16612.72	19575.50	17830.98
20/ 2/77	40.36	6.44	29.08	14603.00	16710.47	15010.74	16318.00	15179.47
21/ 2/77	48.30	10.56	18.67	13840.00	14339.82	14878.14	15162.00	14350.71
22/ 2/77	36.60	13.36	24.75	17124.00	20402.52	18986.54	19583.10	18085.16
23/ 2/77	29.73	19.06	31.25	23965.00	22160.88	22320.68	24323.50	21353.03
24/ 2/77	27.03	11.44	31.17	21822.00	22746.13	23552.62	22823.10	23655.35
25/ 2/77	20.41	4.76	20.33	21702.00	24539.55	21933.01	24485.50	23126.28
26/ 2/77	20.47	6.66	21.67	24096.00	25278.56	22584.83	24000.90	21944.56
27/ 2/77	22.44	8.67	30.17	22605.00	23533.67	23255.66	23492.60	22998.62
28/ 2/77	31.41	9.81	32.33	20352.00	20466.08	20817.28	21748.00	21946.41
1/ 3/77	23.27	6.10	29.75	20228.00	22909.29	20515.56	22663.60	21641.63
2/ 3/77	17.94	12.14	8.67	25466.00	26941.96	26935.46	27482.30	24621.15
3/ 3/77	20.40	15.09	33.08	25091.00	25368.34	25121.15	26388.40	25374.50
4/ 3/77	19.58	11.52	22.50	24215.00	25469.04	25635.52	27222.40	26633.09
5/ 3/77	21.47	7.61	30.58	22030.00	24447.88	23060.17	23761.60	23090.52
6/ 3/77	32.78	8.21	33.50	18730.00	21718.63	19818.72	18834.20	18228.30
7/ 3/77	45.10	12.72	26.08	15433.00	15760.84	16379.48	16302.30	15595.22
8/ 3/77	44.96	7.82	32.08	13138.00	15944.61	14885.69	15048.60	14716.15
9/ 3/77	42.58	6.78	26.58	14030.00	16064.53	12926.67	16297.40	13670.35
10/ 3/77	26.57	23.94	12.17	23664.00	25363.17	24268.24	24872.30	21650.44
11/ 3/77	21.23	28.64	21.33	27746.00	27295.69	28498.08	29466.80	28234.31
12/ 3/77	28.79	16.58	37.33	22210.00	23238.38	25106.06	23434.80	24890.34
13/ 3/77	43.88	6.93	34.83	13678.00	16124.54	15440.71	15237.10	16233.38
14/ 3/77	29.44	8.02	20.17	17931.00	20729.87	18419.16	22200.90	19292.89
15/ 3/77	26.76	5.38	32.50	19036.00	22114.28	16156.95	21326.30	18601.54
16/ 3/77	35.33	4.20	34.50	15788.00	19099.38	16105.79	18400.40	16570.20
7/ 3/77	35.63	11.58	22.83	18123.00	20338.40	19396.57	19578.50	16921.27
18/ 3/77	26.64	7.03	21.58	20274.00	22865.78	21334.75	23073.10	20767.64
19/ 3/77	27.66	9.69	34.42	21078.00	22869.43	20017.96	22212.20	20549.56
20/ 3/77	24.65	8.86	37.00	20476.00	24448.09	24040.62	23056.40	21756.23
21/ 3/77	31.85	12.39	36.50	21161.00	22377.04		21944.70	

APPENDIX 4A

SURVEY TO DETERMINE THE DIFFERENCE BETWEEN THOSE THAT RETROFIT THEIR HOMES WITH INSULATION AND THOSE THAT DO NOT.

A. Background Information

1. Name: ________________________________
2. Age: __________
3. Approximate family income: ______________
4. Own or rent home: ________
5. Years residing at current address: __________
6. Do you plan to move in the next few years? _____ (yes, no)
7. Age of home: ________
8. Square feet: ________
9. Design: ____________ (2 story, 1 story)
10. What was the highest heating bill last year? ________

B. Questions Concerning the Decision to Insulate

1. Have you insulated your home in the last 5 years?
   Yes____ (go to question 3)
   No ____ (go to question 2)
2. Have you thought about adding insulation to your attic?
   Yes____
   No ____

   If YES: What have you done about it so far?
   <u>INTERVIEWER</u>: Record responses in the "Free" column on the checklist below; check all applicable. If respondent can't think of anything, read off checklist (Well, have you checked to see how much insulation you have not?, etc.). Record any "yes" responses in the "Prompt" column. Don't prompt if you get any responses, except to say, "<u>Anything else</u>?"

Free	Prompt	
____	____	Checked my attic to see how much insulation is there now.
____	____	Measured my attic.
____	____	Looked at insulation and checked prices at building supply stores.
____	____	Called a contractor to get an estimate.
____	____	Asked the Public Service Company to perform an inspection.
____	____	Other: ______________________________

If NO: Could you tell me why you haven't considered it?
INTERVIEWER: Do not read checklist; just check off all applicable statements.

____ I have enough insulation in my attic already. (How much do you have?) __________R-value or __________ inches. What type?__________
____ I'd like to put insulation in but don't have the money right now.
____ I'd like to install insulation but I just haven't gotten around to doing it.
____ I haven't really thought about installing insulation.
____ I don't think insulation really saves heating fuel.
____ I won't be living here much longer.
____ I don't live in a house with an attic.
____ My attic has a finished floor, so installing insulation would be difficult.
____ I don't own the residence I'm living in.
____ Other:

3. Who did the work?
   Private contractor__________
   I did__________
4. What was the approximate cost of the job?______________
   ____
5. What factors were most influential in your decision to insulate.
   ____
   ____
6. Were you familiar with the Public Service Company's program to reinsulate homes? Yes____
   No ____
7. How did you find out about their program?______________
   ____
   ____
8. In your opinion, did the investment in insulation pay off?
   Yes____
   No ____

9. What other things have you done to conserve natural gas_____or electricity_____?

Free Prompt

_____ _____ Applied weather stripping?
_____ _____ Installed storm windows?
_____ _____ Caulked windows?
_____ _____ Turned down thermostat? What setting?_____
_____ _____ Other_____________________________

C. Questions Concerning the Economics of Conservation

1. How strongly would you consider buying a solar heated and cooled home for your next home if the fuel savings exactly matched the increased mortgage costs at today's fuel prices? Again, consider all the factors you feel are important. (Check one)
_____ Definitely would buy a solar home.
_____ Would consider buying a solar home.
_____ Don't feel strongly either way.
_____ Would not consider buying a solar home.
_____ Definitely would not buy a solar home.

If person answers that he or she would not buy a solar home, ask why.
____

Free Prompt

_____ _____ Are you sure it works?
_____ _____ Do you think costs will fall?
_____ _____ Do you like the way it looks?
_____ _____ Other_____________________

2. (Ask non-adopters) Suppose you were going to add more insulation to your home. How many years should it take to pay for itself?
____ 2 years
____ 4 years
____ 6 years
____ 8 years
____ 10 years
____ 12 years
____ 14 years
____ 16 years
____ 18 years
____ 20 years

(Ask adopters) When you were first thinking of adding more insulation to your home, how many years did you think it should take to pay for itself?
____ 2 years
____ 4 years
____ 6 years
____ 8 years
____ 10 years
____ 12 years
____ 14 years
____ 16 years
____ 18 years
____ 20 years

3. Suppose you buy another home. Thicker insulation could be added. It would add $2000 to the price. This would increase your monthly payment by $20 and your down payment by $200. How much would you have to save in average monthly fuel bills before you install the insulation?
____ $10 per month
____ $15 per month
____ $20 per month
____ $25 per month
____ $35 per month
____ $45 per month
____ $55 per month
____ $65 per month

D. Opinion Questionnaire

On the next pages are some statements about energy--the energy problem, how you use energy, saving energy, and so on. We want <u>your opinion</u> about each statement: whether you agree or disagree. 1 is used to represent very strong disagreement; 5 indicates very strong agreement.

	Circle One				
	STRONGLY DISAGREE				STRONGLY AGREE
1. There is little anyone can do to avoid high electricity and heating fuel price increases.	1	2	3	4	5
2. Many times I feel that we might just as well make many of our decisions by flipping a coin.	1	2	3	4	5
3. Solar energy is the best alternative to oil, gas, or electricity.	1	2	3	4	5
4. Most of the ideas which get printed nowadays aren't worth the paper they are printed on.	1	2	3	4	5

Circle One

	STRONGLY DISAGREE				STRONGLY AGREE
5. Utilities are taking unfair advantage of homeowners with their price increases.	1	2	3	4	5
6. There are going to be severe shortages of fuels in this country so that everyone will not be able to get all the fuels they want.	1	2	3	4	5
7. It isn't wise to plan too far ahead because most things turn out to be a matter of good or bad fortune anyhow.	1	2	3	4	5
8. Buying a solar home could be risky because it might not operate well or last long.	1	2	3	4	5
9. The price of gas and electricity is going to continue to go up rapidly.	1	2	3	4	5
10. In this complicated world of ours the only way we can know what's going on is to rely on leaders or experts who can be trusted.	1	2	3	4	5
11. I don't have the time to adopt energy-saving measures myself.	1	2	3	4	5
12. Adding insulation to a poorly-insulated house usually pays for itself in reduced heating costs in less than 4 years.	1	2	3	4	5
13. Taking used cans, bottles, and newspapers to a recycling center isn't important enough to be worth the trouble.	1	2	3	4	5
14. For most people, the cost of putting in attic insulation is so great that they will never get their money back in savings on their heating bills.	1	2	3	4	5
15. Most insulation contractors will give a free estimate of the cost of installing attic insulation.	1	2	3	4	5
16. The energy shortage is just another problem we can solve with new and better technologies.	1	2	3	4	5
17. A windfall profits tax should be imposed on oil companies.	1	2	3	4	5

