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THE EFFECTS OF ATMOSPHERIC VARIABILITY ON
ENERGY UTILIZATION AND CONSERVATION

Summary of Research Conducted Between
1 July 1975 and 31 March 1976

by

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ABSTRACT

A summary of research activities between 1 July 1975 and 31 March 1976 is given. Part 4 of "Atmospheric Transport Processes", dealing with "Radioactive Tracers", has been completed during this contract period. The study of atmospheric variability revealed that the 22- to 26-day vacillation in the potential and kinetic energy modes of the Northern Hemisphere is related to the behavior of the planetary long-waves, and that the midwinter dip in zonal available potential energy is reflected in the development of blocking highs. Attempts to classify weather patterns over eastern and central United States have proceeded satisfactorily to the point where testing of our method for longer time periods appears desirable. A "physical-adaptive" model of energy demand and its response to changes in weather regimes is under development. This model includes parameters pertaining to engineering factors of building construction, to weather-related factors, and to socio-economic factors. Preliminary testing of this model yielded very encouraging results. Expansion of model applications to different types of structures and larger regions is presently underway. A CRT-display model for energy demand within the conterminous United States also has passed preliminary tests. A major effort was expended to obtain disaggregated data on energy use from utility companies within the United States. A report of these efforts is presented.

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PREFACE

This report describes the first-year efforts in our study of "The Effects of Atmospheric Variability on Energy Utilization and Conservation". The original proposal, submitted in August 1975, foresaw a five-year involvement by an interdisciplinary research team, combining expertise from the fields of atmospheric science, engineering, computer science and economics.

Since an unforeseen delay of approximately three months in our original contract negotiations caused a slight shift in our time schedule, and since the date of submission of this report falls approximately three months short of the expiration date of our first-year grant, many of the studies which we undertook have to be reported as "in progress" with the results being of only a tentative nature. A Final Report at the end of the first-year grant period (31 July 1976) will contain a more detailed summary of research results achieved by that date.

We have made considerable progress in the study of atmospheric variability. Our investigations into the consequences of the 22- to 26-day vacillation in the atmospheric energy budget and of the midwinter dip in zonal available potential energy, in terms of their impact upon the occurrence of those weather regimes that produce anomalous meteorological conditions, are revealing relationships that we believe to be of significance. As discussed herein, both phenomena appear to have considerable effect upon midlatitude weather patterns.

Development of a physical-adaptive model to describe energy consumption for space conditioning in residential and commercial buildings is proceeding satisfactorily. This model contains as input engineering factors regarding the structural design of buildings, weather factors, and socio-economic factors. In its final stage -- not yet achieved -- the model will be capable of answering to changes in input parameters specified by decision makers.

The development of a CRT display model for the weather and demographic dependence of the energy demand on a national basis has progressed to the point where refinements from the physical-adaptive model will have to be incorporated.

A major effort has been devoted to negotiations with utility companies on a nation-wide basis, to gain insight into the availability of detailed and disaggregated energy-use data. In general, we found most utilities receptive to our ideas and wishes. We are looking forward to receiving and processing a vast amount of data. These data will be accumulated in a data bank which, we hope, will be of outstanding quality and will have wide applicability in our studies. However, recipients of this report are cautioned that we cannot divulge specific information on our inventory of data collected on individual energy consumers;

and further, that we cannot make data collected on individual energy consumers available to "third parties" unless the contributing utility company and the utility customer should have so authorized in advance and in writing.

Elmar R. Reiter
Professor of Atmospheric Science
Principal Investigator

I. Scope of Work According to Research Proposal

Our proposal of August 1975 listed the following research objectives:

A. Final editing for reviewer's and editor's comments, and printing of Part 4 of the Critical and Creative Review on "Atmospheric Transport Processes - Radioactive Tracers" will be concluded during the anticipated contract period.

B. The ongoing studies of atmospheric variability and energy requirements will be concerned with the following three separate but related tasks:

1. Task 1. Atmospheric Variability

a. Determination of relationships between the major atmospheric circulation features and regional weather characteristics of the United States.

b. Identification of those weather regimes, and of those atmospheric parameters within these regimes, which affect energy demand and consumption.

c. Establishing the variability of, and significant simultaneous interregional differences between, these weather regimes.

2. Task 2. Development of models for assessing the sensitivity of energy demand and consumption to weather regimes, and the economic consequences.

3. Task 3. Determining the effects of characteristic weather regimes upon the potential for, and cost effectiveness of, solar and wind energy utilization.

The research tasks listed under B. above were envisioned as a five-year project. A more detailed summary from the August 1975 proposal of those efforts which we expected to accomplish during the first year is reproduced here as Table 1. It will be recalled, however, that the somewhat complicated contractual negotiations were not completed until autumn 1975; and that as a result Task III was eliminated from our first-year effort, and the start of our major work on the complex problems inherent in Task II was necessarily delayed by almost three months.

The principal investigator has devoted approximately 16.67% of his time (about 2.0 months) to this project since the beginning of the present contract period on 1 August 1975. However, by virtue of an increase in the CSU contribution of one-half month, he was able to free the funds equivalent to these efforts in order that an additional Co-Investigator, Dr. G.R. Johnson, Associate Professor of Mechanical Engineering, could commence work on the project some 9 months earlier than had been anticipated. The principal investigator expects to devote an additional 1.5 months (12.5% of his time) to this project during the remainder of the current term.

TABLE 1. OUTLINE OF A 5-YEAR PROGRAM TO INVESTIGATE THE EFFECTS OF ATMOSPHERIC VARIABILITY ON ENERGY UTILIZATION AND CONSERVATION

YEAR	ATMOSPHERIC VARIABILITY	WEATHER EFFECTS ON ENERGY DEMAND	SOLAR & WIND ENERGY POTENTIAL
1	<p>I. Investigate relationships between major atmospheric circulation features and quasi-periodic fluctuations in the hemispherically averaged energy parameters as well as other non-periodic recurring phenomena (e.g., the mid-winter dip in zonal available potential energy). Studies will include the interrelationships between positions, amplitudes, trends and inter-annual fluctuations of these parameters.</p> <p>Ia. Prepare a catalog of northern hemispheric planetary wave positions, amplitudes & major flow features for the years 1960-1975, and from this develop a climatology of variations associated with the several favored positions of these major waves.</p> <p>Ib. Commence defining the characteristic North American synoptic weather patterns, & their frequencies & variations that are associated with the predominant planetary wave features determined in Ia, above.</p>	<p>II. Commence collection on data needed to analyze those demands for energy which are weather sensitive, with emphasis on electricity, natural gas and meteorological data.</p> <p>IIa. Initiate pilot studies to establish seasonally-typical, daily, natural gas & electricity demand per capita for space conditioning in a separate, major, regionally-representative, urban center of each of the 9 U.S. census regions, explanatory variables to include weather (temperature initially, & then wind speed, insolation/cloudiness & humidity), real prices and real income.</p> <p>IIb. Initiate more detailed pilot studies for Colorado cities of over 50,000, to include differentiation within and between cities as to high or low income and newer or older neighborhoods.</p> <p>IIc. "Map" the U.S. in terms of population density (by county & metropolitan area) for weighting according to varying secular weather anomalies at different time scales and CRT displays.</p> <p>IIId. Provisionally "calibrate" the map in IIc, above, with the regional space-conditioning energy requirements determined from IIa, above.</p>	<p>III. Acquire satellite data needed to determine % of possible sunshine by regions.</p> <p>IIIa. Commence preparation of regional sunshine climatologies.</p> <p>IIIb. Obtain detailed topographic maps and available climatological wind statistics for the U.S., with emphasis on areas and seasons having prominent terrain features and in which the prevailing flow does not tend to be weak and variable.</p> <p>IIIc. Commence analyses to deduce regions and seasons with a high probability of localized micro- and mesoscale wind accelerations sufficient for significant exploitation of wind-generated energy.</p>

II. Work Performed During the Present Contract Period

A. Critical and Creative Review "Atmospheric Transport Processes, Part 4: Radioactive Tracers"

1. The first draft of the manuscript, 729 typewritten pages including figures and a list of references, was submitted to ERDA on 15 November 1975. It is now being reviewed by a panel of experts under the direction of Dr. C. Telegadas. A table of contents for the manuscript is shown in Table 2.

Revisions of the manuscript recommended by reviewers and editors, and the subsequent proofreading and indexing work, will have to be accomplished during the remainder of the present contract period and during the next one-year period covered by our new proposal.

2. In line with our work on radioactive trace substances in the atmosphere, the principal investigator has maintained an active interest in data sources for such substances, their analysis, and the interpretation of analysis results in the light of atmospheric transport processes.

A review paper on "Stratospheric-Tropospheric Exchange Processes" was published by the principal investigator in August 1975 (Reiter, 1975a). After further consideration of evidence from atmospheric motion and radioactivity data, the stratospheric mass budget estimates listed in that publication had to be adjusted slightly (Reiter, 1975b; 1976a; Singh et al., 1975). The results can be summarized as follows:

a. Seasonal adjustments in the height of the mean tropopause level

In spite of some ambiguities in the definition, and therefore in the exact location, of the tropopause level, it is evident from statistical studies that this level in each hemisphere undergoes seasonal fluctuations, becoming lower during fall and higher during spring. Staley (1962) pointed out that this seasonal variation contributes toward a net flux of air between stratosphere and troposphere, upward or downward depending on the season. The lowering and rising of the tropopause should not be envisioned as a continuous process, however. It comes about by an imbalance between the vertical mass fluxes produced by the mean Hadley circulation in low latitudes, and by eddy-transport processes mainly in the jet-stream region of middle latitudes. There also is a compensatory horizontal mass flux within the stratosphere, directed from the summer to the winter hemisphere.

Reiter (1975a) provides an estimate of changes in the median tropopause pressure over North America between January 1963 and July 1963. Since the total mass of stratospheric air above the winter tropopause is approximately 4260×10^{17} g, the seasonal variation of tropopause heights over North America -- when applied to the whole Northern Hemisphere -- amounts to approximately 10% of the mass equivalent to one hemispheric stratosphere.

Table 2. Table of Contents for the Critical and Creative Review

"Atmospheric Transport Processes, Part 4: Radioactive Tracers".

1. INTRODUCTION

- Definition of Quantities Used in Tracer Work
- Conservation of Mass
- Atmospheric Transport of Radioactive Debris
- Decay of Radioactive Material
- Scales of Motion and Radioactive Tracers
- Chemical Sources and Sinks

2. GROUND-LEVEL NATURAL RADIOACTIVITY AND TROPOSPHERIC CIRCULATION

- Radon
- Daughter Products of Emanation from Soil
- Biological Impact

3. COSMOGENETIC RADIONUCLIDES AND ATMOSPHERIC STRUCTURE

- General Background
- Cosmogenic Radionuclides as Tracers of Atmospheric Motion
- Radiocarbon, ^{14}C
- Biological Impact
- Tritium, ^3H or T
- Biological Impact
- Beryllium and Phosphorus
- Sulphur, Chlorine, Sodium, Argon and Others

4. ANTHROPOGENIC RADIONUCLIDES IN THE ATMOSPHERE

- Introduction
- Fission Products and Neutron Activation Products
- Argon-41
- Manganese-54
- Iron-55
- Cobalt-60
- Zinc-65
- Krypton-85
- Strontium-89
- Strontium-90
- Strontium-90 in the Soil and in the Food Chain
- Biological Impact of ^{90}Sr
- Yttrium-91
- Zirconium-95

Table 2. Continued.