APPENDIX 4B

BILL COMPUTATION AND DATA MERGING PROGRAM

The data collected from the Public Service Company of Colorado provided a time profile of gas consumption dating from January of 1974 to June of 1978. It was necessary to develop a computer routine to merge these consumption records with the socioeconomic data obtained from the family survey. In addition, a routine was necessary to compute monthly bills for each family. Both tasks were accomplished via the program displayed on the following pages. Sparing the reader the details, the family data are read along with consumption records, rate structures, cost adjustment factors, and heating degree days. The program check to the month, applies the appropriate rate, computes the bill, and writes all the data to disk. The result was approximately 3,328 records. However, not every record possessed the full complement of data. In some instances, households did not reside at residence in question during the full 64 months; therefore, 0's were recorded for the prior period. In performing the regression studies, those records with no consumption were discarded. The resultant count of usable records was closer to 2,600.

```
USER,EPRJQHC,HAL.
PURGE,GAS2.
ATTACH,FTNLIB/UN=LIBRARY.
FTN,OPT=0,R=3.
DEFINE,GAS2.
LDSET,LIB=FTNLIB.
LGO,,GAS2.
#
      PROGRAM GAS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      REAL AGE(50),INCM(50),DELINC(50),YRRES(50),PLANMV(50),AGEHM(50),
     1SQFT(50),STRY(50),BILL(50),INFNT(50),CHLD(50),WNINSL(50),INSULQ
     2(50),THGHT(50),WHY(50),COST(50),KNOWPC(50),KNOWTC(50),FACT1(50),FA
     3CT2(50),FACT3(50),FACT4(50),FACT5(50),SOLAR(50),PAYB(50),SAVE(50),
     4V1(50),V2(50),V3(50),V4(50),V5(50),V6(50),V7(50),V8(50),V9(50),V10
     5(50),V11(50),V12(50),V13(50),V14(50),V15(50),V16(50),V17(50),CONS(
     650,75),BILLTOT(50,75),ADJ(40),RATE(6,39),MO(50),MOA(
     650),YR(50),YRA(50),DEGDAY(70),INSCOST(50,75)
     7,WN1(50),WN2(50),WN3(50),WN4(50),WN5(50),FAMNUM(50),BSQF(50),HEAT
     8(50),WN1A(50,75),WN2A(50,75),WN3A(50,75),WN4A(50,75),WN5A(50,75)
     9,BLOAD(50),NWDAT(50,75)
      LIM1=4.
      LIM2=16.
      LIM3=60.
      LIM4=60.
      LIM5=60.
      IFAM=52
      IENDAT=64
      DO 600 J=1,IFAM
      READ(5,200)AGE(J),INCM(J),DELINC(J),YRRES(J),PLANMV(J),AGEHM(J),
     1SQFT(J),STRY(J),BILL(J),INFNT(J),CHLD(J),WNINSL(J),INSULQ(J),THGHT
     2(J),WHY(J),COST(J),KNOWPC(J),KNOWTC(J),FACT1(J),FACT2(J),FACT3(J),
     3FACT4(J),FACT5(J),SOLAR(J),PAYB(J),SAVE(J),V1(J),V2(J),V3(J),V4(J)
     4,V5(J),V6(J),V7(J),V8(J),V9(J),V10(J),V11(J),V12(J),V13(J),V14(J),
     5V15(J),V16(J),V17(J)
     6,FAMNUM(J),WN1(J),WN2(J),WN3(J),WN4(J),WN5(J),HEAT(J),BSQF(J)
     7,BLOAD(J)
      READ(5,201)(CONS(J,JJ),JJ=1,IENDAT)
  600 CONTINUE
      DO 601 JJ=1,11
      READ(5,202)(RATE(J,JJ),J=1,6)
  601 CONTINUE
      READ(5,203)(MO(JJ),YR(JJ),JJ=1,11)
      READ(5,206)(DEGDAY(J),J=1,IENDAT)
      READ(5,204)(MOA(J),YRA(J),J=1,37)
      READ(5,205)(ADJ(J),J=1,37)
C     CREATE MONTHLY BILLS
      DO 100 J=1,IFAM
      DO 100 JJ=1,IENDAT
      DO 10 I=1,11
      DATCON=JJ
      RATEDAT=MO(I)+(YR(I)-74.)*12.
      IF(DATCON.EQ.1)GO TO 7
      IF(DATCON.LT.RATEDAT)GO TO 7
   10 CONTINUE
    7 CONTINUE
      RAT1=RATE(1,I)
      RAT2=RATE(2,I)
      RAT3=RATE(3,I)
      RAT4=RATE(4,I)
      RAT5=RATE(5,I)
      RAT6=RATE(6,I)
      IF(DATCON.LE.WNINSL(J))GO TO 18
      INSCOST(J,JJ)=WHY(J)
      GO TO 19
   18 CONTINUE
      INSCOST(J,JJ)=0.0
   19 CONTINUE
      IF(WN1(J).EQ.0)WN1(J)=64
      IF(DATCON.LT.WN1(J))GO TO 180
      WN1A(J,JJ)=1
      GO TO 181
  180 WN1A(J,JJ)=0
  181 CONTINUE
```

```
      IF(WN2(J).EQ.0)WN2(J)=64
      IF(DATCON.LT.WN2(J))GO TO 182
      WN2A(J,JJ)=1
      GO TO 183
  182  WN2A(J,JJ)=0
  183 CONTINUE
      IF(WN3(J).EQ.0)WN3(J)=64
      IF(DATCON.LT.WN3(J))GO TO 184
      WN3A(J,JJ)=1
      GO TO 185
  184 WN3A(J,JJ)=0
  185 CONTINUE
      IF(WN4(J).EQ.0)WN4(J)=64
      IF(DATCON.LT.WN4(J))GO TO 186
      WN4A(J,JJ)=1
      GO TO 187
  186 WN4A(J,JJ)=0
  187 CONTINUE
      IF(WN5(J).EQ.0)WN5(J)=64
      IF(DATCON.LT.WN5(J))GO TO 188
      WN5A(J,JJ)=1
      GO TO 189
  188 WN5A(J,JJ)=0
  189 CONTINUE
      DO 11 I=1,37
      ADJDAT=MOA(I)+(YRA(I)-74.)*12.
      IF(DATCON.LT.ADJDAT)GO TO 8
   11 CONTINUE
    8 CONTINUE
      ADJA1=ADJ(I)
      ADJA=1
      IF(DATCON.LE.11.)ADJA1=0
      CONS1=0
      CONS2=0
      CONS3=0
      CONS4=0
      CONS5=0
      BILL1=0
      BILL2=0
      BILL3=0
      BILL4=0
      BILL5=0
      BILL6=0
      IF (DATCON.LT.57) GO TO 17
      RAT1=2.48
      RAT2=0.091
      RAT3=0.091
      RAT4=0.091
      RAT5=0.091
      RAT6=0.091
      LIM1=1.0
   17 CONTINUE
      CONS1=CONS(J,JJ)-LIM1
      BILL1=RAT1*ADJA*1.05
      IF(CONS1.GT.0)GO TO 12
      GO TO 20
   12 CONTINUE
      CONS2=CONS1-LIM2
      BILL2=CONS1*RAT2*ADJA*1.05
      IF(CONS2.GT.0)GO TO 13
      GO TO 20
   13 CONTINUE
      BILL2=LIM2*RAT2*ADJA*1.05
      CONS3=CONS2-LIM3
      BILL3=CONS2*RAT3*ADJA*1.05
      IF(CONS3.GT.0)GO TO 14
      GO TO 20
   14 CONTINUE
      BILL3=LIM3*RAT3*ADJA*1.05
      CONS4=CONS3-LIM4
      BILL4=CONS3*RAT4*ADJA*1.05
      IF(CONS4.GT.0)GO TO 15
      GO TO 20
   15 CONTINUE
      BILL4=LIM4*RAT4*ADJA*1.05
      CONS5=CONS4-LIM5
      BILL5=CONS4*RAT5*ADJA*1.05
      IF(CONS5.GT.0)GO TO 16
      GO TO 20
   16 CONTINUE
      BILL5=LIM5*RAT5*ADJA*1.05
      BILL6=CONS5*RAT6*ADJA*1.05
   20 CONTINUE
      BILLTOT(J,JJ)=BILL1+BILL2+BILL3+BILL4+BILL5+BILL6+ADJA1*CONS(J,JJ)
      IF (CONS(J,JJ).EQ.0) BILLTOT(J,JJ)=0
      NWDAT(J,JJ)=JJ
  100 CONTINUE
C     PUNCH AND WRITE
      DO 101 JJ=1,IENDAT
      DO 101 J=1,IFAM
      WRITE(6,207)AGE(J),INCM(J),DELINC(J),YRRES(J),PLANMV(J),AGEHM(J),
     1SQFT(J),STRY(J),BILL(J),INFNT(J),CHLD(J),WNINSL(J),INSULQ(J),THGHT
     2(J),WHY(J),COST(J),KNOWPC(J),KNOWTC(J),FACT1(J),FACT2(J),FACT3(J),
     3FACT4(J),FACT5(J),SOLAR(J),PAYB(J),SAVE(J),V1(J),V2(J),V3(J),V4(J)
     4,V5(J),V6(J),V7(J),V8(J),V9(J),V10(J),V11(J),V12(J),V13(J),V14(J),
     5V15(J),V16(J),V17(J),CONS(J,JJ),BILLTOT(J,JJ),DEGDAY(JJ),INSCOST
     6(J,JJ),WN1A(J,JJ),WN2A(J,JJ),WN3A(J,JJ),WN4A(J,JJ),WN5A(J,JJ)
     7 ,FAMNUM(J),HEAT(J),BSQF(J)
     8,BLOAD(J),NWDAT(J,JJ)
  101 CONTINUE
```

```
200 FORMAT  (F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,
   1         F2.0,1X,F2.0,1X,F1.0,F1.0,2X,F3.0,1X,F1.0,1X,F2.0,7X,
   2         F3.0,1X,F1.0,1X,F1.0,1X,F1.0,3X,5F1.0,1X,F1.0,3X,F1.0,1X,
   3         F2.0/F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,
   4         F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,F1.0,1X,
   5         F1.0,1X,F1.0,1X,F1.0,1X,F1.0,45X,F3.0/
   6         F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,F2.0,1X,F1.0,1X,F2.0,1X,
   7F2.0)
201 FORMAT(12F3.0,4X,12F3.0/12F3.0,4X,12F3.0/12F3.0,4X,4F3.0)
202 FORMAT(12F5.3/12F5.3/12F5.3/12F5.3/12F5.3/6F5.3)
203 FORMAT(11(F2.0,F2.0,1X))
204 FORMAT(13(F2.0,F2.0,1X)/13(F2.0,F2.0,1X)/11(F2.0,F2.0,1X))
205 FORMAT(13F5.5/13F5.5/13F5.5/11F5.5)
206 FORMAT(5X,12F5.0/5X,12F5.0/5X,12F5.0/5X,12F5.0/5X,12F5.0/5X,4F5.0)
207 FORMAT(1H ,10(F6.0,1X)/11(F6.0,1X)/ 5(F6.0,1X)/17(F3.0,1X),3(F6.0,
   11X)/11F6.0)
    STOP
    END
```

APPENDIX 4C

SUMMARY OF REGRESSION RESULTS FOR INDIVIDUAL FAMILIES

Nonadopters

NOTE: X if not in equation
-- indicates that the variable is not statistically significant

Family Number	Constant	Degree Days	Insulation	Other Adjustments*					R^2	Sample Size
				W1	W2	W3	W4	W5		
13	12.4 (3.89)	.122 (27.6)	X	--	X	X	X	X	.92	64
14	29.6 (5.80)	.169 (23.7)	X	--	X	X	X	X	.89	64
15	45.5 (9.16)	.164 (24.57)	X	30.7 (1.77)	X	X	X	X	.95	32
16	35.3 (5.31)	.170 (18.)	X	--	X	X	X	X	.83	64
17	76.7 (6.0)	.194 (14.5)	X	--	-26.3	X	X	X	.87	32
19	38.0 (1.9)	.207 (10.6)	X	-37.7 (1.8)	X	X	X	X	.95	7
23	21.7 (6.5)	.185 (39.6)	X	--	X	X	X	X	.96	64
24	47.7 (5.5)	.141 (13.5)	X	--	X	X	-24.8 (2.7)	X	.74	64
26	42.3 (7.59)	.19 (24.6)	X	--	X	--	-23.5 (2.2)	X	.90	64
28	28.6 (5.08)	.224 (32.8)	X	--	X	-25.2 (4.2)	X	X	.94	64
29	65 (10.90)	.197 (24.5)	X	-20.6 (2.2)	--	X	-28.8 (2.2)	X	.90	64
34	42.3 (10.23)	.148 (25.58)	X	--	X	X	--	X	.91	63
38	22.8 (10.28)	.079 (25.6)	X	--	X	X	X	X	.91	63
47	53.1 (7.99)	.185 (19.68)	X	--	-25.8 (3.50)	X	X	X	.86	64
50	74.1 (6.82)	.320 (23.35)	X	--	--	X	X	--	.90	50
58	27.3 (8.7)	.11 (24.9)	X	--	X	X	X	X	.90	64

*W1 is apply weather stripping.
W2 is install storm windows.
W3 is caulk windows.
W4 is turn down thermostat.
W5 is other measures.

Adopters

Family Number	Constant	Degree Days	Insulation	Other Adjustments					R^2	Sample Size
				W1	W2	W3	W4	W5		
2	34.3 (7.0)	.15 (23.9)	--	-37.9 (1.6)	X	X	X	X	.90	64
3	26.1 (5.0)	.18 (26.8)	--	--	X	X	X	X	.92	64
4	45.6 (8.6)	.207 (30.5)	-.018 (2.55)	--	X	X	X	X	.93	64
7	31.7 (5.03)	.231 (25.4)	.079 (4.41)	--	X	X	X	X	.91	64
8	37.8 (8.6)	.130 (24.1)	-.057 (2.49)	--	X	X	-18.3 (-2.0)	X	.91	64
9	44.3 (7.36)	.244 (25.01)	--	--	X	X	-29.6 (1.89)	X	.95	37
11	111.2 (3.4)	.188 (21.0)	-.19 (5.5)	--	X	X	-57.8 (1.8)	X	.89	64
20	--	.16 (6.4)	--	X	--	X	X	X	.59	27
27	21.3 (4.02)	.187 (25.1)	-.05 (1.50)	--	X	X	X	X	.91	64
30	27.5 (5.33)	.199 (28.8)	-.059 (1.17)	-30.0 (4.5)	--	X	X	X	.93	63
31	29.0 (10.2)	.09 (26)	-.12 (5.04)	--	X	X	X	X	.92	69
32	35.9 (2.59)	.307 (14.87)	--	--	X	X	X	--	.90	35
33	62.9 (5.91)	.139 (28.20)	-.258 (3.60)	--	X	X	X	X	.93	63
36	51.46 (4.25)	.149 (11.11)	-.094 (2.94)	--	X	X	X	X	.80	30
40	42.7 (11.82)	.119 (23.82)	-.081 (3.85)	-27.0 (1.54)	X	X	X	X	.90	64
42	71.6 (7.75)	.185 (15.13)	-.119 (1.74)	--	X	X	--	--	.79	63
43	44.7 (7.60)	.135 (18.20)	-.073 (1.54)		--	-13.4 (1.50)	--	X	.85	64
44	27.4 (2.80)	.095 (7.45)	--	--	X	X	--	X	.68	29
45	54.1 (2.59)	.095 (7.07)	--	--	X	X	X	X	.69	29
46	25.74 (3.88)	.182 (21.2)	X	--	X	X	--	X	.95	22
47	53.1 (7.99)	.185 (19.68)	X	--	-25.8 (3.50)	X	X	X	.86	64
48	45.1 (3.6)	.264 (21.79)	-.153 (4.6)	--	X	X	24.9 (1.52)	X	.93	36
51	46.6 (6.41)	.224 (24.86)	-.056 (1.65)	--	X	X	X	X	.91	63
52	--	.174 (9.85)	-.109 (1.92)	--	--	X	X	X	.90	16
53	49.9 (10.02)	.177 (30.68)	-.032 (3.84)	--	X	X	X	X	.94	64
57	54.0 (5.90)	.224 (17.46)	X	--	X	X	-66.9 (5.3)	X	.83	64
59	40.5 (3.66)	.219 (14.03)	X	--	X	X	X	X	.75	64

APPENDIX 5A

INTERINDUSTRY MODELLING APPLIED TO REGIONAL ENERGY ANALYSIS

INTRODUCTION

Modern day input-output analysis is the culmination of the work begun by Francois Quesney in his Tableau Economique published in 1758, and later, extensions by Leon Walras, Gustav Cassel, and Vilfredo Pareto (1874). The culmination is found in the statement of an interdependent production model developed by W.W. Leontief of Harvard (1936) (see also Miernyk, 1965). The key to Leontief's analytical system is the construction of the input-output, or transactions, table which shows the flow of commodities from each of a number of producing sectors to all other consuming sectors for intermediate and final consumption. From this basic description of the flows among economic sectors are developed two other critical tables: the table of direct factor requirements and the table of direct and indirect requirements. Each of these is discussed below.

The transactions table. Table 5A.1 depicts a highly simplified, aggregated version of a hypothetical transactions table for a regional economy. The basic data are described in three major portions of the table termed the processing sector, the final demands sector and the payments sector.

TABLE 5A.1 Hypothetical transactions table.