- Molybdenum-99
- Rhodium-102
- Ruthenium-103
- Cadmium-109
- Antimony-125
- Iodine-131
- Tellurium-132
- Xenon-133
- Cesium-137
- Cesium-137 in the Food Chain
- Biological Impact of ^{137}Cs
- Barium-140
- Cerium-144
- Neodymium-147
- Tungsten-185
- Iridium-192
- Plutonium
- Biological Impact of Plutonium
- Uranium and Other Transuranic Elements

5. MODELLING OF TRANSPORT PROCESSES

- Close-In Deposition
- Modelling of Deposition on the Ground
- Modelling of Deposition by Rainout and Washout Processes
- Meso- and Synoptic-Scale Transport Processes
- Global Transport Models
- One-Dimensional Models
- Two-Dimensional Models
- Three-Dimensional Models
- Stratospheric-Tropospheric Transport Processes

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APPENDIX B - NUCLEAR EXPLOSIONS (KNOWN AS WELL AS PRESUMED) SINCE 1945

APPENDIX C - NUCLEAR POWER REACTORS IN THE UNITED STATES, MARCH 31, 1974

b. Transport by the mean meridional circulation across the tropopause

The upward fluxes from the troposphere into the stratosphere and consequently, for reasons of continuity, the downward fluxes into the troposphere accomplished by the Hadley circulation, can be obtained from Louis (in Reiter et al., 1975) as follows:

<u>Season</u>	<u>Mass Flow</u>	<u>Total Flux in 3 Months</u>	<u>Contribution to Northern Hemisphere</u>
Dec. - Feb.	10×10^{12} g/sec	788×10^{17} g	622×10^{17} g
March - May	4×10^{12} g/sec	311×10^{17} g	272×10^{17} g
June - August	7.5×10^{12} g/sec	583×10^{17} g	389×10^{17} g
Sept. - Nov.	7×10^{12} g/sec	544×10^{17} g	560×10^{17} g
Annual Total Flux to Northern Hemisphere			1843×10^{17} g

This flux corresponds to 43% of the mass equivalent to one hemispheric stratosphere.

c. Transport by the mean meridional circulation into the other hemisphere

From Louis (in Reiter et al., 1975) we can estimate the interhemispheric exchange of mass within the stratosphere as a function of season. We arrive at the following numbers

<u>Season</u>	<u>Mass Flow</u>	<u>Total Flux in 3 Months into Northern Hemisphere</u>
Dec. - Feb.	6.5×10^{12} g/sec	505×10^{17} g
March - May	2.0×10^{12} g/sec	156×10^{17} g
June - August	-6.5×10^{12} g/sec	-505×10^{17} g
Sept. - Nov.	-2.0×10^{12} g/sec	-156×10^{17} g

Thus, the mass flux between the stratospheres of the two hemispheres replaces 661×10^{17} g of mass from one hemisphere within one year. This is equivalent to 16% of the mass of one hemispheric stratosphere.

d. Transport by large-scale eddy exchange, mainly in the midlatitude jet-stream region

Intrusion of stratospheric air into the troposphere by synoptic scale eddies occurs mainly within the jet-stream front during the tropopause-folding process, i.e., during periods of active cyclogenesis. A number of case studies illustrating this mass-transfer process are available in the literature (e.g., Danielsen, 1960, 1961, 1964, 1968; Danielsen et al., 1970; Mahlman, 1964a,b, 1965a,b, 1966; Reiter, 1963a,b, 1964, 1968; Reiter et al., 1969; Reiter and Mahlman, 1964, 1965a,b,c,d; Staley, 1960, 1962). The return flow of tropospheric air into the stratosphere occurs at levels above the jet-stream fronts, and at potential temperatures characteristic of the core of the jet stream itself (Reiter et al., 1969).

Only very few studies are available which give quantitative estimates of this eddy flux across the tropopause level (Danielsen, 1960; Reiter and Mahlman, 1965a,b,c,d; Reiter et al., 1969). Our best guesses indicate that 22 to 23 cyclogenetic events per year in the polar-front jet-stream region of the North American longitude sector, with an average mass-transport contribution of about 6×10^{17} g each, provide an annual mass flux out of the stratosphere of approximately 135×10^{17} g in the sector 70° to 180° W, and of approximately 405×10^{17} g around the hemisphere. This number includes only the latitude belt 40° to 60° N. If one were to allow for the effects of the subtropical and arctic-front jet streams of winter, and of the tropical easterly jet stream of summer, one might estimate the total eddy mass flux from the stratosphere to the troposphere to be 800×10^{17} g. For reasons of mass continuity, an equal amount of tropospheric air will have to enter the stratosphere in eddy-exchange processes. This flux corresponds to roughly 20 percent of the mass equivalent to one hemispheric stratosphere.

e. Meso- and small-scale eddy-transport processes

Thunderstorms penetrating the tropopause level, as well as small-scale turbulence continuously present in the atmosphere, will contribute in a minor way towards the mass exchange between troposphere and stratosphere. Since these processes are either very slow acting (due to a relatively small vertical eddy-exchange coefficient normally effective at tropopause level), or present with significant magnitude only very sporadically (e.g., clear-air turbulence at tropopause level, or thunderstorms penetrating the tropopause), the total contribution towards the mass flux from the stratosphere to the troposphere from meso- and small-scale eddy processes most likely lies near 1% per year of the mass equivalent to one hemispheric stratosphere.

From the foregoing discussion, the annual mass budget of the stratosphere of the Northern Hemisphere appears as follows:

Seasonal adjustments of tropopause level	10%
Mean meridional circulation	43%
Stratospheric exchange within hemispheres	16%
Large-scale eddies	20%
Small-scale eddies	<u>negligible</u>
Total	89%

These transport processes would act on an atmospheric tracer that has been introduced into the Northern Hemisphere stratosphere, and which disperses from there into the Northern Hemisphere troposphere and into the Southern Hemisphere stratosphere. A typical tracer of this sort is ^{90}Sr injected in large quantities into the Northern Hemisphere lower and middle stratosphere during the US and USSR atmospheric tests before the test-ban treaty went into effect (1963).

Figure 1 shows the Northern and Southern Hemisphere burdens of ^{90}Sr , as well as the total stratospheric burden, as functions of time. The e-folding residence time of ^{90}Sr in the Northern Hemisphere appears to be 14 months (before the effects of French and Chinese tests are felt). If we assume concentrations of radioactive debris, N , to diminish according to

$$\frac{\Delta N}{\Delta t} = -\frac{1}{T} N,$$

where T is the e-folding residence time, N is taken to be 100%, ΔN is 89% and Δt is one year, we arrive at $T = 1.12$ years or 13.4 months.

According to Fig. 1 the e-folding residence time in the Southern Hemisphere stratosphere appears to be of the order of 21 months. Assuming that the mean meridional and eddy-exchange processes between stratosphere and troposphere are as effective in the Southern as in the Northern Hemisphere, we have to blame the discrepancy in e-folding residence times between the two hemispheres on the following fact: Interhemispheric exchange processes within the stratosphere tend to reduce the radioactive burden of the Northern Hemisphere where the original source was located. At the same time this transport process increases the Southern Hemisphere burden. In approximation we can write, therefore,

$$\frac{\Delta N}{\Delta t} = -\frac{1}{T} N + S,$$

where S ($= 16\%$) is the "source" of stratospheric debris for the Southern Hemisphere in the form of transport from the Northern Hemisphere. This 16% contribution towards the mass budget of the stratosphere now appears as a "source" of debris and has to be removed from the "sink" effects of the mass budget. Therefore, for the Southern Hemisphere, we will have

Figure 1. Stratospheric inventory of ^{90}Sr [after Krey et al., 1974].

to assume $\Delta N = 89 - 16 = 73\%$. For $N = 100\%$ and $\Delta t = 1$ year we thus arrive at $T = 1.75$ years or 21 months, exactly what Fig. 1 indicates.

e-folding residence times for other radioactive tracers introduced into the lower and middle stratosphere under similar conditions yield similar residence times (for references see Reiter, 1976b).

The above discussion encourages us to the following statements:

(1) The estimate of an annual exchange of 16% of the mass equivalent to one hemispheric stratosphere between the Northern and Southern Hemisphere stratospheres appears to be accurate when applied to tracers in the lower and middle stratosphere.

(2) The total effects of other transport processes listed above have been estimated with similar reliability.

Further activities during the present project period in the field of atmospheric radioactive trace constituents included participation by the principal investigator in the 16th General Assembly of the IUGG, Grenoble, France (25 August - 6 September 1975), with partial support from ERDA. (A travel report was submitted to ERDA on 10 September 1975). An invited paper on "The Transport of Tracers by Global Circulation Systems of the Atmosphere" was presented by the principal investigator in the session on "Isotopes and Impurities in Snow and Ice". The text of this paper will appear in a forthcoming proceedings volume. Another paper on "Significant Modulations of the Atmospheric Energy Cycle during Winter" was presented in the session on "GARP First Objective: Weather Predictability".

At this IUGG meeting the principal investigator also conducted negotiations for data on radioactive trace contaminants and on atmospheric circulation patterns with Dr. Oeschger of the Eidgenoessische Technische Hochschule in Zurich, Switzerland, with Dr. Reinhold Reiter (no relation) of the Institut fuer Atmosphaerische Umweltforschung in Garmisch-Partenkirchen, and with Dr. K. Labitzke of the Free University of West Berlin. These negotiations are presently being followed up. Dr. R. Reiter recently indicated in a letter that more data on cosmogenetic radionuclides had been analyzed at his laboratory. Their interpretation with respect to stratospheric residence time, however, encountered some difficulties. These we hope to resolve during a forthcoming visit of the principal investigator to Germany.

B. Studies on Atmospheric Variability and Energy Requirements

Table 1 lists the tasks which were to have been carried out during the first year of our proposed five-year effort. The following represents a brief overview of our research results to date (end of March, 1976). Most of these research efforts are still in progress. Results will be presented in a comprehensive and detailed report at the termination of the present grant period.

1. Task I. Atmospheric Variability

a. Major atmospheric circulation features and quasi-periodic fluctuations in hemispherically averaged parameters

This phase of our investigation also received partial support under an NSF grant. Under that grant the variability aspects of the atmospheric general circulation are being utilized to arrive at a quantitative understanding of atmospheric feedback mechanisms, which is a prerequisite to climate modelling. The ERDA-sponsored aspects of our research depart from the same data base. Here, however, the thrust of our inquiry is in the direction of hemispheric and regional weather-pattern recognition, a statistical presentation of such patterns to allow an assessment of likely and extreme demands on energy, and an exploitation of medium- to long-range forecasting capabilities.

We also wish to acknowledge the generous support which we received from the National Center for Atmospheric Research (NCAR) in the form of computer time. NCAR is supported by the National Science Foundation.

With what we had in hand -- mainly 15 years of National Meteorological Center (NMC) upper-air data decks -- we were quite successful in establishing significant modulations of atmospheric general circulation parameters, especially during the "cold half" of the year. We also have established some preliminary indications of possible causes for some of these modulations. The following is a short resumé of our findings. More detailed descriptions can be found in reports by McGuirk et al., 1975; McGuirk and Reiter, 1976; and Barbieri, 1976.

The eddy (E) and mean zonal (Z) modes of available potential (A) and kinetic energy (K) were computed from the available NMC data on a daily basis covering the region from 20°N to the pole and the layer from 1000 mb to 100 mb. Especially in AZ these daily data reveal significant modulations within a frequency band corresponding to a period of 22 to 26 days. An example of daily energy-mode data is given in Fig. 2. Fig. 3 reveals the significance of the spectral peak at 22 to 26 days.

Application of a narrow band-pass filter centered at a period of 22 days (an example of the results is given in Fig. 4) leads us to the following conclusions:

(1) There is considerable interannual variability in the phase and mean amplitude of this 24-day vacillation from winter season to winter season.

(2) The vacillation virtually disappears during summer.

(3) Once the vacillation is established during fall it maintains itself with remarkable constancy throughout the cold season (i.e., October through March).

Figure 2. Daily atmospheric energy by mode for the layer 1000 to 100 mb and northward of 20°N for 1969.

Figure 3. Arithmetically averaged power spectral density of energy modes for October through April seasons from 1968 to 1971. Data are normalized by period to give a measure of the variance per unit bandwidth.

Figure 4. Bandpass filtered daily energy by mode for 1 November 1969 through 15 April 1971. (Units in 10^5 joules/m².)

We suspected that this vacillation -- given its relatively long periodicity and large amplitude -- would be reflected mainly in the behavior of the phases and amplitudes of planetary long waves. To check this assumption, the contribution of each planetary wave mode from wave numbers 1 to 8 towards the (band-pass filtered) 24-day oscillation was computed. Typical examples are shown in Figs. 5, 6 and 7. The following conclusions could be reached:

(4) It is mainly wave numbers 1, 2 and 3 which contribute -- either in phase or out of phase -- to the observed 24-day cycle in the atmospheric energy parameters.

(5) In different winter seasons these contributions from the planetary long-wave modes vary in terms of their amplitude and phase relationships.