		Purchasing Sector			Final Demand	Total Output
		X_1	X_2	X_3		
Producing Sector	X_1	1.00	2.25	.20	1.55	5.00
	X_2	2.00	6.00	1.00	16.00	25.00
	X_3	.20	3.00	1.80	15.00	20.00
Payments Sector		1.80	13.75	17.00	3.00	35.55
Total Outlays		5.00	25.00	20.00	35.55	85.55

In Table 5A.1 the sectors denoted X_1, X_2 and X_3 are the producing sectors of the processing sector of the economy (the portion of the table bounded by double lines). Each of these sectors may deliver its output for intermediate use, i.e., a sale from X_1 at the left of the table to X_1, X_2 or X_3 at the column heads, and also to the final demand or final consumption sectors. Thus, in our example, X_1 delivers or sells $1.00 of its own output to itself, $2.25 worth of output to sector X_2 and $.20 worth of output to sector X_3. Sector X_1 also sells $1.55 worth of output to final consumption.

Any column within the transactions table describes the purchases made by each sector at the column head from each of the producing sectors as well as the purchase of primary inputs. Thus, sector X_2 purchases $2.25 worth of output from X_1, $6.00 worth of output from itself, $3.00 worth of output from X_3, and $13.75 worth of primary inputs. The system is basically double entry accounting in which every sale constitutes a purchase, and we purposely double count. The entries in the column headed "total output" are the sums of the corresponding column entries. Since each sale and each purchase are accounted for, the column and row totals for the sectors X_1, X_2 and X_3 are equal.

We simply have restricted our example to an aggregate final demand and payments sector. The final demand sector would generally consist of sales to households, sales to governments, sales to export markets, inventory changes and investments. The payments sector would consist of payments to households in the form of wages and salaries, payments of taxes to governments, depreciation, rents, interests, dividends, and payments for imports. The extent of disaggregation in these sectors and in the processing sector will depend largely upon the purposes of the study, the availability of data, and the time and money available to the researcher.

Once the basic economic data presented in the transactions table have been collected, the second table of the model, the direct or technical coefficients table, can be computed.

The technical coefficients table. Table 5A.2 is the table of direct coefficients for our hypothetical example. The entries in this table are to be interpreted as the requirements from each of the producing sectors at the left of the table in order for each sector at the top to produce one dollar's worth of output.

TABLE 5A.2 Direct coefficients per dollar output.

		Purchasing Sector		
		X_1	X_2	X_3
Producing Sector	X_1	.20	.09	.01
	X_2	.40	.24	.05
	X_3	.04	.12	.09

The entries in this table are computed by dividing each column entry in the processing sector of the transactions table, Table 5A.1, by the respective column total. Thus, for each dollar of output produced by X_1, X_1 requires $1.00/$5.00 = $.20 from itself, $2.00/$5.00 = $.40 from X_2, and $.20/$5.00 = $.04 from X_3. Each of the other columns has a like interpretation.

The information on final demands and total outputs obtained from Table 5A.1 can be combined with the information contained in Table 5A.2 to obtain t system of equations expressed in Equation 5A.1 belc

$$X_1 = .20\ X_1 + .09\ X_2 + .01\ X_3 + Y_1 \qquad (5A.1)$$
$$X_2 = .40\ X_1 + .24\ X_2 + .05\ X_3 + Y_2$$
$$X_3 = .04\ X_1 + .12\ X_2 + .09\ X_3 + Y_3$$

where X_1, X_2 and X_3 are the total outputs of the three sectors, Y_1, Y_2 and Y_3 are the respective deliveries to final demand by the three sectors. The coefficients are the entries in the direct coefficients table.

In matrix notation our system becomes that shown in Equation 5A.2:

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} = \begin{bmatrix} .20 & .09 & .01 \\ .40 & .24 & .05 \\ .04 & .12 & .09 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \qquad (5A.2)$$

or more simply stated as in Equation 5A.3:

$$\overline{\underline{X}} = A\overline{\underline{X}} + \overline{\underline{Y}} \qquad (5A.3)$$

where $\overline{\underline{X}}$ is the vector of total outputs, A is the matrix of direct coefficients, and $\underline{Y}$ is the vector of final demands.

Proceeding to a solution for $\overline{\underline{Y}}$ from Equation 5A.2 above we may write:

$$X_1 - .20\ X_1 - .09\ X_2 - .01\ X_3 = Y_1 \qquad (5A.4)$$
$$-.40\ X_1 + X_2 - .24\ X_2 - .05\ X_3 = Y_2$$
$$-.04\ X_1 - .12\ X_2 + X_3 - .09\ X_3 = Y_3$$

or

$$(1 - .20)\ X_1 - .09\ X_2 - .01\ X_3 = Y_1 \qquad (5A.5)$$
$$-.40\ X_1 + (1 - .24)\ X_2 - .05\ X_3 = Y_2$$
$$-.04\ X_1 - .12\ X_2 + (1 - .09)\ X_3 = Y_3$$

Again, writing the above system in matrix form we have Equation 5A.6:

$$\begin{bmatrix} (1 - .20) & - .09 & - .01 \\ -.40 & (1 - .24) & - .05 \\ -.04 & - .12 & (1-.09) \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \qquad (5A.6)$$

The matrix on the left of Equation 5A.6 is the Leontief matrix as shown in Equations 5A.7 and 5A.8 below:

$$\left(\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} .20 & .09 & .01 \\ .40 & .24 & .05 \\ .04 & .12 & .09 \end{bmatrix} \right) \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \qquad (5A.7)$$

which, in matrix notation, reduces to:

$$(I - A)\ \overline{\underline{X}} = \overline{\underline{Y}} \qquad (5A.8)$$

where I is the identity matrix, (I-A) is the Leontief matrix and A, $\underline{X}$, and $\underline{Y}$ are as defined previously.

The direct and indirect requirements table. We now have the ingredients necessary to solve the Leontief system in terms of quantities of outputs required to sustain final demand. This is done through the use of matrix inversion techniques which need not be dealt with here (see Miernyk, 1965).

Each element in Table 5A.3 represents the total direct and indirect requirements from each sector at the left of the table which are necessary in order for the sector at the top of the table to deliver an increase of one dollar of output to final demand. Thus, if there is an increase of one dollar in the final demand for the output of sector X_1, there will be a total direct and indirect production increase of \$1.33 in sector X_1, a direct and indirect impact of \$.71 in sector X_2, and a direct and indirect impact of \$.15 for the output of sector X_3. Using the information contained in Table 5A.3 with the previous information, we premultiply both sides of Equation 5A.8 above by the Leontief inverse as in Equation 5A.9 below.

$$(I\text{-}A)^{-1}\ (I\text{-}A)\ \overline{\underline{X}} = (I\text{-}A)^{-1}\ \overline{\underline{Y}} \qquad (5A.9)$$

which reduces to:

$$\overline{\underline{X}} = (I\text{-}A)^{-1}\ \overline{\underline{Y}} \qquad (5A.10)$$

or

$$X_1 = 1.3319\ Y_1 + .1614\ Y_2 + .0235\ Y_3 \qquad (5A.11)$$
$$X_2 = .7710\ Y_1 + 1.4135\ Y_2 + .0855\ Y_3$$
$$X_3 = .1523\ Y_1 + .1935\ Y_2 + 1.1112\ Y_3$$

Table 5A.3 illustrates the concept of economic interdependence. An alteration in the quantities of any goods demanded may be expected to stimulate production in other sectors, which, in turn, stimulates still more production elsewhere in the economy. Table 5A.3 shows the magnitudes of all direct and indirect effects after the initial stimulation of demand has worked itself out.

TABLE 5A.3 Hypothetical direct and indirect requirements per dollar delivered to final demand.

	X_1	X_2	X_3
X_1	1.3319	.1614	.0235
X_2	.7110	1.4135	.0855
X_3	.1523	.1935	1.1112

Forecasting with input-output models. In addition to its usefulness in describing the structure of an economy at one period in time, the input-output model has applicability in making short-run projections of economic activity, given certain assumptions as to the levels of final demand. Its use as a forecasting tool is extended by projecting new production coefficients. Ideal use of the model in forecasting is to project for short-run situations followed by updating of the basic model and subsequent forecasts. Forecasting space heating energy requirements with the input-output model is discussed briefly below.

Projecting space heating energy use by sector. As a first step in projecting a future level of output and a future flow of energy to sectors, each element in the final demand sector of the original transactions table is projected. These projections form a single projected final demand vector. In our hypothetical model, the projected final demands are \$3.00, \$19.00, and \$17.00, respectively, for sectors X_1, X_2, and X_3. Each row of the initial $(I-A)^{-1}$ transposed matrix is then multiplied by the projected final demand for a particular sector, and the resulting columns are added to obtain the projected gross outputs. The process in our example is shown in the following computation:

$$(I-A)_T^{-1} = \begin{bmatrix} 1.3319 & .7110 & .1523 & (3.00) \\ .1614 & 1.4135 & .1935 & (19.00) \\ .0235 & .0855 & 1.1112 & (17.00) \end{bmatrix} =$$

$$\begin{bmatrix} 3.9957 & 2.1330 & .4569 \\ 3.0666 & 26.8565 & 3.6765 \\ \underline{.3995} & \underline{1.4535} & \underline{18.8904} \\ 7.4618 & 30.4430 & 23.0238 \end{bmatrix}$$

The projected gross outputs are \$7.5, \$30.4, and \$23.0, respectively, for X_1, X_2, and X_3. These gross output figures are then multiplied by each respective column entry in the direct coefficients table (Table 5A.2) to obtain the projected transactions table as follows:

.20 x 7.5 = 1.5   .09 x 30.4 = 2.7   .01 x 23.0 = .2
.40 x 7.5 = 3.0   .24 x 30.4 = 7.3   .05 x 23.0 = 1.2
.04 x 7.5 = .3   .12 x 30.4 = 3.6   .09 x 23.0 = 2.1

The projected transactions table is that shown in Table 5A.4 below.

TABLE 5A.4 Hypothetical projected transactions table.

	X_1	X_2	X_3	Final Demand	Total Output	Energy
X_1	1.5	2.7	.2	3.0	7.4	77.70
X_2	3.0	7.3	1.2	19.0	30.5	64.05
X_3	.3	3.6	2.1	17.0	23.0	20.70
Payments	2.6	16.9	19.5		39.0	
Total Outlay	7.4	30.5	23.0	39.0	99.9	162.45

The new vector of projected total output may be multiplied by space heating energy utilization coefficients to obtain the total projected energy requirements accompanying the projected output. Space heating energy coefficients are estimated from physical model output. Suppose, for our example, that the direct energy coefficients for X_1, X_2, and X_3 are, respectively, $E_1 = 10.5$, $E_2 = 2.1$, and $E_3 = .9$. The energy requirements would be:

$$[10.5 \quad 2.1 \quad .9] \begin{bmatrix} 7.4 \\ 30.5 \\ 23.0 \end{bmatrix} = 162.45$$

This compares to the initial level of energy use derived in the same manner from the original total output levels:

$$[10.5 \quad 2.1 \quad .9 \begin{bmatrix} 5.0 \\ 25.0 \\ 20.0 \end{bmatrix} = 123.0$$

Appendix 5B reveals the extent of disaggregation of economic activities for which energy forecasts can be made via the Greeley I-O model.

APPENDIX 5B

GREELEY PROJECTED TRANSACTION AND GAS CONSUMPTION TABLES

The five tables in this appendix provide details of disaggregated transactions between selling sectors (at the left) and buying sectors (top of columns) for the model years 1983, 88, 93, 98 and 2003. Estimated natural gas demand by sector as a function of mean monthly temperature is also shown for the five model years. Explanations and discussion of these data are contained in Sections 5.6.1, 5.8, 5.9 and in Appendix 5A.

TABLE 5B.1 Greeley projected transactions table, 1983 (x $1,000).

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	508.	15.	52.	0.	0.	0.	0.	0.	0.	0.
2	PRINT-PUB	50.	4.	132.	1392.	14.	40.	11.	15.	5.	82.
3	MFG NEC	58.	15.	1407.	1385.	0.	5.	33.	1.	0.	0.
4	CONST	1301.	15.	118.	16018.	18.	32.	32.	0.	92.	0.
5	TRANSPORT	912.	0.	476.	1.	6.	17.	1.	3.	0.	2996.
6	COMMUNICAT	442.	25.	124.	73.	109.	28.	11.	13.	9.	248.
7	ELECTRICTY	630.	54.	261.	1.	36.	126.	0.	11.	121.	167.
8	NAT GAS	621.	13.	169.	337.	80.	16.	1.	1.	4.	155.
9	WATER-SAN	45.	25.	42.	1191.	7.	9.	1.	1.	0.	31.
10	WHOLESALE	741.	268.	365.	4970.	0.	0.	0.	0.	150.	0.
11	RETAIL	868.	239.	638.	1688.	1104.	332.	40.	49.	65.	0.
12	RESTAURANT	216.	0.	6.	1.	0.	0.	0.	0.	0.	0.
13	HOTEL-MOT	0.	0.	52.	0.	0.	0.	0.	0.	0.	0.
14	FIRE	1168.	761.	1646.	9172.	654.	3990.	594.	301.	1077.	479.
15	HEALTH SER	0.	0.	48.	137.	0.	0.	0.	0.	0.	0.
16	SERV NEC	224.	434.	1052.	1974.	157.	64.	41.	78.	498.	1647.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	COLLEGES	3.	4.	0.	0.	0.	0.	0.	0.	0.	0.
19	LOCAL GOVT	200.	8.	207.	1881.	57.	1662.	681.	528.	186.	769.
20	SUBTOTALS	7985.	1880.	6797.	40223.	2244.	6321.	1447.	1001.	2208.	6574.
21	HOUSEHOLDS	11238.	3456.	18348.	15210.	4021.	8231.	1282.	1229.	721.	18624.
22	FED-ST GOV	1499.	200.	1730.	3135.	339.	2256.	552.	253.	40.	1118.
23	PROFIT DEP	6828.	1283.	6126.	6359.	188.	2980.	1276.	859.	2665.	4341.
24	IMPORTS	65938.	2016.	17481.	34888.	10.	2325.	8075.	6123.	469.	156076.
25	TOTALS	93489.	8834.	50482.	99814.	6801.	22113.	12632.	9465.	6102.	186732.