Since there seems to be a significant response of individual planetary wave modes to the 24-day vacillation, we anticipated that this response would also reveal itself in the appearance of planetary wave patterns at the 500-mb surface. Figs. 8 and 9 show the contribution of wave numbers 2 and 3, respectively, to the 500-mb contour pattern on the two successive dates of minima (left sides of diagrams) and maxima (right sides) in hemispheric AZ values. The variability with time and space of these wave patterns suggests the following:

(6) A significant "pumping" of the amplitudes of these waves in their hemispheric distribution is experienced with the 24-day cycle of AZ.

(7) From the orientation of the trough and ridge axes of these harmonic wave patterns we can estimate qualitatively their contribution towards momentum and/or heat fluxes in line with, or opposed to, the mean gradient of these quantities. The tilt of these axes persists during the 24-day vacillation.

The "pumping" of certain dominant planetary wave modes, as exhibited in Figs. 8 and 9, should have a significant impact on regional weather patterns, perhaps through such phenomena as the frequency, intensity and pathways of cyclonic and anticyclonic disturbances. We have not yet had a chance to explore this hypothesis. It would seem to us, however, that it holds great potential for regional extended-range weather forecasting during the cold season, perhaps up to two weeks ahead.

From our NMC data base we were able to identify time periods within the cold season during which the values of AZ suffer a marked decrease from their normal seasonal distribution. An example is shown in Fig. 10. The following conclusions were reached from our investigation:

(8) The "midwinter dip" of AZ occurs at different time periods in different winters, and is of varying length (on the average more than one month in duration) and intensity. The 15-year mean AZ curve (Fig. 10) shows a slight depression from a smooth seasonal behavior during

Figure 5. Bandpass filtered contributions to total AE by planetary wave numbers 1 through 4 (solid lines) for the 1968-69 cold season. Bandpass filtered total AE is given by the dashed line for reference and the stippled area gives the positive in-phase contribution of each wave number to the total AE.

Figure 6. Same as Fig. 5, except for the 1969-70 cold season.

Figure 7. Same as Fig. 5, except for the 1970-71 cold season.

12-30-70

1-11-71

1-17-71

1-29-71

Figure 8. Fourier-analyzed 500 mb synoptic patterns for two successive AE minima (left) and maxima (right) periods for wave number 2. The amplitude variations (in meters) are typical.

12-30-70

1-7-71

1-15-71

2-6-71

Figure 9. Same as Fig. 8, except for wave number 3.

Figure 10. Daily values of AZ (arbitrary units) inferred from the 500 mb temperature variance pattern (denoted by x). Average AZ for fifteen years (denoted by solid line).

January and February, suggesting that such "dips" occur relatively often during that part of the year.

(9) The reduction of AZ during the dip period is not compensated by equivalent rises in AE, KZ or KE. Our investigation indicates that part of the tropospheric energy is transported into the stratosphere during such dip events. While a small part of the tropospheric AZ is also converted into "unavailable" potential energy by an adiabatic redistribution of air masses and subsequent irreversible mixing, this process again does not fully account for the observed decrease in AZ since the total potential and internal energy of the hemisphere (that is, $c_p T$) decreases significantly during such periods.

(10) By a "superposed epoch" treatment of 500-mb charts for the observed cases of a midwinter dip in AZ, we established that blocking anticyclones tend to form in the region of the Bering Straits during the time when AZ reaches a maximum prior to the dip. Blocking activity reaches a maximum in the North Pacific (with indications of the formation of a second block in the North Atlantic west of the United Kingdom) when AZ has reached minimum values. The planetary flow returns to a nearly normal configuration when AZ values recover to their pre-dip values (Figs. 11, 12 and 13).

Again, the tie between the behavior of AZ on time scales in excess of one month and the synoptic weather patterns around the hemisphere, specifically the appearance of blocking high-pressure ridges, suggests the applicability of our findings to long-range weather prediction. We are presently attempting to define parameters that would help us specify the occasions on which AZ plunges into a dip configuration, and to find out if this dip interacts with the 24-day vacillation.

(11) It is perhaps trivial to mention that the stratospheric vortex responds to the midwinter dip in AZ by at least a minor, if not a major, warming.

(12) Major adjustment occurs in the planetary wave number 2 of the tropospheric flow in conjunction with a midwinter dip in AZ. If at the beginning of the dip the European ridge associated with this wave number is found east of 32°E longitude, the phase angle of this wave tends to retrograde towards the west during the period in which the hemispheric AZ values decline. If the ridge is found initially to the west of this longitude the phase angle tends to progress. This indicates a preferred location in which the Pacific and Atlantic blocks attain their maximum intensity, perhaps governed by the location of the major orographic barriers and of the distribution of continents and oceans in the Northern Hemisphere. Again, the long-range forecasting implications of this phase behavior should be explored. Effects on the migration of precipitation-bearing disturbances over the major agricultural regions of the Northern Hemisphere during the presence and absence of such blocking anticyclones might have significant implications on the availability of winter moisture to the winter wheat crops of the U.S. and the U.S.S.R. Such implications yet remain to be explored.

CONTOUR FROM 495DM TO 600DM INTERVAL 15DM

Figure 11. Mean height contours (in decameters) at 500 mb for twelve midwinter dips in AZ for day of maximum AZ preceeding the dip.

CONTOUR FROM 4950M TO 6000M INTERVAL 150M

Figure 12. Same as Fig. 11, except for day of minimum AZ.

CONTOUR FROM 4950M TO 6000M INTERVAL 150M

Figure 13. Same as Fig. 11, except for day of maximum AZ following the dip.

In the course of our research for atmospheric parameters with significant interannual variability we investigated the behavior of the polar front as specified by the position of the -30°C isotherm on the 500-mb surface. A recent paper by Baese and Arpe (1974) indicates this temperature to be an adequate choice. Fig. 14 shows the mean position of the polar front thus specified for the month of January during 15 years between 1956 and 1972. (1961 and 1962 were missing.) Our conclusions from this phase of the investigation were:

(13) The mean January position of the polar front reveals the largest interannual variability near 160°W , i.e., over the central and western North Pacific. Such a variability could have a major impact on the flux of sensible and latent heat from the ocean. The latent-heat flux variations also should impact on the amount of moisture transported away from the North Pacific and made available in precipitation. No estimates of such effects have been made as yet.

(14) Another region of large variability of the polar front exists near 60°E , in the general longitude of Kazakhstan. We have not yet had time to verify whether or not this frontal behavior is, at least in part, to blame for the agricultural problems encountered in that region. The agricultural regions of the U.S. show a smaller, but still significant, interannual variability of the mean polar-front position during January.

The agricultural implications of this variability have not yet been explored, nor has the possibility of correlations between the polar-front position in the agriculturally productive regions of the Northern Hemisphere and the phase and amplitude of hemispheric waves responding to the 24-day cycle in AZ or the midwinter dip in AZ.

The possible response of air-sea interaction to vacillations and interannual variabilities in the atmosphere suggested in (12) and (13) above, prompted us to investigate more closely the heat transfer between ocean and atmosphere. This study is still in progress. Preliminary results are as follows:

(15) There are some winter seasons in which the sensible-heat flux from the ocean, integrated over all North Pacific and Atlantic areas north of 20°N , shows a 22- to 26-day cycle. In other winter seasons this cycle is obscured.

(16) In some years the fluxes from North Atlantic and North Pacific are positively correlated; in other years the correlation becomes insignificant.

(17) In the northwestern parts of the oceans, where cold, dry continental air masses are advected out over warm water, and near 160°W [c.f. (13), above], the amplitudes of this cycle are strongest and the cycle is best defined.

Figure 14. Average latitudinal position of the -30°C isotherm at 500 mb during January as a function of longitude, for fifteen years, 1956-1972 with 1961 and 1962 missing.

(18) Significant fluctuations of the area-averaged sensible-heat transfer from the ocean exist also on time scales of approximately one week, probably due to transient-wave phenomena in the atmosphere.

We have not yet been able to carry out a planned investigation of any possible correspondence between the observed cycles in AZ and the cycles in the sensible-heat transfer from the ocean, the latter perhaps expressed in terms of the generation of destruction of available potential energy. Nor are our estimates of the transfer of latent heat from the ocean to the atmosphere completed as yet. We fully expect, however, to find significant fluctuations with time of the latent-heat transfer as well.

b. Tasks I.a and I.b: Estimating regional weather patterns from large-scale flow

Variations in the planetary scale wave patterns which are associated with the 22- to 26-day vacillations in hemispheric energy parameters (see Figs. 8 and 9) should also be manifested in the behavior of regional weather patterns. However, the location and significance of such manifestations, and the extent to which they may explain a change from one predominant regional weather regime to another, are not yet well defined. On the other hand, Fig. 15 (after Petterssen, 1956), which shows the rate of alternation between anticyclones and cyclones during winter, suggests that the effects of changes in planetary scale features would most likely be felt over the conterminous United States.

To test this hypothesis, we are attempting to quantify various predominant U.S. weather patterns and to relate them to global-scale features. An eigenvector analysis immediately suggests itself as an approach in this investigation. Several researchers have noted the facility which eigenvectors offer for describing weather patterns with a minimum of numerical values (e.g., Essenwanger, 1975; Craddock and Flood, 1969; Lorenz, 1956; Holmstrom, 1963; Stidd, 1967). Eigenvectors and their associated eigenvalues are used to determine patterns which describe most of the variance in the field of a scalar quantity along with the relative contribution of each pattern (eigenvector). The pattern of the areal distribution of a variable, such as presented on a synoptic weather map, can be expressed adequately as the sum of linear multiples of several eigenvectors. We use these linear multipliers, or coefficients, of the eigenvectors to describe each pattern.

Initially, we prepared an eigenvector analysis of the January 1969 850-mb temperatures along a single latitude, 40°N, to determine whether this simple measure might suffice for specifying basic variations in the lower-tropospheric temperature pattern across the Eastern United States. This approach did not turn out to be successful, however, in helping us to "classify" temperature patterns that govern the energy demand for space conditioning over the Eastern United States. Following an examination of other parameters and computational schemes for this same month, we concluded that eigenvector analyses of the 850-mb temperature field for a 5°-by-5° latitude-longitude grid would satisfactorily represent low-level regional thermal effects and adequately depict synoptic

Figure 15. Rate of alternation (percent) between cyclones and anticyclones in winter.

scale variations in winter-season temperature patterns over North America. In this scheme, the first three eigenvectors described 96% of the variance in the field over the entire month, and each day's pattern is expressed simply by the coefficients of these three eigenvectors. The eigenvectors used to describe this variance are presented in Fig. 16.

The core of the problem discussed here involves relating these coefficients, determined on a regional scale, to the large-scale planetary wave patterns through some regression scheme. That is, some means of quantifying the planetary wave pattern must be developed and related to the regional parameters. We are presently exploring harmonic analyses of the 500-mb height field at 40°N to determine descriptors for these planetary scale values. Specifically, we used the mean height value (the amplitude of wave number 0) and the phases and amplitudes of wave numbers 1 through 6.

Concurrently, we are performing a simple multiple-regression analysis on the two sets of data, with the goal of expressing each of the 850-mb-temperature eigenvector coefficients as a linearized function of the planetary wave parameters. Some success has been achieved, especially in relating the eigenvector coefficients to the phase of wave number 4. A simple linear relationship between these data may not provide the best depiction. Hence, we are continuing our investigation in an attempt to develop a more realistic means of handling the data. As we examine other months, the developed regression coefficients may change. It remains to be seen whether such changes in coefficient values will adversely affect the limits within which we can classify temperature patterns that determine the energy demand within the contiguous United States.

2. Task II: Development of Models for Assessing the Sensitivity of Energy Demand and Conservation to Weather Regimes, and the Economic Consequences.

The first-year objectives of this task are as follows:

- "a. To determine improved relationships between weather severity and the rate of electricity and natural gas consumption for space conditioning.
- b. To develop a CRT display of weather-induced variations in energy requirements which will emphasize the geographical dependence (because of population density and climate) of demand fluctuations.
- c. To identify weather-sensitive energy-intensive activities, to ascertain the availability for those activities of production and energy-usage data corresponding to the observed scale of anomalous-weather variations, and to design procedures for defining and quantifying weather effects upon those activities."