Projected monthly natural gas consumption for space heating in 1983 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	5982.	3230.	16379.	13013.	3363.	4954.	1489.	875.	369.	13116.
17.3°	1934.	4528.	5562.	38872.	12482.	3009.	304.	302.	2373.	20142.
29.7°	1433.	3393.	4137.	29105.	9511.	2254.	228.	227.	1777.	15229.
34.0°	1413.	3364.	4086.	28854.	9499.	2235.	225.	224.	1763.	15156.
40.8°	1347.	3221.	3885.	27634.	9239.	2140.	215.	214.	1688.	14641.

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 SUBTOTALS
1	FOOD PROC	0.	12280.	0.	0.	0.	0.	240.	0.	27.	13122.
2	PRINT-PUB	2878.	104.	12.	1133.	358.	161.	12.	148.	237.	6788.
3	MFG NEC	0.	0.	0.	0.	0.	99.	20.	0.	33.	3057.
4	CONST	217.	9.	82.	234.	12.	109.	0.	116.	209.	18616.
5	TRANSPORT	168.	0.	1.	96.	171.	230.	207.	76.	32.	5392.
6	COMMUNICAT	1360.	1301.	112.	1147.	887.	244.	104.	472.	213.	6924.
7	ELECTRICTY	2397.	379.	75.	292.	513.	262.	316.	574.	209.	6425.
8	NAT GAS	452.	184.	32.	155.	321.	604.	264.	515.	186.	4111.
9	WATER-SAN	310.	75.	40.	46.	117.	46.	69.	74.	150.	2281.
10	WHOLESALE	9317.	0.	274.	36.	735.	1374.	69.	293.	268.	18860.
11	RETAIL	427.	1891.	100.	1095.	1908.	1065.	566.	51.	613.	12739.
12	RESTAURANT	1.	0.	0.	567.	0.	58.	4.	0.	8.	861.
13	HOTEL-MOT	0.	0.	0.	27.	0.	0.	4.	0.	401.	484.
14	FIRE	2317.	215.	369.	1287.	4694.	1550.	1340.	0.	505.	32119.
15	HEALTH SER	0.	0.	0.	0.	2685.	0.	1.	106.	368.	3345.
16	SERV NEC	6667.	1243.	29.	3943.	2679.	1135.	200.	610.	748.	23422.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	52.	9855.	9907.
18	COLLEGES	0.	0.	0.	0.	0.	3.	45.	0.	4.	59.
19	LOCAL GOVT	2029.	214.	43.	695.	1157.	713.	43.	0.	321.	11394.
20	SUBTOTALS	28541.	17895.	1169.	10752.	16237.	7653.	3506.	3086.	14387.	179906.
21	HOUSEHOLDS	27362.	7152.	702.	17959.	37007.	11621.	14142.	32209.	11118.	241633.
22	FED-ST GOV	6288.	1169.	60.	5483.	2425.	1876.	0.	2601.	559.	31583.
23	PROFIT DEP	12359.	5406.	494.	41139.	58096.	17157.	24.	563.	4396.	172540.
24	IMPORTS	229830.	5766.	54.	58426.	19398.	7855.	3008.	2447.	855.	621040.
25	TOTALS	304381.	37387.	2480.	133760.	133162.	46163.	20681.	40906.	31315.	1246701.

Projected monthly natural gas consumption for space heating in 1983 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	50896.	19256.	1530.	14637.	38139.	18039.	18419.	33633.	13211.	396358.
17.3°	127824.	8122.	10672.	30052.	30208.	16408.	16462.	25421.	29213.	383890.
29.7°	96815.	6185.	8289.	22518.	23304.	12392.	12798.	19595.	21997.	291187.
34.0°	96409.	6171.	8339.	22323.	23410.	12328.	12883.	19705.	21851.	290238.
40.8°	93375.	6000.	8271.	21379.	22953.	11893.	12777.	19196.	21036.	281104.

TABLE 5B.1 (Continued).

		21 HOUSEHOLDS	22 FED-ST GOV
1	FOOD PROC	1367.	0.
2	PRINT-PUB	853.	0.
3	MFG NEC	10496.	0.
4	CONST	2334.	0.
5	TRANSPORT	906.	29.
6	COMMUNICAT	11389.	35.
7	ELECTRICTY	6166.	41.
8	NAT GAS	5326.	28.
9	WATER-SAN	2349.	3.
10	WHOLESALE	0.	0.
11	RETAIL	241948.	316.
12	RESTAURANT	19801.	3.
13	HOTEL-MOT	667.	0.
14	FIRE	69794.	54.
15	HEALTH SER	27734.	0.
16	SERV NEC	22386.	355.
17	SCHOOLS	0.	10761.
18	COLLEGES	2227.	23250.
19	LOCAL GOVT	8473.	3479.
20	SUBTOTALS	434216.	38354.
21	HOUSEHOLDS	1998.	272998.
22	FED-ST GOV	105681.	293.
23	PROFIT DEP	22175.	218.
24	IMPORTS	25060.	367.
25	TOTALS	589131.	312229.

Projected monthly natural gas consumption for space heating in 1983 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)		
14.1°	506458.	9075.
17.3°	487707.	8763.
29.7°	360899.	6643.
34.0°	355797.	6643.
40.8°	336986.	6424.

TABLE 5B.2 Greeley projected transactions table, 1988 (x $1,000).

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	667.	20.	113.	0.	0.	0.	0.	0.	0.	0.
2	PRINT-PUB	65.	6.	287.	1823.	20.	54.	15.	20.	7.	115.
3	MFG NEC	76.	20.	3049.	1815.	0.	7.	46.	2.	0.	0.
4	CONST	1709.	20.	257.	20989.	26.	43.	44.	0.	124.	0.
5	TRANSPORT	1198.	0.	1031.	2.	8.	23.	2.	4.	0.	4193.
6	COMMUNICAT	581.	35.	270.	96.	158.	38.	15.	18.	12.	348.
7	ELECTRICTY	827.	74.	565.	2.	53.	172.	0.	15.	163.	234.
8	NAT GAS	815.	18.	365.	442.	115.	22.	2.	2.	5.	217.
9	WATER-SAN	58.	35.	91.	1561.	10.	13.	2.	2.	0.	43.
10	WHOLESALE	973.	369.	792.	6512.	0.	0.	0.	0.	202.	0.
11	RETAIL	1140.	329.	1383.	2212.	1595.	454.	55.	67.	87.	0.
12	RESTAURANT	284.	0.	13.	2.	0.	0.	0.	0.	0.	0.
13	HOTEL-MOT	0.	0.	113.	0.	0.	0.	0.	0.	0.	0.
14	FIRE	1533.	1049.	3567.	12018.	945.	5444.	820.	414.	1450.	670.
15	HEALTH SER	0.	0.	104.	180.	0.	0.	0.	0.	0.	0.
16	SERV NEC	294.	598.	2279.	2586.	227.	87.	57.	107.	671.	2305.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	COLLEGES	3.	6.	0.	0.	0.	0.	0.	0.	0.	0.
19	LOCAL GOVT	263.	11.	448.	2464.	83.	2268.	940.	725.	250.	1076.
20	SUBTOTALS	10487.	2591.	14727.	52703.	3240.	8625.	1997.	1375.	2972.	9201.
21	HOUSEHOLDS	14759.	4762.	39759.	19930.	5806.	11232.	1769.	1689.	971.	26069.
22	FED-ST GOV	1968.	275.	3749.	4108.	490.	3078.	762.	348.	53.	1564.
23	PROFIT DEP	8967.	1767.	13275.	8332.	271.	4067.	1762.	1180.	3588.	6076.
24	IMPORTS	86594.	2777.	37880.	45713.	14.	3172.	11145.	8413.	632.	218463.
25	TOTALS	122775.	12172.	109390.	130784.	9822.	30174.	17435.	13005.	8216.	261373.

Projected monthly natural gas consumption for space heating in 1988 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	7856.	4450.	35492.	17050.	4857.	6760.	2055.	1202.	497.	18359.
17.3°	2540.	6236.	12002.	50935.	18010.	4104.	419.	415.	3195.	28190.
29.7°	1882.	4672.	8926.	38138.	13724.	3074.	314.	311.	2393.	21314.
34.0°	1856.	4632.	8817.	37809.	13705.	3048.	310.	308.	2373.	21212.
40.8°	1769.	4436.	8383.	36210.	13330.	2919.	297.	294.	2273.	20492.

TABLE 5B.2 (Continued).

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 SUBTOTALS
1	FOOD PROC	0.	16517.	0.	0.	0.	0.	324.	0.	36.	17678.
2	PRINT-PUB	3880.	140.	18.	1547.	644.	225.	16.	180.	323.	9386.
3	MFG NEC	0.	0.	0.	0.	0.	139.	27.	0.	45.	5226.
4	CONST	293.	12.	124.	319.	22.	152.	0.	141.	285.	24560.
5	TRANSPORT	226.	0.	2.	130.	308.	321.	279.	92.	44.	7963.
6	COMMUNICAT	1833.	1750.	169.	1565.	1596.	341.	140.	572.	290.	9828.
7	ELECTRICTY	3232.	510.	113.	399.	924.	366.	427.	696.	285.	9054.
8	NAT GAS	609.	247.	49.	212.	578.	844.	357.	624.	254.	5777.
9	WATER-SAN	419.	101.	60.	63.	211.	64.	94.	89.	205.	3121.
10	WHOLESALE	12559.	0.	413.	49.	1323.	1918.	94.	355.	365.	25923.
11	RETAIL	576.	2544.	151.	1495.	3435.	1487.	764.	62.	834.	18668.
12	RESTAURANT	2.	0.	0.	774.	0.	81.	5.	0.	11.	1171.
13	HOTEL-MOT	0.	0.	0.	36.	0.	0.	5.	0.	546.	701.
14	FIRE	3124.	290.	557.	1757.	8451.	2163.	1808.	0.	687.	46747.
15	HEALTH SER	0.	0.	0.	0.	4833.	0.	2.	128.	501.	5748.
16	SERV NEC	8987.	1672.	44.	5383.	4824.	1584.	270.	739.	1019.	33732.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	63.	13423.	13486.
18	COLLEGES	0.	0.	0.	0.	0.	4.	61.	0.	5.	79.
19	LOCAL GOVT	2735.	288.	64.	949.	2084.	995.	58.	0.	437.	16139.
20	SUBTOTALS	38474.	24071.	1764.	14679.	29233.	10682.	4731.	3739.	19595.	254887.
21	HOUSEHOLDS	36885.	9619.	1059.	24518.	66628.	16220.	19081.	39032.	15142.	354928.
22	FED-ST GOV	8476.	1572.	91.	7486.	4365.	2619.	0.	3152.	762.	44919.
23	PROFIT DEP	16660.	7271.	746.	56163.	104598.	23948.	32.	683.	5988.	265373.
24	IMPORTS	309815.	7756.	82.	79763.	34925.	10963.	4059.	2965.	1164.	866295.
25	TOTALS	410311.	50289.	3742.	182609.	239748.	64433.	27903.	49570.	42651.	1786402.

Projected monthly natural gas consumption for space heating in 1983 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	68608.	25900.	2308.	19983.	68666.	25178.	24851.	40757.	17994.	553683.
17.3°	172321.	10926.	16073.	41014.	54239.	22875.	22210.	30816.	39780.	536300.
29.7°	130517.	8320.	12484.	30731.	41842.	17275.	17267.	23753.	29954.	406891.
34.0°	129970.	8302.	12559.	30466.	42033.	17186.	17382.	23887.	29755.	405610.
40.8°	125887.	8071.	12457.	29176.	41211.	16580.	17238.	23270.	28645.	392938.

		21 HOUSEHOLDS	22 FED-ST GOV
1	FOOD PROC	1846.	0.
2	PRINT-PUB	1151.	0.
3	MFG NEC	14172.	0.
4	CONST	3151.	0.
5	TRANSPORT	1224.	39.
6	COMMUNICAT	15378.	47.
7	ELECTRICTY	8325.	56.
8	NAT GAS	7191.	38.
9	WATER-SAN	3172.	4.
10	WHOLESALE	0.	0.
11	RETAIL	326685.	423.
12	RESTAURANT	26736.	4.
13	HOTEL-MOT	901.	0.
14	FIRE	94238.	72.
15	HEALTH SER	37447.	0.
16	SERV NEC	30226.	475.
17	SCHOOLS	0.	14400.
18	COLLEGES	3007.	31114.
19	LOCAL GOVT	11441.	4656.
20	SUBTOTALS	586291.	51326.
21	HOUSEHOLDS	2698.	365333.
22	FED-ST GOV	142693.	392.
23	PROFIT DEP	29942.	292.
24	IMPORTS	33837.	491.
25	TOTALS	795461.	417833.

Projected monthly natural gas consumption for space heating in 1983 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)		
14.1°	683834.	12145.
17.3°	658516.	11727.
29.7°	487297.	8889.
34.0°	480406.	8889.
40.8°	455008.	8597.

TABLE 5B.3 Greeley projected transactions table, 1993 (x $1,000).