In view of the accelerated work schedule alluded to previously, earlier plans as to the manner of accomplishing these objectives and the

attendant data-acquisition efforts were modified. We eliminated a number of exploratory statistical studies which had been contemplated so as to first demonstrate thoroughly that energy-consumption relationships which incorporate explicit consideration of variations in temperature, wind, cloudiness and humidity were not only feasible but superior for most purposes to those based solely upon temperature change. Rather, we proceeded directly to the adoption of a physical modelling approach to the determination of weather effects upon the energy required for space conditioning.

It is recognized, that regardless of its theoretical plausibility, this approach has not been attempted heretofore on a scale larger than that of a few selected individual test structures. Nevertheless, initial contacts with a number of utility companies confirmed significant impacts due to wind and cloudiness variations upon their weather-sensitive natural gas and electricity loads, and the availability in sufficient diversity and quantity of the disaggregated (individual customer) short-term (daily and hourly) consumption data needed to develop and test the required models. With this encouragement, we concluded that the potential advantages far outweighed the risks of our approach.

This decision was influenced in no small way by the limited future applicability of purely statistical relationships under circumstances wherein the cost and availability of different energy forms are changing rapidly, and hence, consumption patterns determined for the 1975-76 heating season might not provide a reliable prediction of gas and electricity demand for a 1976-77 winter with essentially the same weather conditions. The aggregate of individual customer decisions to add insulation, storm windows, shutters and weather stripping, to change thermostatic settings, to install more efficient space-conditioning equipment, to adhere to behavioral energy-conservation practices, etc., could so invalidate statistical formulae that the results of such an approach on our part might not serve the best interests of either ERDA or the cooperating utility companies. A further consideration was the fact, that for most utilities the weather-sensitive portion of their total gas and electricity sendout is not only greater than the residual but has been growing at a substantially faster rate than this residual. We will, however, compute a great number of energy-weather statistics for an extensive variety of users. These data will be required for comparisons to be made between physical model predictions of the space-conditioning energy which "should have been" consumed by different commercial and residential customers (assuming adherence to model assumptions as to thermostatic settings, construction specifications, characteristic behavioral patterns, incidental heat generated by lighting, appliances or ancilliary equipment, etc.) and that actually consumed in carrying out their normal day-to-day routines.

a. Tasks II.a and II.b: Quantifying weather effects on energy consumed in space conditioning.

The demand for space-conditioning energy may be considered synonymous with the demand for physical comfort inside the buildings where people live and work. As such, direct energy use is but one input to the physical processes which maintain desired ranges of temperature and humidity inside buildings, regardless of outside conditions. Other inputs are the design and materials embodied in each building, which passively condition the inside of a building, and the equipment used to actively condition the inside of the structure. If all other inputs are considered fixed, then for given outside weather conditions and given use or habit patterns, the energy required for space conditioning can be derived as a function of the comfort ranges to be maintained inside the building. It follows that for a given comfort range, physical structure, space-conditioning technology and use pattern, the energy demand for space conditioning can be determined as a function of weather variables.

This phase of the study focuses upon the last-named relationship, that is, energy demand for space conditioning as a function of weather. If all other variables could be considered fixed, then the relationship could be estimated directly using historical data. In fact, numerous load studies have been done by utilities throughout the U.S., and statistical models have been developed which explain over 90% of the variation in hourly system demand for electricity (e.g., FPC, 1970) and natural gas (e.g., AGA, 1969).

The accuracy of these load-study results depends upon the nonvariability of physical structures, use patterns and comfort levels. Indeed, within the framework of these studies, it is reasonable to assume that only the weather changes. 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 the explanatory 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 just beginning to stabilize after recent 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 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, 1974b).

As a consequence of such limitations, we have decided to base our model on physical features which can be derived from basic heat-transfer relationships. Such models have been used extensively by architects and engineers (e.g., Kusuda, 1972, 1974; Johnson et al., 1975), but with a few exceptions (e.g., Petersen, 1974) these studies have been concerned with structural design as opposed to retrofitting existing structures.

(1) Physical modelling of space conditioning energy requirements

The validity of models based upon physical features has been demonstrated for an individual structure in numerous studies (Fox, 1973; Jones and Hendrix, 1975; Kruger, 1974; Sepsy et al., 1975a,b,c; Peavy et al., 1975; Hill et al., 1975). These studies have shown that heat loads calculated from design procedures (e.g., ASHRAE, 1972) can be effectively used and do yield reasonable results, particularly the heat transmission losses or gains. Calculations of heat losses or gains due to infiltration have not been as satisfactory. However, this should not be judged as a shortcoming of the procedures. Detailed infiltration calculations are quite complex and, therefore, simplification procedures are usually introduced to reduce the amount of calculations required. These procedures yield conservative estimates. In the past, load calculations have been used to size the space-conditioning equipment; and since most systems are oversized by a factor of two, the accuracy of these calculations has not been questioned.

The study on the Twin Rivers development in East Windsor Township, New Jersey (Fox, 1973) is perhaps the most ambitious project to have used a physical model to calculate the energy requirements for space conditioning. The study was relatively successful. Many simplifications were used, such as air-change methods for infiltration calculations and heat loads based on degree-day data rather than hourly calculations using actual weather data.

(a) Physical model components

The physical model under development in this study is an extension of the models cited above. However, the end result is not the sizing of space-conditioning equipment, but rather the energy requirements for space conditioning. Obviously, a model cannot be developed for each building in a region to be studied. Nevertheless, buildings can be grouped into classifications and aggregated. Figure 17 presents an overall block diagram of the model and the data flow.

The physical model under development consists of the following:

1. A generalized computer program which has been proven accurate for predicting space-conditioning energy requirements.

Figure 17. Block diagram of Policy Maker-Model Interaction.

ii. A set of modules generated from the above program, each module representing a particular building classification. For example, modules that describe single-family residential dwellings, mobile homes, multi-family residential units, small commercial structures, larger commercial structures, industrial structures, etc.

iii. A classification of buildings that make up the population region to be studied. Classification includes not only building type but the number of such buildings. The population regions to be studied will consist of a large metropolis, a suburb and a rural city in each of the nine census regions in the United States.

iv. Suitable multipliers for use in describing occupant use or habit patterns. These include thermostatic settings and infiltration-rate adjustments.

v. Work underway during the past year has comprised: formation of the physical model; and its validation.

The model has been written and is operational, using a computer program developed by Johnson et al. (1975) to determine the impact of conservation policies on energy requirements. This program has been used to generate modules that simulate individual building types. Currently, modules exist for single-family detached residences, multi-family townhouses, mobile homes, and large commercial buildings. These modules are in various stages of validation. The ultimate objective of the current effort is to successfully model a small community. A community located in the western high plains was chosen, because of the availability of sufficiently detailed energy information on space conditioning and its simplicity. These results will be discussed in the following section.

(b) The computer program of a physical model

The approach followed in developing the physical model is described in this section. A generalized physical model based upon heat-transfer equations was written, following accepted standards (ASHRAE, 1972, Ch. 19-22) and recently recommended revisions thereto (ASHRAE, 1975).

This program differs from previous heat-transfer calculations, in that the built-in tables contain resistance factors for various materials. The user has to merely specify wall and ceiling materials, and the program calculates the appropriate resistances in order to arrive at an overall heat-transmission coefficient. Infiltration is handled using the Crack Method rather than the less well-defined air-change method. This can be accomplished because of the increased bookkeeping capability afforded by using the digital computer.

The program has been written so that it generates modules which can be used in a stand-alone mode. For example, the generalized program is not used each time for each set of building calculations, but rather generates a program for a specific type of building. In this way a more efficient program can be executed for the particular building type.

The input information for this program consists of the building description or a list of materials, and meteorological data (e.g., insolation, percent cloudiness, ambient temperature, ground temperature, and wind speed). The ambient temperatures are the primary driving function. The wind speed is used in the infiltration calculations, and the insolation and cloudiness are used in the solar heat-gain calculations.

Specialized programs are obtained from the generating program and placed in a library. Programs are available for simulating single-family detached homes, mobile homes, multi-family dwellings, such as townhouses and large commercial buildings. Validation efforts are in progress on these models and are discussed in the following section.

Once the modules have been defined it is necessary to specify a density function of characteristic buildings that make up a "characteristic mix" of the region to be modelled. For example, in small urban environments, a building census would be obtained listing the various numbers, sizes, and classifications of structural types. Modules representing these building classifications are then executed, using historical or synthetic weather information, to determine energy usage for space conditioning.

The model also includes information as to thermostatic settings, and multipliers for infiltration for known building-use and occupant-habit patterns. It is well known that energy usage in buildings can vary by a factor of two, depending upon the operational aspects of the buildings. This includes both the comfort level of the building (i.e., thermostatic setting) and the operational or habit pattern of the building occupants. The latter primarily influences infiltration (i.e., windows being left open in the winter while the building is being heated, or a large number of door openings as is to be expected of families with several little children or pets).

The calculations for the characteristic buildings can be modified by weighting factors. The weighting factor is dependent upon the distribution of building sizes about the characteristic building structural definition and the number of buildings in the class. Summing the overall totals provides a total energy budget for space conditioning for the region under investigation.

(c) Model validation

The physical model is in the process of being validated at the present time. The model has been used to calculate the past year's heating requirements for several single-family detached dwellings in the Fort Collins area. It has been found that the model predicts building heating requirements within 4-5% on a daily basis, and over extended periods of time is accurate to within approximately 2%.

The simulation model was applied to houses typical of those in the western high plains of Colorado and Wyoming. Four specific designs were

selected. These designs formed the basis for obtaining actual and simulated estimates of fuel consumption for heating and cooling.

The selection of the four designs was based on a review of building permits for selected months from the 1969-1973 period and for 1974. Interestingly, a minor trend towards smaller floor plans occurred between these two periods. The selection of typical houses was first made according to floor space and, subsequently, by the type of floor plan. The distribution of permits according to floor area is shown in Figures 18 and 19 for 1969-73 and for 1974, respectively, and summarized in Table 3.

After reviewing these data, house plans with square footages of 1,068 ("Monroe" representing the smaller range of homes), 1,520 and 1,623 ("Adams, B" and "Emerson", respectively, representing the medium range); and 2,078 ("Castle", representing the larger range) were selected. The smaller of these four is a ranch-style house with three bedrooms, two baths, and a partial basement. The medium-range selections represent two types: a tri-level with three bedrooms, two baths, and a finished basement that is counted as part of the floor area; and a bi-level with essentially the same features. The largest of the four house plans is for a two-story frame building with four bedrooms, two baths, and a full basement. Originally, a typical floor plan of over 2,400 square feet was to be chosen, but then it was found that few homes of this size are being built in the western high-plains area. Artists' renderings of each of these homes are shown in Figure 20.

A review of building permits in Denver was carried out as a check on the results obtained in Fort Collins. No significant differences in the distribution of living areas were observed.

Specific homes were selected within each of the four categories and a builder was contacted. Plans, specifications, materials lists, and lists of equipment suppliers were obtained. In turn, the suppliers of heating equipment were contacted concerning the specifications and performance characteristics of the heating plants for each of the homes.

Baseline heating requirements were simulated, using the computer program for detached single-family dwellings for each of the four houses and actual weather data. Results of the simulation are shown below.

Total energy consumed over twelve months, averaged using four identically constructed homes of each type.

	<u>% of Calculated Consumed</u>
Castle	98
Emerson	97
Adams, B	107
Monroe	102

Table 3. Distribution by floor area of building permits issued in Fort Collins, Colorado, from 1969-1973 and in 1974.

<u>Area of Floor Plan</u> <u>(square feet)</u>	<u>Number of Permits</u>	
	<u>1969-1973</u>	<u>1974</u>
800- 899	0	1
900- 999	3	1
1000-1099	28	11
1100-1199	35	5
1200-1299	24	9
1300-1399	14	3
1400-1499	19	11
1500-1599	34	32
1600-1699	60	25
1700-1799	40	22
1800-1899	38	6
1900-1999	25	6
2000-2099	29	13
2100-2199	28	7
2200-2299	5	0
2300-2399	1	0
2400-2499	6	1
2500-2599	0	1
2600-2699	1	0
2700-2799	0	1
3000-3099	0	1
4100-4199	0	1
TOTAL	390	157

Figure 18. Percentage Distribution of Housing Permits in Ft. Collins for selected months from 1969-1973.