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	880.	29.	257.	0.	0.	0.	0.	0.	0.	0.
2	PRINT-PUB	86.	8.	654.	2396.	30.	77.	21.	29.	10.	162.
3	MFG NEC	100.	29.	6942.	2384.	0.	10.	66.	3.	0.	0.
4	CONST	2254.	29.	584.	27576.	40.	61.	64.	0.	172.	0.
5	TRANSPORT	1580.	0.	2347.	2.	12.	33.	3.	5.	0.	5892.
6	COMMUNICAT	766.	50.	614.	126.	237.	54.	21.	26.	17.	488.
7	ELECTRICTY	1091.	105.	1287.	2.	79.	243.	0.	21.	226.	329.
8	NAT GAS	1075.	26.	832.	581.	173.	31.	3.	3.	7.	305.
9	WATER-SAN	77.	50.	208.	2051.	15.	18.	3.	3.	0.	60.
10	WHOLESALE	1283.	527.	1802.	8556.	0.	0.	0.	0.	280.	0.
11	RETAIL	1503.	469.	3149.	2907.	2398.	642.	80.	97.	120.	0.
12	RESTAURANT	374.	0.	30.	2.	0.	0.	0.	0.	0.	0.
13	HOTEL-MOT	0.	0.	257.	0.	0.	0.	0.	0.	0.	0.
14	FIRE	2023.	1497.	8121.	15789.	1421.	7707.	1186.	594.	2007.	941.
15	HEALTH SER	0.	0.	238.	236.	0.	0.	0.	0.	0.	0.
16	SERV NEC	388.	854.	5190.	3397.	341.	123.	82.	154.	929.	3238.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	COLLEGES	5.	8.	0.	0.	0.	0.	0.	0.	0.	0.
19	LOCAL GOVT	347.	16.	1020.	3238.	125.	3211.	1358.	1042.	346.	1512.
20	SUBTOTALS	13831.	3698.	33534.	69244.	4872.	12211.	2887.	1976.	4115.	12929.
21	HOUSEHOLDS	19466.	6798.	90529.	26184.	8730.	15901.	2558.	2426.	1344.	36629.
22	FED-ST GOV	2596.	393.	8537.	5397.	736.	4358.	1101.	500.	74.	2198.
23	PROFIT DEP	11827.	2523.	30226.	10947.	408.	5758.	2547.	1696.	4968.	8538.
24	IMPORTS	114211.	3964.	86251.	60060.	21.	4491.	16113.	12085.	875.	306963.
25	TOTALS	161932.	17376.	249077.	171831.	14768.	42718.	25205.	18683.	11375.	367256.

Projected monthly natural gas consumption for space heating in 1993 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	10362.	6352.	80813.	22402.	7303.	9570.	2971.	1727.	688.	25796.
17.3°	3351.	8899.	27255.	66931.	27058.	5809.	605.	596.	4425.	39610.
29.7°	2483.	6667.	20271.	50114.	20619.	4351.	454.	447.	3315.	29949.
34.0°	2449.	6611.	20023.	49682.	20592.	4314.	448.	442.	3287.	29805.
40.8°	2334.	6330.	19037.	47581.	20028.	4132.	429.	423.	3148.	28793.

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 SUBTOTALS
1	FOOD PROC	0.	22730.	0.	0.	0.	0.	444.	0.	51.	24391.
2	PRINT-PUB	5420.	193.	27.	2190.	1186.	329.	22.	222.	453.	13516.
3	MFG NEC	0.	0.	0.	0.	0.	203.	37.	0.	64.	9838.
4	CONST	410.	17.	192.	451.	40.	222.	0.	174.	399.	32686.
5	TRANSPORT	316.	0.	3.	185.	567.	469.	382.	114.	61.	11972.
6	COMMUNICAT	2561.	2408.	261.	2216.	2939.	499.	192.	708.	407.	14592.
7	ELECTRICTY	4515.	702.	175.	564.	1701.	535.	584.	861.	399.	13421.
8	NAT GAS	851.	340.	76.	300.	1065.	1235.	488.	772.	356.	8517.
9	WATER-SAN	585.	139.	93.	90.	388.	93.	128.	110.	287.	4398.
10	WHOLESALE	17547.	0.	639.	69.	2436.	2807.	128.	439.	511.	37025.
11	RETAIL	804.	3501.	234.	2116.	6323.	2176.	1045.	76.	1170.	28811.
12	RESTAURANT	2.	0.	0.	1095.	0.	118.	7.	0.	15.	1644.
13	HOTEL-MOT	0.	0.	0.	51.	0.	0.	7.	0.	765.	1082.
14	FIRE	4364.	398.	863.	2488.	15557.	3166.	2474.	0.	964.	71563.
15	HEALTH SER	0.	0.	0.	0.	8898.	0.	2.	158.	702.	10235.
16	SERV NEC	12556.	2300.	69.	7620.	8881.	2319.	370.	914.	1429.	51153.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	78.	18818.	18897.
18	COLLEGES	0.	0.	0.	0.	0.	5.	84.	0.	8.	109.
19	LOCAL GOVT	3832.	396.	100.	1344.	3836.	1457.	79.	0.	613.	23861.
20	SUBTOTALS	53753.	33125.	2733.	20781.	53816.	15635.	6475.	4628.	27472.	377712.
21	HOUSEHOLDS	51532.	13238.	1640.	34711.	122656.	23740.	26115.	48304.	21229.	553731.
22	FED-ST GOV	11843.	2163.	141.	10598.	8036.	3833.	0.	3900.	1068.	67472.
23	PROFIT DEP	23276.	10006.	1155.	79512.	192555.	35051.	44.	845.	8394.	430273.
24	IMPORTS	432845.	10673.	127.	112922.	64293.	16046.	5555.	3669.	1633.	1252798.
25	TOTALS	573249.	69205.	5795.	258524.	441355.	94305.	38190.	61346.	59796.	2681986.

Projected monthly natural gas consumption for space heating in 1993 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	95853.	35642.	3575.	28290.	126409.	36851.	34012.	50439.	25227.	805993.
17.3°	240817.	15045.	24859.	58053.	99654.	33434.	30407.	38153.	55776.	780737.
29.7°	182397.	11456.	19309.	43499.	76877.	25250.	23640.	29408.	41998.	592504.
34.0°	181632.	11431.	19424.	43123.	77227.	25119.	23797.	29575.	41719.	590700.
40.8°	175913.	11114.	19267.	41298.	75717.	24234.	23601.	28811.	40163.	572353.

TABLE 5B.3 (Continued).

		21 HOUSEHOLDS	22 FED-ST GOV
1	FOOD PROC	2597.	0.
2	PRINT-PUB	1620.	0.
3	MFG NEC	19935.	0.
4	CONST	4433.	0.
5	TRANSPORT	1721.	53.
6	COMMUNICAT	21632.	62.
7	ELECTRICTY	11710.	74.
8	NAT GAS	10115.	50.
9	WATER-SAN	4462.	5.
10	WHOLESALE	0.	0.
11	RETAIL	459527.	566.
12	RESTAURANT	37608.	5.
13	HOTEL-MOT	1267.	0.
14	FIRE	132558.	96.
15	HEALTH SER	52674.	0.
16	SERV NEC	42517.	635.
17	SCHOOLS	0.	19271.
18	COLLEGES	4229.	41638.
19	LOCAL GOVT	16093.	6231.
20	SUBTOTALS	824699.	68685.
21	HOUSEHOLDS	3795.	488898.
22	FED-ST GOV	200718.	525.
23	PROFIT DEP	42117.	391.
24	IMPORTS	47597.	657.
25	TOTALS	1118926.	559155.

Projected monthly natural gas consumption for space heating in 1993 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)		
14.1°	961907.	16252.
17.3°	926294.	15694.
29.7°	685450.	11896.
34.0°	675758.	11896.
40.8°	640032.	11505.

TABLE 5B.4 Greeley projected transactions table, 1998 (x $1,000).

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	1168.	43.	604.	0.	0.	0.	0.	0.	0.	0.
2	PRINT-PUB	114.	12.	1533.	3161.	48.	114.	32.	44.	14.	229.
3	MFG NEC	132.	43.	16281.	3146.	0.	15.	102.	4.	0.	0.
4	CONST	2992.	43.	1370.	36388.	63.	91.	97.	0.	247.	0.
5	TRANSPORT	2098.	0.	5504.	3.	19.	49.	4.	8.	0.	8323.
6	COMMUNICAT	1017.	75.	1440.	166.	377.	80.	32.	40.	25.	690.
7	ELECTRICTY	1448.	158.	3019.	3.	126.	361.	0.	32.	325.	465.
8	NAT GAS	1427.	39.	1951.	766.	275.	46.	4.	4.	11.	430.
9	WATER-SAN	102.	75.	488.	2707.	24.	27.	4.	4.	0.	85.
10	WHOLESALE	1704.	788.	4227.	11290.	0.	0.	0.	0.	403.	0.
11	RETAIL	1996.	701.	7386.	3835.	3804.	953.	122.	147.	173.	0.
12	RESTAURANT	497.	0.	70.	3.	0.	0.	0.	0.	0.	0.
13	HOTEL-MOT	0.	0.	604.	0.	0.	0.	0.	0.	0.	0.
14	FIRE	2685.	2238.	19045.	20835.	2254.	11431.	1816.	902.	2885.	1330.
15	HEALTH SER	0.	0.	557.	312.	0.	0.	0.	0.	0.	0.
16	SERV NEC	515.	1276.	12170.	4483.	541.	182.	126.	234.	1335.	4574.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	COLLEGES	6.	12.	0.	0.	0.	0.	0.	0.	0.	0.
19	LOCAL GOVT	461.	24.	2392.	4272.	198.	4763.	2080.	1582.	498.	2136.
20	SUBTOTALS	18362.	5527.	78642.	91371.	7728.	18111.	4419.	3001.	5915.	18262.
21	HOUSEHOLDS	25842.	10159.	212306.	34552.	13848.	23583.	3916.	3684.	1932.	51739.
22	FED-ST GOV	3447.	587.	20021.	7121.	1168.	6463.	1686.	759.	106.	3105.
23	PROFIT DEP	15701.	3770.	70885.	14445.	647.	8539.	3899.	2575.	7140.	12060.
24	IMPORTS	151619.	5925.	202272.	79253.	34.	6661.	24668.	18354.	1257.	433591.
25	TOTALS	214970.	25968.	584126.	226741.	23425.	63357.	38588.	28373.	16350.	518757.

Projected monthly natural gas consumption for space heating in 1998 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	13756.	9494.	189520.	29560.	11585.	14194.	4549.	2623.	989.	36437.
17.3°	4451.	13296.	63815.	88342.	42888.	8615.	925.	905.	6366.	55957.
29.7°	3299.	9962.	47462.	66146.	32682.	6453.	694.	678.	4768.	42309.
34.0°	3253.	9877.	46882.	65575.	32638.	6398.	686.	670.	4728.	42106.
40.8°	3100.	9457.	44574.	62803.	31745.	6128.	656.	641.	4529.	40675.

TABLE 5B.4 (Continued).

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 SUBTOTALS
1	FOOD PROC	0.	32249.	0.	0.	0.	0.	620.	0.	74.	34757.
2	PRINT-PUB	7930.	274.	44.	3251.	2218.	511.	31.	281.	659.	20500.
3	MFG NEC	0.	0.	0.	0.	0.	315.	52.	0.	93.	20183.
4	CONST	599.	24.	307.	670.	76.	345.	0.	220.	582.	44114.
5	TRANSPORT	462.	0.	5.	274.	1060.	728.	533.	144.	89.	19305.
6	COMMUNICAT	3747.	3416.	416.	3289.	5496.	774.	268.	894.	593.	22836.
7	ELECTRICTY	6606.	995.	279.	837.	3181.	830.	816.	1088.	582.	21149.
8	NAT GAS	1245.	482.	120.	445.	1991.	1915.	681.	975.	519.	13328.
9	WATER-SAN	855.	198.	148.	133.	725.	145.	179.	139.	419.	6456.
10	WHOLESALE	25671.	0.	1019.	103.	4555.	4353.	179.	555.	745.	55590.
11	RETAIL	1177.	4967.	372.	3141.	11826.	3375.	1459.	97.	1704.	47233.
12	RESTAURANT	4.	0.	0.	1625.	0.	183.	10.	0.	22.	2414.
13	HOTEL-MOT	0.	0.	0.	76.	0.	0.	10.	0.	1115.	1805.
14	FIRE	6385.	565.	1374.	3693.	29094.	4911.	3455.	0.	1404.	116302.
15	HEALTH SER	0.	0.	0.	0.	16640.	0.	3.	200.	1022.	18736.
16	SERV NEC	18369.	3264.	110.	11310.	16608.	3596.	516.	1155.	2082.	82446.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	99.	27413.	27511.
18	COLLEGES	0.	0.	0.	0.	0.	9.	117.	0.	11.	154.
19	LOCAL GOVT	5591.	562.	159.	1995.	7173.	2260.	110.	0.	893.	37147.
20	SUBTOTALS	78642.	46996.	4353.	30842.	100643.	24247.	9041.	5847.	40019.	591968.
21	HOUSEHOLDS	75393.	18781.	2612.	51517.	229385.	36818.	36468.	61030.	30924.	924490.
22	FED-ST GOV	17326.	3069.	225.	15730.	15028.	5945.	0.	4928.	1556.	108269.
23	PROFIT DEP	34053.	14196.	1840.	118010.	360106.	54358.	62.	1067.	12228.	735581.
24	IMPORTS	633264.	15143.	203.	167597.	120237.	24885.	7758.	4636.	2378.	1899732.
25	TOTALS	838677.	98185.	9232.	383696.	825400.	146253.	53329.	77508.	87105.	4260040.

Projected monthly natural gas consumption for space heating in 1998 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	140235.	50568.	5695.	41988.	236403.	57150.	47496.	63727.	36748.	1233628.
17.3°	352496.	21372.	39561.	86156.	186121.	51772.	42490.	48234.	81279.	1195041.
29.7°	266983.	16273.	30728.	64555.	143581.	39099.	33034.	37179.	61201.	907086.
34.0°	265863.	16238.	30911.	63998.	144236.	38896.	33254.	37389.	60794.	904392.
40.8°	257492.	15787.	30661.	61289.	141416.	37525.	32979.	36423.	58528.	876408.