Figure 19. Same as Figure 18, except for 1974.

Figure 20. Artist's Rendering of 4 Typical Homes Whose Baseline Heating Requirements were Simulated.

Artists Rendering

The Adams B

TOTAL FLOOR AREA
1520 ft²

Figure 20. Continued.

Artists Rendering

SECOND LEVEL FLOOR PLAN

*The Emerson*TOTAL FLOOR AREA1623 ft²

Approx. Room Dimensions

Figure 20. Continued.

CASTLE

TOTAL FLOOR AREA
2078 ft²

Colonial two-story with all the necessary size and luxury for a large or growing family • Four Bedrooms and Two Baths on the Second Floor • Large Entry With Open Stairway • Spacious Living Room • Formal Dining Room • U-Shape Kitchen With Eating Space • Family Room With Fireplace Located Next To Kitchen • Full Unfinished Basement • Two Car Garage • Paneling

PLAN 809

Figure 20. Continued.

Figure 21. A Comparison of the Measured and Predicted Daily Energy Utilization for January 1976 of a Mobile Home Court. The Lower Diagram Shows the Observed Weather Conditions During this Period.

In addition to the single-family detached-home model validation, the model has been used to generate a large commercial building module, using design information obtained for a modern hospital in the western high plains for which daily gas-consumption and weather data are available, and three modules for studying mobile homes. The mobile-home modules are for the 12-foot width, the 14-foot width, and the dual 24-foot width configurations. An entire mobile-home court in the same general area was then simulated, using actual weather observations. A comparison of the predicted and actual daily January 1976 energy utilization is shown in Figure 21 along with the actual weather observations. As can be seen, the agreement is very good. Over this 26-day period the actual gas consumed was within 0.5% of the simulated gas consumption. It should be pointed out that the units are all gas heated. The mobile court consists of 265 mobile homes of which approximately one-third are 12 by 60-foot units, one-third are 14 by 60-foot units, and one-third are 24 by 60-foot units. Typical thermal characteristics of the mobile homes are listed in Table 4.

To complete the model-validation program, a western high-plains rural city will be modelled during the coming three months, using the characteristic modules discussed above and others under development. Comparisons of simulation-model results with the energy actually consumed may reveal the necessity for refinements in the model, such as a need for additional modules or revision of the thermostatic settings and structural characteristics assumed for that city, in the delineation of microclimates defined by the meteorological analyses, and/or in the building census. Such refinements will be incorporated before we attempt to draw conclusions as to the feasibility of applying this model for estimating either that portion of the total energy usage in a rural city environment which must have been consumed for other purposes, or the extent to which there are inefficiencies in the consumption of energy for space conditioning.

Table 4. Characteristics of "Typical" 12-foot x 60-foot Mobile Home.
(Note: 60-foot mobile homes are actually 56 feet in length, the 60-foot length is to the hitch.)

AREAS:

Ceiling	672 ft ²
Walls	841
Skirt	408
Windows	75
Doors	36
Floor	672

COEFFICIENT OF TRANSMISSION:

Ceiling with R-30 insulation (required)	0.027
Walls with R-9 insulation	0.075
Single-glass window	1.13
Door	0.49
Door + metal storm	0.197
Floor with R-9 insulation	0.079
Aluminum sheet	0.61

(2) Adaptive model of socio-economic effects

The physical model is at the core of our general modelling approach, but in addition we are developing a capability to simulate actions taken by people in response to changes in economic variables. One approach to simulating this adaptive or behavioral factor is furnished by the micro-economic theory of consumers' demand. Under this approach demands for all goods and services may be derived from a system of demand equations in which prices and incomes are the explanatory variables. This is one of the most highly developed and widely applied models in economic literature. Moreover, it has been applied in various forms and degrees of sophistication to the demand for natural gas and electricity.

Annual demand for electricity has been estimated by Fisher and Kaysen (1962), Houthakker and Taylor (1970), Mount et al. (1973), and many others. Baxter and Rees (1968) estimated quarterly electricity demand, and Balestra and Nerlove (1966) did a well-noted study of annual natural gas demand. Other related studies include the estimation of hourly electricity demand as a function of prices and income (Cargill and Meyer, 1971), and the estimation of hourly electricity demand considering weather and income (but not prices) as explanatory variables (Hendricks, Koenker and Podlasek, 1975).

Such studies provide some insight into the relative magnitudes of price and income elasticities of energy demand, both long and short run; but they do not furnish usable coefficients, nor even a modelling methodology, suited to the attainment of our objectives. This is true, in part, because of two important omissions. First, none of these studies has coped with the problem of declining block prices for electricity and natural gas (Taylor, 1975). Second, none have considered the price of building materials.

Our model must predict changes in buildings which are made on the basis of relative costs of construction materials (e.g., insulation) and of electricity or natural gas. Thus, to reflect the true structure of the economic decision model which is at the base of the demand for energy, the actual prices of energy and building materials must be specified.

However, there is a still more fundamental shortcoming of the consumers'-demand approach; its application must depend upon historical data, and therefore suffers from the deficiencies discussed earlier. The socio-economic portion of our model needs to be compatible with the physical model; that is, it must be able to predict changes in the physical model's parameters which result from investment decisions (e.g., to retrofit) or adjustments in habit patterns (e.g., lowering of thermostatic settings).

Compatibility of physical and socio-economic components is achieved by building an adaptive model based on assumed cost-minimization behavior and lagged adjustment. The modelling approach is "behavioral" as opposed to "econometric". While behavioral models lack the formal statistical structure of regression models, their use in this study is justified by

the requirements of our overall modelling philosophy. Furthermore, it is not obvious that an approach based on "rules of thumb" is less realistic or even less rigorous than more conventional econometric approaches (for a discussion of this point see Cyert and March, 1962; and Day, 1963).

At every decision point, the adaptive model computes the lowest cost combinations (in real terms) of building materials, space-conditioning systems and direct energy use for various comfort levels in a variety of "characteristic" structures. It is assumed that as the actual cost of space conditioning rises above the minimum cost, the consumer will adjust in three ways: i. investment in retrofitting (assuming energy prices always go up - buildings cannot be un-retrofitted); ii. changing thermostatic settings; and iii. changing use patterns.

The first action will be taken gradually by the whole population. Factors influencing the speed of convergence toward minimum-cost solutions are: difference between minimum and actual costs as a proportion of income; age of building; age of space-conditioning equipment in place; and rate at which new buildings are being constructed.

The problem of predicting adjustments in comfort levels (thermostatic settings) is difficult, but a plausible approach is to assume that comfort levels will be adjusted when utility costs rise above a certain proportion of income. Another approach is to use existing surveys as rules of thumb. Perhaps the most reasonable approach is to simply treat both use patterns and comfort levels as parameters, and to look at these as potential sources of adjustment which could be triggered by price incentives or by campaigns to create a conservation consciousness.

(a) Adaptive model formulation

As of the date of this report, the general form of the adaptive component has been formulated, and work is underway to specify the parameters of this model as they apply to the physical modules representing residential and commercial buildings characteristic of a western high-plains rural city. The following is a description of the salient features of the adaptive component. Figure 22 is a flow diagram showing the general structure of the model.

The adaptive component is based on a linear program whose solutions are minimum-cost combinations (real dollars) of retrofitting and direct energy use in maintaining various comfort levels. Decreasing returns to retrofitting are piece-wise approximated through the use of bounded retrofitting activities. Returns to retrofitting are discounted at high interest rates (12% to 24%) justified by the cost of short-term credit to many consumers (e.g., interest on credit-card accounts).

Residential consumers are presumed not to fully appreciate that their utility rates are a decreasing function of their energy consumption. Instead, they assume that a reduction of 25% in heat loss leads to a 25% reduction in their space-conditioning bill. That is, residential customers base their decision on an average price. Replacement

Figure 22. Flow Diagram Showing the General Structure of the Adaptive Socio-Economic Model.

or retrofitting of old furnaces or air conditioners is represented by activities which require old space-conditioning systems as input. The energy saved by thus altering space-conditioning systems is an increasing function of the age of the system altered. To illustrate: In a given residential area, certain proportions of the furnaces will belong to several age categories or "vintages". The profitability of replacing each vintage will depend, for a given interest rate, upon the price of energy. As energy prices rise, replacement will become more profitable for each vintage. The decision to replace or retrofit is also conditioned by the income of the owner of the building. For lower income residences, the cost of borrowing is higher, and thus the future energy savings are worth less to poorer than to wealthier homeowners.

Commercial buildings are presumed to be owned and operated by customers fully aware of their utility rates, and who pay interest on loans lower than the credit-card rate. Commercial buildings are often leased, in which case lessors and lessees alike are assumed to reconsider energy use only annually when energy prices are reflected in new rental costs. Residences are assumed to reconsider thermostatic settings monthly when energy bills exceed a certain percent of income (alternatively, exceed a certain percent of past bills).

(b) Coupling of adaptive and physical models

The prototype adaptive components currently being constructed are based on the physical modules which describe a variety of the buildings characteristic of those found in a western high-plains rural city. These will have been completed in a form designed for interfacing with the physical modules before the end of the current project year. It will then be possible to couple the physical model described above with the adaptive model, so as to handle components which are not strictly dependent on physical parameters but rather reflect use or habit patterns and the costs of energy. Such an adaptive-physical model should be able to actually predict the requirements for space-conditioning energy based on weather information. The output from this coupled model will then be introduced into the CRT-display model, to generate preliminary policy-level information for simulated use by decision makers in determining the impacts of weather effects on energy requirements for space conditioning. During the coming year, the adaptive-physical model will be utilized to calculate the energy requirements for space conditioning in a large commercial-industrial metropolis, a suburban area and a rural city. The cities modelled will be selected from one of the nine census regions, on the basis of satisfactory completion of negotiations with those electricity and gas utility companies whose data and interest provide the greatest likelihood for the fulfillment of project objectives.

b. Data collection.

ERDA must accept from the outset the fact that in a number of instances a prerequisite to data availability may be a commitment on our part that we will not under any circumstances, or for as yet unspecified periods of time, divulge the name and/or location of the specific customer(s) and/or utility for which some of the weather-effects relationships will be derived. That is, for reasons which are considered

good and sufficient by some of the utility companies, industries and commercial enterprises with which cooperative agreements are being negotiated, it will be necessary that at times our results be expressed in generic and regional terms (e.g., a "food-processing industry in the south central U.S."). We will, of course, endeavor to secure releases from such commitments whenever possible, however these may be contingent upon our having first obtained relationships for several "food-processing industries", in which case a specific company might not mind being identified as part of a statistic wherein their individual contribution to the average and variance cannot be determined. Alternatively, release might be contingent upon a lapse of some number of months following the period for which the results were determined, or perhaps the completion of that change in company procedures indicated by the results of our investigation.

(1) Energy consumption data

An as yet preliminary but still extensive effort has been carried out in connection with attempts to acquire the electricity and gas consumption data needed to determine the degree of weather sensitivity for different energy-intensive users. In view of the extent to which utility companies are being subjected to continual requests for their data in ever-increasing detail for a great variety of purposes, we elected to address our initial inquiries to the directors of the 50 state energy offices (FEA 1974a, 1975). Our preference and ultimate aim was to establish contact directly with the individual electricity and gas utilities which are the actual possessors of the requisite data, and which are familiar with the nature of their customers' energy usage. However, comprehensive official data-collection programs are already underway in a few states, and in others the state energy offices and/or public service/utility commissions are held responsible for cognizance, if not coordination, of investigations such as ours. We, therefore, adjudged it incumbent upon us to accept the resultant inconvenience of working through these authorities should their collectives prove adequate for our purposes, or should they so request. It also seemed appropriate to ensure that these officials would have no objection to our establishing independent working arrangements with any utilities that might deem cooperation with us of potential benefit to them in connection with the development of improved load-forecasting techniques.

Following distressingly protracted exchanges of correspondence with state energy offices or public service/utility commissions and then with individual utilities across the country, in an attempt to elicit a willingness to consider cooperating with us in these studies, visits were made to electricity, natural gas and consolidated utility companies in the cities shown in Fig. 23. The absolute necessity for personal confrontations cannot be overemphasized if a utility is to become convinced that, among other considerations:

- (1) There would be a reasonable probability of specific direct as well as indirect benefits to them should they elect to participate in our studies.