		21 HOUSEHOLDS	22 FED-ST GOV
1	FOOD PROC	3846.	0.
2	PRINT-PUB	2398.	0.
3	MFG NEC	29519.	0.
4	CONST	6564.	0.
5	TRANSPORT	2549.	71.
6	COMMUNICAT	32031.	83.
7	ELECTRICTY	17340.	99.
8	NAT GAS	14978.	67.
9	WATER-SAN	6608.	6.
10	WHOLESALE	0.	0.
11	RETAIL	680452.	757.
12	RESTAURANT	55689.	6.
13	HOTEL-MOT	1877.	0.
14	FIRE	196288.	128.
15	HEALTH SER	77998.	0.
16	SERV NEC	62957.	850.
17	SCHOOLS	0.	25789.
18	COLLEGES	6262.	55721.
19	LOCAL GOVT	23830.	8339.
20	SUBTOTALS	1221186.	91917.
21	HOUSEHOLDS	5620.	654256.
22	FED-ST GOV	297216.	702.
23	PROFIT DEP	62366.	523.
24	IMPORTS	70480.	879.
25	TOTALS	1656867.	748276.

Projected monthly natural gas consumption for space heating in 1998 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)		
14.1°	1424360.	21749.
17.3°	1371624.	21002.
29.7°	1014992.	15920.
34.0°	1000640.	15920.
40.8°	947737.	15396.

TABLE 5B.5 Greeley projected transactions Table, 2003 (x $1,000).

		1 FOOD PROC	2 PRINT-PUB	3 MFG NEC	4 CONST	5 TRANSPORT	6 COMMUNICAT	7 ELECTRICTY	8 NAT GAS	9 WATER-SAN	10 WHOLESALE
1	FOOD PROC	1567.	69.	1440.	0.	0.	0.	0.	0.	0.	0.
2	PRINT-PUB	153.	19.	3656.	4201.	82.	179.	53.	71.	21.	326.
3	MFG NEC	178.	69.	38829.	4182.	0.	24.	166.	6.	0.	0.
4	CONST	4013.	69.	3268.	48365.	106.	143.	160.	0.	374.	0.
5	TRANSPORT	2814.	0.	13128.	4.	33.	77.	7.	13.	0.	11847.
6	COMMUNICAT	1365.	118.	3434.	221.	638.	125.	53.	65.	37.	982.
7	ELECTRICTY	1942.	249.	7201.	4.	213.	566.	0.	52.	491.	662.
8	NAT GAS	1914.	62.	4653.	1019.	466.	72.	7.	6.	16.	613.
9	WATER-SAN	137.	118.	1163.	3597.	41.	42.	7.	6.	0.	121.
10	WHOLESALE	2285.	1247.	10081.	15005.	0.	0.	0.	0.	608.	0.
11	RETAIL	2677.	1110.	17614.	5098.	6446.	1496.	200.	239.	262.	0.
12	RESTAURANT	666.	0.	166.	4.	0.	0.	0.	0.	0.	0.
13	HOTEL-MOT	0.	0.	1440.	0.	0.	0.	0.	0.	0.	0.
14	FIRE	3601.	3542.	45421.	27693.	3820.	17954.	2974.	1464.	4360.	1893.
15	HEALTH SER	0.	0.	1329.	415.	0.	0.	0.	0.	0.	0.
16	SERV NEC	690.	2020.	29025.	5959.	916.	286.	206.	381.	2017.	6511.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	COLLEGES	8.	19.	0.	0.	0.	0.	0.	0.	0.	0.
19	LOCAL GOVT	618.	37.	5705.	5678.	335.	7481.	3407.	2568.	752.	3040.
20	SUBTOTALS	24629.	8748.	187554.	121444.	13097.	28444.	7240.	4871.	8939.	25996.
21	HOUSEHOLDS	34662.	16081.	506330.	45924.	23470.	37040.	6414.	5980.	2919.	73650.
22	FED-ST GOV	4623.	929.	47747.	9465.	1980.	10151.	2761.	1232.	160.	4420.
23	PROFIT DEP	21060.	5967.	169054.	19199.	1096.	13411.	6388.	4180.	10791.	17167.
24	IMPORTS	203370.	9378.	482401.	105337.	57.	10461.	40410.	29792.	1900.	617211.
25	TOTALS	288344.	41104.	1393086.	301370.	39700.	99507.	63213.	46055.	24710.	738444.

Projected monthly natural gas consumption for space heating in 2003 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	18451.	15027.	451987.	39290.	19633.	22293.	7452.	4258.	1494.	51868.
17.3°	5976.	21004.	152053.	117471.	72633.	13532.	1514.	1467.	9631.	79678.
29.7°	4429.	15767.	113087.	89956.	55348.	10137.	1135.	1100.	7214.	60243.
34.0°	4368.	15633.	111705.	87197.	55274.	10051.	1122.	1087.	7154.	59954.
40.8°	4162.	14968.	106207.	83510.	53762.	9626.	1073.	1040.	6852.	57918.

		11 RETAIL	12 RESTAURANT	13 HOTEL-MOT	14 FIRE	15 HEALTH SER	16 SERV NEC	17 SCHOOLS	18 COLLEGES	19 LOCAL GOVT	20 SUBTOTALS
1	FOOD PROC	0.	47696.	0.	0.	0.	0.	890.	0.	113.	51775.
2	PRINT-PUB	12300.	405.	72.	5120.	4195.	847.	45.	363.	1010.	33117.
3	MFG NEC	0.	0.	0.	0.	0.	522.	74.	0.	142.	44192.
4	CONST	929.	36.	504.	1055.	143.	572.	0.	284.	890.	60911.
5	TRANSPORT	717.	0.	9.	432.	2005.	1207.	767.	186.	136.	33381.
6	COMMUNICAT	5811.	5053.	684.	5180.	10395.	1284.	386.	1154.	907.	37895.
7	ELECTRICTY	10246.	1472.	459.	1319.	6016.	1376.	1172.	1404.	890.	35735.
8	NAT GAS	1932.	713.	198.	701.	3765.	3176.	979.	1259.	794.	22344.
9	WATER-SAN	1327.	292.	243.	210.	1371.	240.	257.	180.	641.	9994.
10	WHOLESALE	39818.	0.	1675.	162.	8615.	7219.	257.	716.	1140.	88829.
11	RETAIL	1825.	7346.	612.	4946.	22365.	5596.	2097.	125.	2609.	82663.
12	RESTAURANT	6.	0.	0.	2560.	0.	303.	15.	0.	34.	3754.
13	HOTEL-MOT	0.	0.	0.	120.	0.	0.	15.	0.	1707.	3282.
14	FIRE	9904.	836.	2260.	5816.	55023.	8144.	4966.	0.	2149.	201821.
15	HEALTH SER	0.	0.	0.	0.	31471.	0.	5.	258.	1565.	35044.
16	SERV NEC	28492.	4827.	180.	17813.	31410.	5963.	742.	1491.	3187.	142117.
17	SCHOOLS	0.	0.	0.	0.	0.	0.	0.	128.	41968.	42096.
18	COLLEGES	0.	0.	0.	0.	0.	14.	168.	0.	17.	226.
19	LOCAL GOVT	8672.	831.	261.	3142.	13567.	3747.	158.	0.	1367.	61367.
20	SUBTOTALS	121979.	69508.	7158.	48576.	190341.	40210.	12994.	7546.	61268.	990543.
21	HOUSEHOLDS	116940.	27777.	4295.	81138.	433823.	61057.	52412.	78771.	47345.	1656029.
22	FED-ST GOV	26874.	4540.	369.	24774.	28422.	9859.	0.	6360.	2382.	187048.
23	PROFIT DEP	52818.	20996.	3025.	185862.	681049.	90145.	89.	1378.	18721.	1322397.
24	IMPORTS	982235.	22396.	333.	263960.	227398.	41269.	11149.	5983.	3641.	3058683.
25	TOTALS	1300845.	145217.	15181.	604310.	1561033.	242540.	76645.	100039.	133357.	7214702.

Projected monthly natural gas consumption for space heating in 2003 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)										
14.1°	217514.	74791.	9364.	66130.	447096.	94775.	68261.	82252.	56261.	2002503.
17.3°	547122.	31670.	65012.	135698.	351707.	85719.	61137.	62313.	124521.	1939858.
29.7°	414394.	24115.	50497.	101677.	271321.	64736.	47532.	48032.	93761.	1472481.
34.0°	412656.	24063.	50798.	100799.	272559.	64401.	47848.	48303.	93139.	1468111.
40.8°	399663.	23394.	50387.	96532.	267229.	62130.	47452.	47055.	89666.	1422626.

TABLE 5B.5 (Continued).

		21 HOUSEHOLDS	22 FED-ST GOV
1	FOOD PROC	6065.	0.
2	PRINT-PUB	3782.	0.
3	MFG NEC	46553.	0.
4	CONST	10351.	0.
5	TRANSPORT	4020.	94.
6	COMMUNICAT	50515.	112.
7	ELECTRICTY	27346.	133.
8	NAT GAS	23621.	90.
9	WATER-SAN	10420.	9.
10	WHOLESALE	0.	0.
11	RETAIL	1073095.	1013.
12	RESTAURANT	87823.	9.
13	HOTEL-MOT	2960.	0.
14	FIRE	309553.	172.
15	HEALTH SER	123006.	0.
16	SERV NEC	99286.	1137.
17	SCHOOLS	0.	34511.
18	COLLEGES	9876.	74567.
19	LOCAL GOVT	37581.	11159.
20	SUBTOTALS	1925851.	123005.
21	HOUSEHOLDS	8862.	875542.
22	FED-ST GOV	468720.	940.
23	PROFIT DEP	98353.	700.
24	IMPORTS	111149.	1176.
25	TOTALS	2612935.	1001362.

Projected monthly natural gas consumption for space heating in 2003 by sector for five mean monthly temperatures (x 1000 cubic feet).

Mean Monthly Temperature (°F)		
14.1°	2246263.	29105.
17.3°	2163098.	28105.
29.7°	1600676.	21304.
34.0°	1578043.	21304.
40.8°	1494614.	20604.

APPENDIX 5C

DATA SOURCES BY SECTOR IN GREELEY, COLORADO

This section is devoted to the presentation of an annotated bibliography of the information sources which have been found superior in Greeley. A number of alternative sources were available which were not used. The selection of the best information and the methods of attaining it are discussed in greater detail in Gray et al. (1977b), McKean and Weber (1978), and McKean and Weber (1979).

Construction SIC[*] 15,16,17

Colorado. Department of Labor and Employment. Files.

Industry survey data.

Information gained by interviews with contractors was used to calculate a ratio between contract value and outlay for labor on a two-digit SIC level. This ratio was then applied to the annualized employment and wage data provided by the Colorado Department of Labor and Employment to estimate total gross output.

Manufacturing SIC 20,23,25,27,28,29,32,33, 34,35,38,39

Colorado. Department of Labor and Employment. Colorado Manpower Rivew. Monthly.

Colorado. Department of Labor and Employment. Files.

Industry survey data.

Information gained by interviews was used to calculate a ratio between total gross output value and outlay for labor on a two-digit SIC level. This ratio was then applied to the annualized employment and wage data provided by the Colorado Department of Labor and Employment to estimate total gross output at the two-digit level.

Transportation and Communication SIC 40,41, 42,45,47,48

Colorado. Department of Labor and Employment. Files.

Colorado. Public Utilities Commission. Files.

Colorado. State Auditor. Files.

Industry survey data.

Information pertinent to railroad and telephone communications was gained from filed PUC reports and survey. Because of the nature of the accounting systems employed by the firms involved, a significant amount of prorating was required to allocate the data to approximate the study region.

Data on employment and earnings for components her than rail and air transportation sectors are obtained from the Colorado Department of Labor and Employment and the survey provided an estimation for the output level.

Electric and Natural Gas Utilities SIC 491, 492,493

Colorado. Department of Labor and Employment. Files.

Colorado. Public Utilities Commission. Files.

Colorado. State Auditor. Files.

Industry survey data.

A certain amount of prorating and imputation was also involved in this sector to match the geographic location of activity to the study region. Electric activities under the control of local public authorities were identified by examining reports filed with the State Auditor. Information gained from the Colorado Department of Labor and Employment and from interviews provides cross-checks throughout the estimation of the activities of this sector.

Wholesale Trade SIC 50,51; also

Retail Trade SIC 52,53,54,55,56,57,58,59

Colorado. Department of Labor and Employment. Colorado Manpower Review. Monthly.

Colorado. Department of Labor and Employment. Files.

Colorado. Department of Revenue. Annual Report. Annual

Industry survey data.

Finance, Insurance, and Real Estate SIC 60,61, 62,63,64,65,66

Colorado. Department of Labor and Employment. Colorado

Manpower Review. Monthly.

Colorado. Department of Labor and Employment. Files.

Colorado. Department of Regulatory Agencies. Division of Insurance. Insurance Industry in Colorado: Statistical Report. Annual.

Colorado. Department of Revenue. Annual Report. Annual.

County Clerk Office, respective counties. Files.

Federal Credit Banks of Wichita. Files.

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[*] Standard Industrial Classification.

Federal Home Loan Bank Board. Combined Financial Statements - Member Savings and Loan Associations of the Federal Home Loan Bank System. Annual.

Industry survey data.

Sheshunoff & Company, Inc. The Banks of Colorado. (A private publication.) Annual.

The output value of the finance sector was entered as the estimated value of interest charges incurred within the region. Interest earnings by commercial banks were readily identified in the Sheshunoff publication; likewise, the Federal Credit Banks of Wichita provided data relevant to the operations of the Production Credit Association and Federal Land Bank Association. Regional information on the activities of savings and loan associations was not readily available so that data published for Colorado in the Federal Home Loan Bank Board's Combined Financial Statements were prorated by the wage and salary formula for the study region.