Figure 23. Cities visited in connection with utility energy-data acquisition.

(2) They could tolerate the subsequent as well as initial costs in time, money and effort (i.e., data identification and retrieval, consultations, etc.) which such studies inevitably entail.

(3) We would observe any safeguards which they or their customers might impose to ensure data confidentiality.

The discussions with utility company executive and operating personnel were typically in depth across a broad range of matters before there was acknowledgement that any satisfaction of our data aspirations might be possible. They extended from early reassurance that the data could be furnished in such formats as were convenient to the utility (i.e., that they were not being requested to fill out any forms designed by us), to the procedures by which we could determine meteorological values representative of the locations for which energy-consumption data might be provided from the available National Weather Service or other weather observations. It was necessary to elaborate upon the motivating factor for these studies as well as prospective applications for our anticipated results, and upon information or assistance needed by us in addition to their raw sendout data. Additionally, it was essential to discuss the methodology of physical model development and findings to date.

Once these introductory exchanges were completed, however, utility response was magnificent in almost every case, with agreement in principle to participate, subject to a favorable policy decision on the part of the company and affected individual customers. Examples of the kinds of short-term disaggregated electricity and natural gas consumption data identified as available from one or more utility companies in most, and possibly all, of the nine census regions, at such time as negotiations for their provision are completed, are listed in Table 5.

Although considerable quantities of the desired data in gratifying diversity have already been received, or are known to be enroute from several of the utilities visited, in most instances negotiations are still in progress for their acquisition. It therefore seems inadvisable that company names and the areas which they serve should be listed here. Suffice it to say that we are delighted with the reception utilities have accorded our proposal and their willingness to participate within their individual capabilities to do so. Several of the utilities visited invited our attention to utility companies not yet contacted by us but known by them to have undertaken sizable metering programs of the type likely to provide the kinds of data we wished to acquire, and to be pursuing research projects which our investigations could complement to mutual advantage.

We have every expectation that those data will be forthcoming which are needed to determine whether, and to what extent, the rates of energy consumed by most residential and commercial structures, commercial enterprises and industries are weather sensitive.

Steam is another energy form which is distributed in large quantities for space heating and cooling to the inner city of a number of

ENERGY FORM

USER TYPE						
	STEAM		GAS		ELECTRICITY	
	SPACE CONDITIONING	PROCESSING	SPACE CONDITIONING	PROCESSING	SPACE CONDITIONING	PROCESSING
<u>RESIDENCES</u>						
Single-Family Detached			X		X	
Multi-Family Detached			X		X	
Mobile Homes			X		X	
Condominiums			X		X	
Apartments, Bi-Level			X		X	
Apartments, High-Rise	X		X		X	
Subsidized Housing Tracts			X		X	
Housing Developments			X		X	
Small-Rural Community					X	
a. No Industry			X		X	
b. One Large Industry			X		X	
ETC.						
<u>COMMERCIAL BUILDINGS</u>						
Office Buildings	X		X		X	
Churches			X		X	
Department Stores	X		X		X	
Laundry and Dry Cleaning			X	X	X	
Shopping Centers			X		X	
Food Stores			X		X	
Service Garages			X		X	
Government-Public	X		X		X	
Hospitals	X		X		X	
Hotels and Motels	X		X		X	
Florists			X		X	
Schools	X		X		X	
Theaters	X		X		X	
Public Utilities			X		X	
ETC.						
<u>INDUSTRIES</u>						
Chemical Industry			X	X	X	X
Fabricated Metal Products			X	X	X	X
Food Products			X	X	X	X
Lumber Products			X	X	X	X
Machinery			X	X	X	X
Paper Products			X	X	X	X
Rubber Products			X	X		X
Clay Products			X	X		X
Drug Industry			X	X		X
Tobacco Products			X	X	X	X
Refineries			X	X	X	X
Steel Processing			X	X	X	X
Packing Company			X		X	X
Plastics Manufacturer			X	X	X	X
Electronics Manufacturer			X	X	X	X
Cement Company			X	X		
Dairy Products			X	X	X	X
Greenhouses			X			
Mining Company			X	X		X
Dehydrating Company			X	X		
Sewer Service			X			
ETC.					X	X

Table 5. Examples of the Short-Term, Disaggregated, Energy-Consumption Data Typically Available from One or More Utility Companies in most Census Regions.

metropolitan areas. Short-term disaggregated data are available on its consumption also, which we plan to incorporate into our studies. The collection and analysis of steam data will be assigned a somewhat lower priority, due to its less widespread use in space conditioning. Nevertheless, we do intend that it should be considered before we write off any distinctive region of the country as having been completed.

We have not ignored petroleum products in our data-collection plans, however, we have not yet located a source of disaggregated data on the consumption of heating oils on a time scale less than monthly. Therefore, unless successful in this search, it appears that as anticipated it will be necessary to base our predictions of weather-sensitive oil-consumption rates on an extrapolation of the patterns to be established for electricity and natural gas.

Insofar as aviation, automobile and truck fuels are concerned, for purposes of investigating weather effects upon energy consumption by the transportation industry, we have not yet initiated data-acquisition efforts. We have determined that possible sources of these data exist, but confirmation has not been obtained. Tentative plans to follow up on these prospects, in connection with the visits to electricity and gas utility companies noted above, were dropped when appointments could not be worked in between scheduled utility visits. We will inquire further into this energy use at the earliest date practicable, in consideration of the higher priority currently assigned to space conditioning.

As discussed earlier, our energy-modelling plans envision that we will have modelled the energy consumed for space conditioning by a western high-plains rural city before the end of the present contract period, and that during the second year beginning 1 August 1976 we will similarly model the space-conditioning energy requirements of a metropolitan area, a suburb and a rural community representative of one of the nine U.S. census regions. The data for the western high-plains community are already in hand. We are presently in the process of selecting the census region wherein our FY 1977 modelling efforts will be concentrated, on the basis of availability of the desired data and interest in participating in these investigations evinced by utility companies located within that region. We expect to have completed mutually satisfactory negotiations within the next few weeks to this end, and immediately thereafter to commence that targeted data-collection and data-processing effort necessary to accomplish the first major milestone of our energy modelling effort -- the satisfactory specification of those space-conditioning energy needs which are characteristic of a major distinctive region of the country.

As soon as possible thereafter we will consummate comparable negotiations for each of the other eight U.S. census regions, and commence the acquisition and processing of the specific data needed to satisfy project objectives elsewhere around the country. Our intentions are that these data should be readied in all respects for use in advance of a regional requirement therefore by our energy modellers, in order that the modelling effort may proceed from module to module, city to city, and region to region as expeditiously as is feasible. It is therefore

during the next 18 months that data collection and processing will receive primary emphasis.

In this regard, assuming that our modelling accomplishments live up to our expectations, we may anticipate that some utility companies will wish to avail themselves of the basic adaptive-physical model and the associated energy-forecasting methodology before we will have had an opportunity to develop and validate modules tuned to their geographical area. In cases where these are companies which have contributed to the data bank needed to establish weather effects upon energy consumption, it is anticipated that by providing the consulting services, on a gratis but not-to-interfere-with-project-commitments basis, which they may need to extend our models to their locales, we could realize a more rapid satisfaction of our geographically disparate space-conditioning objectives than might otherwise be possible. Such an eventuality might require that we be prepared for an earlier commencement of model development on other energy uses than is presently expected. Although unlikely that so optimistic a projection could materialize, it nevertheless behooves us to simultaneously commence the collection and processing of those consumption data which will be needed later to quantify the weather sensitivity of energy used for purposes other than space conditioning.

It should be noted in this respect, that for comparing the predicted daily space-conditioning requirement for a test metropolis with the total system sendout for that city, we will need to determine that portion of the total which was consumed for other uses. Moreover, until such time as we can also quantify the weather sensitivity of different industrial consumers, there will be a degree of uncertainty in the balance indicated by these comparisons. Should the discrepancy be sizable, it could transpire that planned geographical extensions of the space-conditioning models will need to be deferred, in order that we may first provisionally define any significant industrial weather sensitivity. For this reason as well, our present data-collection and processing efforts are not being limited to space-conditioning requirements, but to the limit of utility patience include every variety of energy use for which a possibility of sensitivity exists.

In fact, the only compromise to our aspirations is the recognition that for space-heating investigations our data bank may be limited to the 3 midwinter months, for space-cooling investigations our data bank should be limited to the 3 midsummer months, for crop-drying investigations our data bank can be restricted to the fall months, etc. In this regard, one year of energy-consumption data is generally sufficient for physical module development and validation as described heretofore. On the other hand, for the study of socio-economic factors, it is desirable that the data base commence before the Arab oil embargo and continue through the succeeding periods of conservation to "the present".

(2) Meteorological data

The primary source of temperature, wind, cloudiness, humidity and precipitation data for these studies will be the official National

Weather Service (NWS) Forecast Office observations which, together with the once or twice daily reports by cooperative climate-program observers, are archived at the National Climatic Center (NCC). However, there is not always an NWS office in the vicinity of a city to be modelled, and when available it is often so located with respect to the city as to be unrepresentative of weather conditions affecting the majority of the area's energy consumers. Hence, although the NWS data may be obtained on magnetic tapes in a form conducive to computer processing, we have commenced the identification and collection of those other meteorological data which are required for determining the manner in which weather varies across a utility's customer-service area. Such sources include the utility companies themselves, universities, other federal, state, county and city organizations (e.g., air-pollution monitoring and control agencies, Department of Agriculture (Forest Service and Agricultural Experiment Stations), Department of the Interior (Bureau of Reclamation and Land Management), Corps of Engineers, U.S. Coast Guard, Department of Defense, law enforcement and highway departments, etc.), private weather services, radio and television stations, individuals, etc.

Unfortunately, much of the data from these other sources exist only in tabulated form or on the original recorder-chart traces. These latter (analog) data are particularly useful, in that they provide the detail desired for determinations of microclimatic variations within a city, but in the aggregate their conversion to forms suitable for our analyses constitutes a formidable data-reduction and processing task. We have scarcely begun this essential but tedious work, which regrettably must presently be done at night and over weekends owing to the nonavailability of suitable digitizing equipment during normal working hours. We are presently in contact with equipment manufacturers, in an attempt to lease digitizers which will be satisfactory for the extraction of data from utility as well as meteorological chart records. The principal problems in selecting the most cost-effective digitizer have been, that whereas mechanical systems entail labor costs, automatic optical systems are not only more expensive but have not worked without monitoring because of annotations and endorsements placed on records by the observers or readers.

The meteorological satellite data needed to resolve uncertainties in subjective cloud observations are mostly available on the premises in connection with other on-going research projects, as are the computer programs for extracting the satellite and conventional weather data from the magnetic tapes procured from NCC.

(3) Engineering and socio-economic data

By "engineering data" are meant the types of information needed to establish the characteristic thermal and dimensional features of an individual structural classification within a particular city or area, in order that the corresponding module of the physical model may be developed and validated. It encompasses information as to the amount of variability among the different buildings within that classification, which enters into the determination for that city of weighting factors accounting for this variability. Hence, the required engineering data include information on the number, mix and differences in size, construction, furnaces/air conditioners, energy form used, etc., corresponding to the actual distribution of the buildings within that classification.

Socio-economic data include information on: the pricing structure for different energy forms; energy conservation-program chronologies; utility billing histories for characteristic residential and commercial customer classifications; changes in comfort levels deducible from external indicators; appliance saturation (from consumer group and utility surveys); material and labor costs of retrofittings (insulation, furnaces, air conditioners, storm windows, etc.) and of new construction; retrofittings completed within the past 3-5 years and in progress; demographic data (1970 census and more recent or detailed regional or local surveys); real estate availability, cost, stability and use of the property according to age, type, location and energy-related features; income levels; tax rates, etc.

As discussed elsewhere in connection with descriptions of our work on physical and adaptive model development, energy audits and building censuses, the collection of these data entail meetings with: architects and engineers; construction, insulation and heating/cooling contractors; developers; city managers, planners, assessors and inspectors; chamber of commerce staff; realtors; union officials; human resources groups; state planning and revenue department staffs; mortgage and home-improvement loan institutions; and utility company personnel. Most of these data have been obtained or are forthcoming for Fort Collins and the western high-plains rural community presently under study; and a number of preliminary contacts have been established for the cities under consideration for our FY 1977 effort, in anticipation of data-acquisition visits to be made to those cities prior to the end of the current contract period.

(4) Industry productivity data

We have not yet solicited the data needed to quantify the manner in which the productivity of a particular industry may vary, with or without a change in energy-consumption rates, as the weather influencing that industry increases in severity. It was concluded that it was first necessary to establish that the requisite short-term, disaggregated, energy-consumption data were available, before contacting industry management personnel with respect to their interest in a cooperative study of weather impacts upon their operational effectiveness. However, inasmuch as a number of utility companies are referring our investigation into the influence of weather upon the rate at which energy is consumed by the commercial and industrial customers to which the requested energy data pertain, before releasing such information, it appears that we may look forward to an early opportunity for discussing such prospects with those corporations willing to consider an operational analysis of this type. It may well be that an industry will be perfectly agreeable to our proposal to merely relate the rate at which its energy consumption varies with the weather, but will prefer to defer any decision as to an energy-effectiveness study which would require information on the rate at which its products are generated. We are hopeful that correspondence received during the next few months is as indicative of industry interest as that which has been expressed to date by utility companies across the country. The necessary visits to those industries would then be scheduled as expeditiously as the available travel funds and coordination with other project travel to the same locale may permit.

c. Environmental factor analyses

(1) Meteorological diagnoses. A prerequisite to determinations of the meteorological values to be correlated with observed variations in end-use energy-consumption rates is the establishment of the extent to which observations by the nearest available weather station(s) are representative of free-atmosphere conditions prevailing throughout the area under study. Our first step is to define those circumstances (wind directions, atmospheric stabilities, wind speeds, etc.) wherein the existing weather reports are nonrepresentative. We then establish correction factors which, when applied to weather-station records, provide a reliable measure of the actual free-atmosphere temperature, wind velocity, cloudiness and humidity at the time of observation.

In this deductive process of "calibrating" the available weather-station data, we examine terrain influences, effects of structures, paved areas, vegetation, water bodies, etc., individually if noteworthy and in the aggregate where appropriate (e.g., urban heat islands, structural forests and city canyons), and their manner of variation with wind velocity, stability and season. These procedures are then repeated to deduce the meteorological conditions affecting the individual user(s) whose energy consumption rates are under investigation. For these latter deductions it is necessary that we have surveyed the environs of each individual test building, so as to determine the circumstances and extent to which terrain, trees, structures, water, etc., in the vicinity cause the meteorological values affecting that building to differ (e.g., due to shielding from sun and wind) from free-atmosphere conditions derived for the available weather-station data.

Validations of the modules developed to model the energy demands of specific structures require that these micrometeorological studies be carried out with considerable attention to detail, to minimize any possibility of erroneous conclusions as to physical model accuracy. We have scarcely scratched the surface of this task. Yet, if the anticipated cooperation is forthcoming from those utilities which possess short-term, disaggregated, electricity and gas consumption data for a great majority of the modules identified, we should be able to contain the attendant fine-scale meteorological analyses to that reasonable total effort necessitated by a restricted number of metropolitan and rural areas.

Upon aggregating the variety and number of "characteristic" structures which make up a test metropolitan or rural area, variations in construction details, thermostatic settings, use/habit patterns, etc., across the spectrum of individual buildings comprising each characteristic structure type permit us to carry out a correspondingly relaxed scale of meteorological analysis. Thus, for the western high-plains city for which the total space-heating energy requirement is to be modelled during the present contract year, we are preparing a mesoscale analysis delineating by (meteorologically) distinctively different areas of that city the manner in which weather elements depart from the calibrated values established for a weather station within the city limits. Correlation between structural types and their locations with respect to

the meteorological anomaly patterns so established is expected to permit the determination of weather effects upon space-heating gas consumption with an accuracy comparable to realistically attainable consolidations of the different buildings making up each characteristic structure type.

It is not suggested that such mesometeorological studies for an area (city) entail less care in their preparation than a microscale study for a particular location (structure), but that some generalization and smoothing is acceptable. Even so, we will devote considerable effort to those analyses to be initiated near the end of the current contract year in connection with our modelling studies of the test cities served by utilities with which cooperative investigations are negotiated. Thereafter, just as it is presumed that we will progressively define a realistic limit to the physical modelling effort which should be invested for calculating the space-conditioning energy required by a city, so too should it be possible to define a commensurate limit to the amount of effort needed to adequately specify the variations in weather which occur across that city. Hence, we are hopeful that, as we gain in understanding, there will be a corresponding reduction in the effort needed to prescribe the weather factor with reasonable accuracy, so as to partly compensate for the increase in the number of cities to be modelled as our analyses are extended to all 9 census regions.

(2) Energy audits which we have undertaken encompass a variety of tasks, depending upon the specific circumstances of the energy user under investigation. The simplest is perhaps the initial discrimination as to weather sensitivity for energy-intensive industries which can be accomplished through inspection of load-factor information made available by cooperating utilities. Where the load factor is consistently high, with negligible variation from working day to working day, month to month, and winter to summer, the industry is obviously not weather sensitive -- at least to a degree determinable with 2% metering accuracies. Where the load factor for an industry is low, this of itself cannot be interpreted as an indicator of weather sensitivity. In these cases, however, consultations with the utility often permit rejections as to the existence of significant weather sensitivity, in that consumption patterns for winter are essentially identical to those for summer with the variability in load almost entirely due to variations in the manufacturing schedule. Hence, our investigations of industrial weather sensitivity may be limited to those users with a low load factor and pronounced seasonal differences in their energy-consumption rates.

Where the cooperating utility possesses information as to the use made of the energy consumed by a customer, e.g., when separate recording meters are installed on process and space-conditioning demands, our investigational procedures can be very much simplified with a corresponding reduction in the need for consultations with plant managers. Furthermore, some utility records include a chronology on the nature and date of plant conversions or modernizations, adoptions of new processes, wing or floor additions, installation of shutters or reflective film on

windows, improvements in space or process insulation, etc., for their major industrial and large commercial customers. Hence, thanks to the forehandedness of certain utility companies, it appears that sufficient data exist for us to quantify weather effects upon industrial energy-consumption rates, and that it will be possible to accomplish these studies with a reasonable level of effort. Therefore, even though negotiations for the requisite energy-consumption and industry productivity data are still pending, and the physical models for defining energy-use patterns for purposes other than space conditioning presently are still only at the conceptual stage of development, it is concluded that the feasibility of carrying out the studies cited in objective "c" at the beginning of section II.B.2, above, has been demonstrated.

It is also due to utility company forehandedness that the short-term energy-consumption data are available which we need to validate the variety of residential and commercial building modules under development in connection with the modelling of space-conditioning energy demands. However, here too there is considerable variation among utility companies as to the availability of collateral information. A small number of electricity and gas utilities have conducted appliance or ancillary equipment and demographic surveys on the individual residences and commercial buildings where they have installed recording meters, but this information is generally lacking. We do not propose to conduct such surveys ourselves, since it appears that those which are available will prove sufficient to tune and validate different modules with the accuracy required for their application to the actual spectrum of buildings to which each characteristic structure pertains.

The load-management or energy-pricing purposes of the statistical studies which prompted utility companies to collect the short-term disaggregated energy-consumption data of interest to us, generally did not have need of information on structural features or furnace/air-conditioner installations. Since this information is vital for module development, it is necessary for us to conduct surveys on the shell and furnace/air-conditioner characteristics of different buildings. It is far simpler and quite sufficient for these surveys to interview a number of insulation and heating/air-conditioning contractors who are familiar with construction and space-conditioning practices in the city (supplemented if necessary by a nighttime aerial or automotive radiometer survey, e.g., to "calibrate" the contractors' assessments and older neighborhoods of a city), than it is to contact individual building occupants or managers.

(3) Building censuses, although discussed elsewhere in this report, are identified separately here for the reason that they constitute a major supportive task which is a basic prerequisite to the successful development and validation of a physical model for reliably calculating the energy needed for space conditioning on a large scale. It is well established that the physical modelling approach is quite accurate for an individual building and more than adequate when applied to a group of similar buildings (Fox, 1973; and section II.B.2a(1)(c) of this report). Thus, considerations as to the degree to which applica-

tion is feasible over a larger area encompassing a great variety of buildings devolve largely into a matter of determining whether a realistic compromise may be reached between acceptable accuracy and level of effort. It is our thesis that the grouping of similar but not identical buildings into common classifications, and the use of appropriate weighting factors to characterize differences between buildings, may be extended to compositing by classes encompassing a broad range of thermally "equivalent" structures.

As indicated previously, we are presently working our way up the scale of progressively more diversified structural mixes, so as to define the degree to which compositing is permissible. This will be done both by comparing module calculations for different structures in "thermal equivalency" assessments, and by testing of the model on increasingly larger and more complex communities. It is anticipated that we will be successful in taking an occasional "order of magnitude" step. That is, we do not intend to adopt the incremental approach.

Assuming the adequacy of our thermal equivalency assessments for classifying structures, application to test cities will require the preparation of a census of buildings of comparable number, size, age, fuel type, construction materials, comfort level, habit or use pattern and location (for correct positioning with respect to areal variations in weather conditions) accuracy for each structural class in the city. In order that this task may be accomplished without an inordinate effort for large cities, we are considering a combination of low-level aerial photographic surveys by day and scanning thermal radiometer surveys by night, together with the use of statistical sampling procedures to be designed in consultation with such experts in this field as Glenn W. Brier (CSU Department of Atmospheric Science) and Paul W. Mielke (CSU Department of Statistics). Preliminary meetings on the development of appropriate statistical sampling procedures have already taken place, with further discussions of this possibility to follow over the next few weeks. We will also arrange a necessarily exploratory meeting with Denver Region FAA officials on low-level aerial surveys, since the cities involved have not yet been designated. In this regard, however, a few utility companies with which there was discussion of this matter stated that they had experienced no difficulty in scheduling inspection flights across metropolitan areas by their own helicopters.

(4) Related considerations. The supportive interest evinced by a number of utilities in this project is indicated by the wealth of constructive comments and suggestions volunteered by experienced planners, economists and operating personnel during the course of our data-acquisition visits. Many of these identify considerations which must be incorporated into our studies, if the results are to provide the desired applicability. A few typical examples are summarized here for purposes of illustration.

(a) Wind velocity. The existence of a significant wind-speed effect upon gas consumed for space heating is universally endorsed by experienced dispatchers, but for the most part consideration

in load forecasts is limited to qualitative applications of worst-case contingency factors when wind could seriously aggravate the effect of cold temperatures. A number of dispatchers volunteered subjective thumb rules which they had developed for their service area on the basis of 20-30 years' experience, or which had been passed on to them, and for which validity was attested to by the consequences of a failure to have applied them on well-remembered past occasions. Rules cited ranged widely geographically, e.g., the necessity to increase the anticipated total system sendout by the equivalent of one heating degree day for every mph, one heating degree day for every 2.5 mph over 10 mph, little wind effect until the wind exceeds 30-40 mph, etc. A possible clue to such variability is offered by regional differences in the service areas of the respective utilities. The first cited is used in a region where the terrain is flat with relatively little sheltering from the wind, whereas the last cited is applied in a large, dense, metropolitan forest wherein winds below mean building-top level are much reduced from those reported by nearby airfields.

Another similar difference seems to exist in the case of electricity consumed for air conditioning. In rural or suburban areas and small cities it appears that awareness of the need to conserve energy may have prompted a wind-speed contribution to decreased demand, in that some families open windows and doors so as to enjoy breeze instead of mechanical cooling. On the other hand, in large, dense, metropolitan areas, where a great many families reside in inner-city apartments and row houses, a combination of wind-blown filth plus the generally decreased winds below mean building-top level in heavily built up structural forests and the heat-island effect evidently render the taking advantage of winds in this manner unacceptable to the average occupant.