Information previously gained in interviews with several major insurance companies suggested that a precise accounting for insurance premiums paid on per county basis was a near impossibility. Another difficulty observed was with respect to loss claims; specifically, in a small region the losses incurred by any one economic sector cannot be predicted with any certainty. Thus, the insurance sector was handled as follows.

Gross insurance premiums paid in the study region were approximated by prorating premiums paid in the State of Colorado by a personal adjusted gross income figure. Premiums paid in Colorado were reported in the State Division of Insurance's Statistical Report; personal income is reported in the Department of Revenue's Annual Report.

Information on documentary fees paid for real estate transactions was secured from the county clerk for Weld County. The fee information was used to estimate the gross value of transactions and survey information was used to estimate the commissions which make up the gross output for the real estate sector.

Survey information provided the means to construct the distribution of the total gross outlays in the finance, insurance, and real estate sector.

Services SIC 70,72,73,74,75,76,78,79,81,86, 89

Colorado Department of Labor and Employment. Colorado Manpower Review. Monthly

Colorado. Department of Labor and Employment. Files.

Colorado. Department of Revenue. Annual Report. Annual.

Industry survey data.

U.S. Department of Commerce. Bureau of the Census. Census of Selected Service Industries, 1972: Area Series, Colorado, 72-A-6. Washington, D.C.: Government Printing Office, 1974.

Sales by the hotels and other lodging facilities sector were estimated from survey and Department of Labor and Employment data.

Health SIC 80

Colorado. Department of Labor and Employment. Files.

Colorado. Department of Revenue. Annual Report. Annual.

Colorado. State Auditor. Files.

Industry survey data.

Health facilities owned by local public authorities have current financial statements on file with the State Auditor. The deliveries of services in nursing home situations were obtained from survey.

Education SIC 82

Colorado. Department of Education. Files.

Colorado. Department of Education. Revenues and Expenditures: Colorado School Districts. Annual.

Information on public school districts is published on an annual basis in Revenues and Expenditures. Information on colleges and universities and Colorado State Extension Services was secured directly.

Water, Sewer, and Trash SIC 494,495,496,497; also

Local and County Roads; also

Local and County Government; also

Local and County Taxes

Colorado. State Auditor. Files.

Industry survey data.

The 1978 audit reports for all local and county government authorities were examined and that data contained therein were aggregated. Information gained in select interviews facilitated the distribution of the various sectors' outlays.

Households

Colorado. Department of Labor and Employment. Files.

Colorado. Department of Revenue. Annual Report. Annual.

Colorado. Public Employees Retirement Association. Files.

Community Services Administration. Federal Outlays in Colorado. Annual. (Prior to fiscal 1975 published by Office of Economic Opportunity.)

Industry survey data.

U.S. Department of Commerce. Bureau of the Census. Census of the Population, 1970:

General Social and Economic Characteristics, Final Report, Colorado, PC (1)-C7. Washington, D.C.: Government Printing Office, 1972.

U.S. Department of the Treasury. Internal Revenue Service. Statistics of Income 1969, Zip Code Area Data from Individual Income Tax Returns. Washington, D.C.: Government Printing Office, 1972.

Household income was shown as emanating from wages and salaries subject to withholding, proprietorship, partnership, and Sub-Chapter S Corporation income, interest, rent and dividend income, and transfer payments.

Households were not surveyed to gain information on their outlay patterns. Rather, there was a reliance on the sales information provided by regional producers. Accordingly, the import figure aside from the post marginal trade sector merchandise, for households were largely a residual value.

State Government; also

Federal Government

Colorado. Department of Education. Revenues and Expenditures; Colorado School Districts. Annual.

Colorado. Department of Highways. Colorado's Annual Highway Report. Annual.

Colorado. Department of Natural Resources. Division of Wildlife. Colorado Big Game Harvest. Annual.

Colorado. Department of Natural Resources. State Board of Land Commissioners. Summary of Transactions. Annual.

Colorado. Department of Planning and Budget. Files.

Colorado. Department of Revenue. Annual Report. Annual.

Colorado. State Auditor. Files.

Colorado. Public Employees Retirement Association. Files.

Colorado. Public Utilities Commission. Files.

Community Services Administration. Federal Outlays in Colorado. Annual. (Prior to fiscal 1975 published by Office of Economic Opportunity.)

Sheshunoff & Company, Inc. The Banks of Colorado. (A private publication.) Annual.

U.S. Department of the Treasury. Bureau of Government Financial Operations. Combined Statement on Receipts, Expenditures, and Balances of the United States Government. Washington, D.C.: Government Printing Office. Annual.

U.S. Department of the Treasury. Internal Revenue Service. Statistics of Income 1969, Zip Code Area Data From Individual Income Tax Returns. Washington, D.C.: Government Printing Office, 1972.

Total gross output for the government sectors was defined in terms of the estimate of revenues from all sources. For private enterprise in the endogenous portion of the model, an estimate was made of income and payroll tax liabilities and fees and royalties paid by each respective sector. There was no real cross-check against these estimates because neither Colorado nor the U.S. Government reports business tax liabilities on a city basis. Further, previous research experience has demonstrated that prorating the reported state level of collections (reported in the Treasury's Combined Statement of Receipts, Expenditures, and Balances and the Department of Revenue's Annual Report) by such factors as population or personal income produces questionable results.

Personal tax and fee liabilities were much more readily estimated by using such publications as the Department of Revenue's Annaul Report, and the IRS's Zip Code Area Data. Exports by the city of Greeley include sales taxes.

For the U.S. Government, the publication Federal Outlays was used as a first approximation of expenditures. Select interviews with the larger agencies, such as the U.S. Postal Service, provided the information to estimate agency operating expenditure patterns. Information on direct payments for such things as schools, interest on government securities held by commercial banks, highways, and local government activities was taken from the Colorado Department of Education's Revenues and Expenditures, Sheshunoff's The Banks of Colorado, Colorado's Annual Highway Report, and files in the Colorado State Auditor's Office.

APPENDIX 5D

VOLUNTARY QUESTIONNAIRE

City of Greeley Inter-Industry Analysis

This questionnaire is designed to enable you to provide us, in as simple a form as possible, a detailed account of your firm's purchases and sales in 1978. The specific focus of the analysis is the component of that activity occurring in the city of Greeley.

This information will be handled in strictest confidence. Your responses will be aggregated with those of other firms in your economy sector, eliminating the possibility that any single firm's responses will be identifiable. Participation on your part is voluntary.

1. We are particularly interested in obtaining data which are a reasonable representation of your firm's current operation. Data for a fiscal or calendar year 1978 or later are preferred. In the event that data are not available in this form, please use any consecutive twelve months since 1977 (please indicate).
2. You may indicate sales and purchases in dollar amounts or percentages.
3. When exact data are not available, please use estimates. If it is not possible to provide information for certain questions, please indicate.

Name of Firm: ______________________________

What is your major product(s) or service(s)? If convenient, list the appropriate SIC classification(s). ______________________

____

____

What was the total number of employees you had at any one time in 1978?

Full Time: __________ Part Time: __________

SALES (REVENUE) ANALYSIS

DEMAND SOURCE: SECTORS TO WHICH YOU SELL	SALES IN CITY OF GREELEY $ or % of Total	OTHER SALES IN WELD AND LARIMER COUNTIES $ or % of Total	SALES ELSEWHERE $ or % of Total
1. IRRIGATED AGRICULTURE			
2. DRYLAND AGRICULTURE			
3. DAIRY FARMS			
4. LIVESTOCK OTHER THAN DAIRY FARMS			
5. AGRICULTURAL SERVICES; FORESTRY			
6. OIL AND GAS EXTRACTION; RELATED SERVICE OPERATORS			
7. NONMETAL MINING; RELATED SERVICE OPERATORS			
8. CONSTRUCTION			
9. FOOD AND KINDRED PRODUCTS MANUFACTURERS			
10. LUMBER; WOOD PRODUCTS MANUFACTURERS			
11. PRINTING AND PUBLISHING; PAPER AND ALLIED PRODUCTS MANUFACTURERS; newspaper advertising			
12. STONE, GLASS, CLAY PRODUCT MANUFACTURERS			
13. FABRICATED METALS; NON-ELECTRICAL MACHINERY MANUFACTURERS			
14. ELECTRICAL MACHINERY & EQUIPMENT, TRANSPORTATION EQUIPMENT; ELECTRONIC INSTRUMENTS & COMPONENTS MANUFACTURERS			
15. ALL OTHER MANUFACTURERS, APPAREL, CHEMICALS, LEATHER, PRIMARY METALS, ETC.			
16. TRANSPORTATION, Air, bus, rail, truck, etc.			
17. U. S. POSTAL SERVICE			
18. COMMUNICATION: RADIO, TELEVISION, TELEPHONE, TELEGRAPH			
19. ELECTRIC COMPANIES			
20. NATURAL GAS COMPANIES			
21. WATER, SEWERAGE & TRASH REMOVAL ENTERPRISES			
22. WHOLESALE TRADE			
23. AUTOMOBILE DEALERS, GASOLINE SERVICE STATIONS			
24. EATING AND DRINKING ESTABLISHMENTS			
25. HOTELS, MOTELS, OTHER LODGING			
26. RETAILERS, NOT ELSEWHERE LISTED			
27. FINANCIAL INSTITUTIONS			
28. INSURANCE (companies, agents, brokers)			
29. HEALTH SERVICE ESTABLISHMENTS			
30. ALL OTHER SERVICE ESTABLISHMENTS, Legal, repair, recreation, etc.			
31. HOUSEHOLDS (direct sales for private consumption)			
32. EDUCATIONAL INSTITUTIONS			
33. SOCIAL SERVICE AGENCIES			
34. CITY OF GREELEY			
35. CITY & COUNTY SALES AND PROPERTY TAXES			
36. WELD COUNTY GOVERNMENT			
37. STATE GOVERNMENT			
38. FEDERAL GOVERNMENT			
39. TOTALS			

At what level of output capacity did your establishment operate during 1978?

LEVEL OF CAPACITY UTILIZATION: __________ %

What is your estimate of your establishment's total water use for all phases of your operation? (Note: please use any convenient unit of measurement; e.g., gallons per day, 1000 gallons per day, acre feet per year, etc.)

TOTAL WATER INTAKE: ____________________

PURCHASES AND EXPENSE (OUTLAYS) ANALYSIS

SUPPLY SOURCE: SECTORS FROM WHICH YOU PURCHASE OR PAY EXPENSES	PURCHASES IN CITY OF GREELEY $ or % of Total	OTHER PURCHASES IN WELD AND LARIMER COUNTIES $ or % of Total	PURCHASES ELSEWHERE $ or % of Total
1. IRRIGATED AGRICULTURE			
2. DRYLAND AGRICULTURE			
3. DAIRY FARMS			
4. LIVESTOCK OTHER THAN DAIRY FARMS			
5. AGRICULTURAL SERVICES; FORESTRY			
6. OIL AND GAS EXTRACTION; RELATED SERVICES			
7. NONMETAL MINING; RELATED SERVICES			
8. CONSTRUCTION			
9. FOOD AND KINDRED PRODUCTS MANUFACTURERS			
10. LUMBER; WOOD PRODUCTS MANUFACTURERS			
11. PRINTING AND PUBLISHING; PAPER AND ALLIED PRODUCTS MANUFACTURERS; newspaper advertising			
12. STONE, GLASS, CLAY PRODUCT MANUFACTURERS			
13. FABRICATED METALS; NON-ELECTRICAL MACHINERY MANUFACTURERS			
14. ELECTRICAL MACHINERY & EQUIPMENT, TRANSPORTATION EQUIPMENT; ELECTRONIC INSTRUMENTS AND COMPONENTS MANUFACTURERS			
15. ALL OTHER MANUFACTURERS, APPAREL, CHEMICALS, LEATHER, PRIMARY METALS, ETC.			
16. TRANSPORTATION, Air, bus, rail, truck, etc.			
17. U. S. POSTAL SERVICE			
18. COMMUNICATION; RADIO, TELEVISION, TELEPHONE (includes media advertising)			
19. ELECTRIC UTILITIES			
20. NATURAL GAS UTILITIES			
21. WATER, SEWERAGE, TRASH REMOVAL SERVICES			
22. WHOLESALE TRADE			
23. AUTOMOBILE DEALERS, GASOLINE SERVICE STATIONS			
24. EATING AND DRINKING ESTABLISHMENTS			
25. HOTELS, MOTELS, OTHER LODGING			
26. RETAIL, NOT ELSEWHERE LISTED			
27. FINANCE, Interest, principal payments			
28. INSURANCE PREMIUMS; PENSION FUNDS; REAL ESTATE, (value purchased, commissions, etc.)			
29. HEALTH SERVICES (medical, hospitals, etc.)			
30. ALL OTHER SERVICES, Legal, repairs, recreation, personal business, leasing, dues, etc.			
31. HOUSEHOLDS (payments subject to withholding)			
32. EDUCATIONAL SERVICES, tuition			
33. SOCIAL SERVICES AGENCIES			
34. CITY OF GREELEY (permits, licenses, direct charges)			
35. CITY AND COUNTY SALES & PROPERTY TAXES			
36. WELD COUNTY GOVERNMENT (permits, licenses, direct charges)			
37. STATE GOVERNMENT			
38. FEDERAL GOVERNMENT (taxes, FICA, FUTA, etc.)			
39. PROFITS, RENTS, DIVIDENDS, LOSSES			
40. DEPRECIATION			
41. TOTALS			

Please indicate the value of your establishment's net inventory change in 1978.
(This may be a positive or negative figure.) NET INVENTORY CHANGE: $ _________.

REFERENCES

American Gas Association, 1969: Load characteristics research manual. A.G.A., New York, NY.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1972: Handbook of fundamentals. ASHRAE, New York, NY.

Box, G.E.P. and G.M. Jenkins, 1976: Time series analysis: forecasting and control. Holden-Day, San Francisco, 575 pp.

Ding, Y.H. and E.R. Reiter, 1980: A preliminary study of the variability in the frequency of typhoon formation over the West Pacific ocean. Environmental Research Paper No. 22, Colorado State University, Fort Collins, CO, (in press).

Federal Energy Administration, 1974: A pilot project in homeowner energy conservation. Final Report. FEA, Washington, D.C.

_____, 1975: Monthly energy review. March 75, Federal Energy Administration National Energy Information Center, Washington, D.C., 92 pp.

Federal Power Commission, 1970: The methodology of load forecasting. The National Power Survey. U.S. Govt. Printing Office, Washington, D.C.

Fox, J.M., 1973: Energy consumption for residential space heating, a case study. Report No. 4. Center for Environmental Studies, Princeton Univ., Princeton, NJ.

Gray, S.L. and J. McKean, 1974: An economic analysis of water use in Boulder, Larimer and Weld counties, Colorado with projections to 1980. Contract Report, Bureau of Reclamation, Department of Economics, Colorado State University, March.

_____ and _____, 1975a: Use of the Colorado input-output model to analyze the impacts of alternative economic scenarios on output, income, water use, and employment in Colorado's economy. Contract Report, Colorado Energy Research Institute, Department of Economics, September.

_____ and _____, 1975b: An economic analysis of water use in Colorado's economy (Colorado input-output model). Contract Report, Office of Water Research and Technology, U.S. Department of Interior, Environmental Resources Center, Completion Report Series No. 70 (fifth printing), Department of Economics, Colorado State University, December.

_____ and _____, 1976: The development of water multiplier impacts from input-output analysis: an empirical example from Boulder, Larimer and Weld counties, Colorado. Journal of Water Resources Research, April.

_____, J. McKean and D. Rohdy, 1975: Estimating the impact of higher education from input-output models: a case study. The Rocky Mountain Social Science Journal, January.

_____, P. Huszar and J. McKean, 1976: Future economic trends - input/output analysis, interindustry analysis and economic profile of the Larimer-Weld region. Consulting Report, Larimer-Weld Regional Council of Governments, Vol. 1: Final Report, Vol. II: Technical Appendices, Vol. III: Executive Summary.

_____, J. McKean and F. Ward, 1977a: Alleviating the impact of resource shortages: an analytical method. Experiment Station Bulletin 131, Colorado State University, Fort Collins, Colorado.

_____, _____ and J. Weber, 1977b: The economy of northwestern Colorado: description and analysis. Contract Report, Bureau of Land Management, Department of Economics, Colorado State University.

_____, _____ and _____, 1977c: The economy of northwestern Colorado: executive summary. Contract Report, Bureau of Land Management, March.

_____, _____ and _____, 1977: The analytical framework: a conceptualization and hypothetical example. Contract Report, Bureau of Land Management, March.

_____, _____, E. Sparling and J. Weber, 1979: Measurement of growth equalized employment multiplier effects: an empirical example. The Annals of Regional Science, November.

Hill, J.E., T. Kusuda, S.T. Liu and F.J. Powell, 1975: A proposed concept for determining the need for air conditioning in buildings based on building thermal response and human comfort. NBS Building Science Series 71. Department of Commerce, Washington, D.C.

Isard, W. et al., 1960: Methods of regional analysis. Regional Science Studies Series 4, M.I.T. Press.

Ivakhnenko, A.G., 1968: The group method of data handling, a rival of the stochastic approximation. Soviet Automatic Control, 13(3), 43-55.

Johnson, G.R., 1978: Modelling the energy consumption for space conditioning for a community. Proceedings from the Conference on Climate and Energy, Asheville, N.C., May.

_____, W.W. Shaner, D.E. Hull and T. Sheng, 1975: Energy conservation by passive solar design factors. Unpublished paper, Dept. of Mechanical Engr., Colorado State Univ., Ft. Collins, CO.

Jones, J.W. and B.J. Hendrix, 1975: Residential energy requirements and opportunities for energy conservation. Center for Energy Studies, Univ. of Texas, Austin, TX.

Kruger, P., 1974: Computer simulation and actual results of an energy conservation program. ASHRAE Journal, October.

Kunrenther, H., R. Ginsberg, L. Miller, P. Sagi, P. Slovic, B. Borkan and N. Katz, 1978: Disaster insurance protection: public policy lessons. Wiley Interscience, New York.

Kusuda, T., 1974: NBSLD, computer programs for heating cooling loads in buildings. Prepared for Housing and Urban Development, Washington, D.C.

———, and F.J. Powell, 1972: Use of modern computer programs to evaluate dynamic heat-transfer and energy use processes in buildings. Proc. of the Joint RILEM-ASTM-CIB Symp., Philadelphia, Penn.

———, J.E. Hill, S.T. Liu, J.P. Barnett and J.W. Bean, 1975: Predesign analysis of energy conservation options for a multi-story demonstration office building. NBS Building Series 78. U.S. Department of Commerce, Washington, D.C.

Leong, H.H., 1975: Using recursive regression polynomials to construct a system description -- an introduction to the GMDH algorithm. M.S. Thesis, Colorado State Univ., Ft. Collins, CO.

Leontief, W.W., 1936: Quantitative input-output relations in the economic system of the United States. The Review of Economics and Statistics, XVII.

Margen, P., L.-A Cronholm, L. Larsson and J.-E. Marklund, 1979: Overall feasibility and economic viability for a district heating/new cogeneration system in Minneapolis-St. Paul. District Heating/Cogeneration Application Studies for the Minneapolis-St. Paul Area. Oak Ridge National Laboratory, ORNL/TM-6830/P3, Dist. Category UC-95d.

McKean J., 1979: An input-output analysis of sportsman expenditures in Colorado. Contract Report, Bureau of Land Management, Department of Economics, Colorado State University.

———, E. Sparling and J. Weber, 1977a: Employment multiplier impacts in Colorado. Consulting Report, Colorado Energy Research Institute.

———, ——— and ———, 1977b: An inter-industry analysis of the impacts of natural gas shortages on Colorado's economy. Consulting Report, Colorado Energy Research.

——— and J. Weber, 1978: The economy of Moffat, Routt and Rio Blanco counties, Colorado: description and analysis. Contract Report, Bureau of Land Management, Department of Economics, Colorado State University.

——— and ———, 1979: An input-output study of the upper Colorado main stem region of western Colorado. Contract Report, Bureau of Land Management, Department of Economics, Colorado State University.

McQuigg, J.D., 1974: Increasing sensitivity of energy demand to weather. Paper presented before 140th meeting of American Assoc. for the Advancement of Science, San Francisco, Feb., (unpublished).

Meriwether, R.F., 1975: Computer modelling techniques for building energy consumption. Proceedings of 5-7 May 1974 Conference on Energy Conservation in Commercial, Residential and Industrial Buildings. Ohio State Univ., Columbus, Ohio.

Middleton, J.W., 1980: A cross-spectral study of the spatial relationships in the North Pacific sea-surface temperature anomaly field. Environmental Research Paper No. 23, Colorado State University, Fort Collins, CO, (in press).

Miernyk, W. 1965: The elements of input-output analysis, New York: Random House, Inc.

New York Power Pool, 1975: Peak demand and energy r quirements. Vol. 1 of report submitted in co pliance with Article VIII, Section 149-b of the Public Service Law of New York State.

Peavy, B.A., D.M. Burch, F.J. Powell and C.M. Hunt, 1975: Comparison of measured and computer-predicted thermal performance of a four bedroom wood-frame townhouse. NBS Building Science Series 57. U.S. Department of Commerce, Washington, D.C.

Petersen, S.R., 1974: Retrofitting existing housing for energy conservation: an economic analysis. National Bureau of Standards, Science Series 64. U.S. Govt. Printing Office, Washington, D.C.

Peterson, J.T., 1969: The climate of cities: a survey of recent literature. Nat. Air Poll. Control Admin., Publication No Ap-59, 48 pp.

Pfouts, R.W., 1960: The techniques of urban economic analysis. Chandler-Davis Publishing Co.

Quesney, F., 1758: <u>Tableau Economique</u>.

Reiter, E.R., 1979: On the dynamic forcing of short-term climate fluctuations by feedback mechanisms. Environmental Research Paper No. 21, Colorado State University, Ft. Collins, CO, 62 pp.

———, G.R. Johnson, W.L. Somervell, Jr., E.W. Sparling, E. Dreiseitl, B.D. Macdonald, J.P. McGurik and A.M. Starr, 1976: The effects of atmospheric variability on energy utilization and conservation. Environmental Research Paper No. 5, Colorado State University, Ft. Collins, CO, 72 pp.

———, E. Dreiseitl, G.R. Johnson, H.H. Leong, B.C. Macdonald, W.L. Somervell, Jr., A.M. Starr, and K.O. Timbre, 1978: The effects of atmospheric variability on energy utilization and conservation. Environmental Research Paper No. 14, Colorado State University, Ft. Collins, CO, 75 pp.

———, C.C. Burns, E. Dreiseitl, G.R. Johnson, H.H. Leong, B.C. Macdonald, J.D. Sheaffer and A.M. Starr, 1979: The effects of atmospheric variability on energy utilization and conservation. Environmental Research Paper No. 18, Department of Atmospheric Science, Colorado State University, Ft. Collins, Colorado, 58 pp.

Richardson, H.W., 1972: Input-output and regional economics. Weidenfeld and Nicolson, London.

Rosenblatt, F., 1952: Principles of neurodynamics, Perceptrons and the theory of brain mechanisms. Spartan Books, Washington.

Sepsy, C.F., R.S. Blancett and M.F. McBride, 1975a: Heat transfer models and energy needs for residential homes. EPRI 137, Report No. 3, EPRI, Palo Alto, CA.

———, B.L. Moentenich and M.F. McBride, 1975b: A study of attic temperatures and heat loss residential homes. EPRI 137, Report No. EPRI Palo Alto, CA.

Starr, A.M., 1978: The simplification of building census input for a physical model of space-heating demands. Proceeding from the Conference on Climate and Energy, Asheville, N.C., May, 1978.

Triennial Report, 1978: The effects of atmospheric variability on energy utilization and conservation. Report submitted to the U.S. Department of Energy under Contract EY-76-S-02-1340, 145 pp.

Walras, L., G. Cassel and V. Pareto, 1874: Tableau Economique, extensions from the work by F. Quesney, 1758.

_____, J.M. Salvadore and M.F. McBride, 1975c: Thermal response and modeling of heating and cooling equipment for residential homes. EPRI 137, Report No. 2, EPRI, Palo Alto, CA.

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on u[illegible] heat-island generation under various synoptic conditions. A detailed building census, comprised of 105,722 heated structures, was obtained by augmenting the information contained in the computerized assessor's files with data extracted from the Yellow Pages telephone directory.

A field survey in Greeley, Colorado, indicated that investment returns from insulating houses might not be as high as hoped for. Possibly a considerable amount of insulating material is applied wastefully. Misinformation seems to be the primary cause of misguided energy conservation. Progress in conservation could be achieved if utility costs were considered in mortgage loan applications, together with principal, interests, taxes and insurance. Detailed energy consumption modelling would be a premise for such fiscal management approaches.

Another extensive field survey yielded data for a local input-output model applied to the city of Greeley. Economic multipliers for dollars of output, space-heating, energy use and employment were developed and used for growth projections to the year 2003 under varying scenarios. Combination of these different multiplyers yielded sector-by -sector assessments of the vulnerability to temperature variations and to energy curtailments.

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Previously Published Environmental Research Papers

No. 1 On the Variability of Hemispheric Scale Energy Parameters, by J.P. McGuirk, E.R. Reiter and A.M. Barbieri, January 1975.

No. 2 On Determining Vertical Wind Velocities from Eole Constant-Density Balloon Data, by Robert M. Banta, June 1975.

No. 3 Atmospheric Eddy Transports and Their Efficiencies, by Srinivasan Srivatsangam, January 1976.

No. 4 Interannual Variations and Regional Effects of Hemispheric Parameters, by Ann M. Starr (neé Barbieri), July 1976.

No. 5 The Effects of Atmospheric Variability on Energy Utilization and Conservation, by E.R. Reiter et al., November 1976.

No. 6 Fluctuations in the Atmosphere's Energy Cycle, by James P. McGuirk, March 1977.

No. 7 Oceanic Latent and Sensible Heat Flux Variability and Air-Interaction, by Anne D. Seigel, April 1977.

No. 8 Observations of Stratospheric Thermal Structure from Satellites, by Thomas J. Kleespies, May 1977.

No. 9 Effects of Coal Mine Drainage on Macroinvertebrates of Trout Creek, Colorado, by Steven P. Canton and James V. Ward, April 1977.

No. 10 Potential Effects of Oil Shale Extraction and Processing Activities on Macroinvertebrates of Piceance and Black Sulphur Creeks, Colorado, by Lawrence J. Gray and James V. Ward, April 1977.

No. 11 Modeling Atmospheric Dispersion of Lead Particulates From a Highway, by Paul C. Katen, July 1977.

No. 12 Residence Time of Atmospheric Pollutants and Long-Range Transport, by Teizi Henmi, Elmar R. Reiter and Roger Edson, July 1977.

No. 13 Quasi-Periodicities of Atmospheric Circulation and Their Application to Long-Range Weather Prediction, by S. Srivatsangam, Chi-Nan Hsiao, and Elmar R. Reiter, November 1977.

No. 14 The Effects of Atmospheric Variability on Energy Utilization and Conservation, by Elmar R. Reiter, et al., February 1978.

No. 15 Long-Range Transport and Transformation of SO_2 and Sulfate, by Teizi Henmi and Elmar R. Reiter, September 1978.

No. 16 The Interannual Variability of Northern Hemisphere Precipitation, by Thomas J. Corona, December 1978.

No. 17 Interannual Variation of Atmospheric Meridional Eddy Transports, by Chi-Nan Hsiao, April 1979.

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