While acknowledging the general predominance of the temperature effect as the principal reason for far less emphasis on wind in attempts to refine their winter load-forecasting relationships, a frequently voiced gas dispatcher complaint was the nonrepresentativeness for their major customer-density locales of winds observed by the nearest National Weather Service (NWS) office (i.e., if even in the general vicinity, then at an airfield on the outskirts 10-30 miles away). A related utility complaint is that whereas NWS temperature forecasts are perhaps of marginal adequacy, wind and cloud forecasts are so unreliable and generalized that any serious consideration of wind or cloudiness effects before the actual observation is a waste of time. Thus, many utilities have, or are installing, their own meteorological networks throughout their system, with not only temperature but wind and insolation data telemetered to control centers on a real-time basis for decision purposes, and have engaged private meteorological services in order to obtain weather forecasts of greater accuracy and timeliness. Three gas dispatchers stated that they would be most appreciative if, in exchange for their cooperation with our project, we would develop reliable wind-forecasting techniques for their service areas.

Direction of the wind with respect to the relative location of utility service areas and water bodies in the vicinity provides a well

recognized need for reliable wind forecasts, and not just because of generally decreased air temperatures downwind of the water body in spring and summer or increased temperatures in fall and winter, but also the probability of greater wind speeds with onshore than offshore flow. Additionally, one midwestern gas utility dispatcher advises that a large number of his residential customers limited their investment in storm windows to the north and west-facing walls, and he has learned that, other things being equal, he must therefore anticipate a greater demand for space-heating gas with easterly component winds.

(b) Humidity. This same midwestern gas dispatcher states emphatically that, other things being equal, his residential customers will burn more gas on "raw" days (high-humidity cold), perhaps because people tend to feel the cold to a greater degree and to disbelieve the accuracy of the indicated room temperature under these conditions. From other remarks made at the time, it seems possible that these "raw days" are also associated with greater cloudiness, which would reduce insolation warming. We will attempt to distinguish between humidity and cloudiness effects in our analyses of the data for this utility company, and also look for the possibility of such occurrences in the consumption rates of other utilities.

It is difficult to discriminate between summer temperature and humidity effects upon electricity consumed for air conditioning throughout the south and southeast where the humidity is almost always high, as evidenced by the rarity of extreme heat but frequent occurrence of prolonged periods with hot nights as well as hot days and the strong correlation between temperature and humidity. Conversely, in the less humid north and northeast where severe summer peaks in the demand for electricity are also due to occasional prolonged invasions of high-humidity tropical maritime air, existing load-forecasting techniques express the humidity effect indirectly by stipulating that extreme demand peaks are associated with 3 or more successive days when both nighttime and daytime temperatures are high. There, individual utilities have been able to avoid explicit consideration of humidity by the use of cooling-degree days as their explanatory variable, since at high latitudes mean daily summer temperatures can rise substantially above the seasonal average for the area only when humidities are also higher than normal. For instance, humidities in the northeast are poorly correlated with temperature in comparison with the southeast, as manifested by the lesser utility concern during average summer hot spells when nighttime temperatures are relatively cool (low humidity). Although the days may then be as warm or warmer than those on which demand peaks occur, the mean daily temperature will be lower.

Thus, statistical load-forecasting methods neglecting humidity but using mean daily temperature (or degree days) have proven adequate only because they apply to a limited geographical area, and have not had to contend with differences in diurnal temperature ranges that can vary from the order of 2°-3°C in the southeast to over 25°C in the southwest. If a single model is to be applied nationally, however, either humidity or some explicit measure of the daily range of temperature must be incorporated.

(c). Ground temperature was found to be second only to air temperature in explaining winter sendout by the gas dispatcher of a large midwestern utility. This parameter, measured 9 inches below the surface, provided a good indicator for the lag that occurs between the passage of a cold front or the onset of a warming trend and the pickup or dropoff, respectively, in gas sendout, because of thermal capacitance of buildings and the ground upon which erected.

Some slight evidence of a lag in gas-heat consumption following air-temperature changes may be detected in comparisons of gas consumption and the temperature trace for light-weight buildings we have examined; but as may be seen in Figure 21, the physical model predicted the change in energy requirements reasonably well without reference to ground temperature. However, model calculations for a large commercial building have responded too rapidly to air-temperature reversals. Soil temperatures for the same general area have been obtained with a view to possible inclusion among the explanatory variables, in the event this discrepancy cannot be handled entirely by appropriate revision of the building-materials resistance table -- perhaps because it may indicate the necessity for greater consideration of ground effects when large basements are involved which extend to a considerable depth below ground level.

(d) Regional temperature differences

A characteristic of utility temperature-demand statistics is that the electricity consumed for space cooling levels off at some temperature below the summer maximum, and conversely, gas and electricity used for space heating levels off at some temperature above the winter minimum. Air conditioners and furnaces throughout the system have then reached their maximum capacities, and are running continuously. A comparison of variations in the climate at which these levelling-off temperatures occur with representative construction standards, thermostat settings and habit patterns for the respective geographical areas should prove useful in connection with our attempts to relate conservation potential to returns on retrofitting investments.

Utilities appreciate that for their large commercial customers the energy demand for space cooling begins at a temperature lower than 65°F, and that the energy consumed for space heating ends at a temperature lower than 65°F, due to the internal heat generated by lighting and ancilliary equipment (elevators, pumps, fans, etc.) Load-forecasting formulae/graphs used by some of those utility companies with a large percentage of their total load due to commercial buildings, show a discontinuity in the system aggregate somewhere between 40° and 75°F. This break is not distinguishable in many of the other temperature-demand statistics we have viewed. We have not yet had an opportunity to inquire into details related to: its nonoccurrence in some statistics; the variability (seasonally and regionally) in the temperature at which it occurs; the appearance of a year-around "U"-shaped temperature-demand profile in the system aggregate of a utility with a large electricity winter-heat load, which bottoms at a lower temperature in winter than in

summer; or the extent to which such large commercial building conservation practices as decreasing the amount of lighting, reducing elevator service, replacement of conventional doors with revolving doors, etc., have not only reduced space-conditioning energy requirements but also impacted upon the temperature-demand peculiarities noted above.

(e) Miscellaneous

However, one space-heating demand which is regionally invariant and well recognized among utility customer-relations personnel, is the demand among the elderly for a higher thermostatic setting to maintain required comfort levels than is needed by younger families.

Several economists, at utilities which read residential meters bi-monthly, remarked that our investigation would be worth every effort their company expended in cooperation, if it were to accomplish no more than to provide them with improved formulae for estimating energy consumption during months when no meter reading was available or weather changed dramatically between the metering and billing dates.

At the other end of the spectrum, among long-range planners of a number of summer-peaking electricity utilities, was the greater concern over potential developments in their winter load than with the immediate summer air-conditioning problem. Existing seasonal power-exchange commitments, and dependence upon the winter period of decreased demand for major maintenance, result in a lower real capacity to satisfy growth in winter than in summer. They are disturbed by indications of a trend in residential and commercial customer new-construction/retrofitting decisions to elect electric heat, as an obvious consequence of uncertainties in gas or petroleum availability and the inconvenience of coal, that is evidently already appearing in some utility statistics. In view of trends such as this, the possibility voiced by some researchers of a worsening global climate lends additional emphasis to the necessity for more reliable techniques of predicting the weather-sensitive demand for energy.

d. Tasks IIc and IId: Energy demand-display model and its calibration

Part of the motivation for carrying out the study of relationships between energy demand and atmospheric variability is to allow a view of simultaneous energy-consumption patterns across the U.S. As weather features develop and move across the country, the energy demand in various areas will rise and abate with the shifting patterns. With these concepts in mind we are developing a display model which will map simultaneous expected energy demand under various weather conditions. Such a display will eventually give aid to decision makers who are responsible for allocating various forms of energy supply under times of stress caused by extreme weather conditions.

Since quantified correlations between energy consumption and various meteorological parameters were not readily available at the start of this investigation, the development of the display model has proceeded under a "variable coefficient" format. This will allow the user of the model to vary the impact of any meteorological factor according to any detailed information as it becomes available to him. In this way the extremes of meteorological conditions can be translated to extremes in energy demand as the causal weather patterns develop and move.

Presently, the mapping of the United States is carried out on a 1° latitude/longitude grid. County populations (1970 census) are entered at the grid point nearest to the county center. It is not anticipated that a narrower population grid will be needed, however this could also be developed. Meteorological data are entered from the 3-hourly synoptic reports prepared by the National Weather Service. These meteorological values enter the grid at the 1° latitude/longitude point which is nearest the station. All observations of any variable for the entire day and for all stations within the grid are linearly averaged to determine a mean daily value at each grid point. Such mean values can be multiplied by an appropriate variable, as noted above, or combined with the given population values. Linearly interpolated values of meteorological variables are assigned to grid points across the U.S. where no direct observations are available.

Currently we are improving upon the efficiency of running the display model on the computer. A trial run was made, however, using temperature data for 16-30 January 1970. This was a period of an extremely cold outbreak across the midwestern and eastern U.S. followed by warmer temperatures. Heating-degree days (65°F, minus average daily temperature at the grid point) were determined for the grid point and multiplied by the population values at that point. Since metropolitan areas tend to predominate above the rural areas when population values are used, we used the logarithm (base 10) of the population times the corresponding heating-degree day value in our display. Figure 24 shows these values across the Eastern U.S. for a date during the extreme outbreak, and Figure 25 shows the same values during the moderating trend. The sequence of daily maps, not presented here, clearly reveals the effect of the cold surge and its subsequent retreat. It also shows the confinement of such temperature effects to certain regions of the U.S.

As more information is gathered, and the adaptive-physical model developments under Tasks IIa and IIb proceed, we will incorporate the various energy and socio-economic factors and their parametric representation into the display model. Should such effects be nonlinear, some reprogramming will be necessary; but this will not be an obstacle to further development. We intend to make such changes at the appropriate time.

We anticipate that before the end of the present contract period the modelling work described in sections II.B.2a(1) and (2), above, will have yielded output which can be used, at least in a provisional way, to satisfy Task IIId.

Figure 24. Population multiplied by heating degree days at 1° latitude/longitude points for January 21, 1970. Heavy lines represent a value of 10^5 while thin lines represent 10^7 .

Figure 25. Same as Figure 24 except for January 29, 1970.

3. Task III: Determining the Effects of Characteristic Weather Regimes Upon the Potential for, and Cost Effectiveness of, Solar and Wind Energy Utilization

Task III was eliminated from the first-year scope of this project during the fall 1975 contractual negotiations, and therefore no related work chargeable directly to ERDA has been carried out. However, in connection with another NSF project, one of the co-investigators has been concerned with the identification of remote lakes subject to winter fishkill which experience sufficiently strong winds of a frequency that the fishkill problem could be eliminated or reduced by wind-powered aeration. During his survey in that capacity he identified many areas along the Front Range of Northern Colorado and Southern Wyoming (to which that project is restricted by budgetary considerations) where terrain-induced acceleration should produce winds substantially stronger than are recorded by official weather observing stations in the same general vicinity.

When budgetary problems due to equipment casualties necessitated a reduction in the scope of that project, 4 of the 6 wind-measurement equipments furnished during the 1975-76 winter by the NCAR Field Observing Facility became available for other purposes. The cancellation of Task III precluded the official studies set forth in our original proposal, which had been planned to document preliminary deductions as to the existence of extensive areas suitable for wind-energy exploitation throughout the northern and central Rockies. Inasmuch as additional data could substantiate anticipated conclusions of the said NSF project, this researcher decided to install these 4 wind systems at opportune locations in the immediate vicinity of Fort Collins where they would also complement the project installations.

These 4 additional stations are indicated as sites numbers 2, 3, 5 and 6 in Figure 26. Sites numbers 1, 4 and 7 in that figure are project installations; but among these, wind entered into the site-7 selection only as a final, localized, on-site, optimizing consideration within a predetermined 2-acre area.

The following facts are relevant. The 1975-76 winter in the project area may be characterized as generally warm and dry with light winds. Sites numbers 2, 3, 5 and 6 were compromise locations, because of funding limitations which prohibited their maintenance by project personnel. It was necessary to install the instrumentation where it could be serviced conveniently by area residents, and to take advantage of trips of opportunity (which limited their period of observation to 2 months at numbers 2, 3 and 6, and 5 months at site number 5). As a consequence, they could not be installed in locations 10-20 miles away which would have been preferable for demonstration purposes, since there the winds are so strong that living conditions are intolerable during a normal winter and residences are lacking.

Figure 26. Locations of weather stations established to document strong Front Range winds.
1. Robbers' Roost Ranch, 2. Virginia Dale, 3. Cherokee Park,
4. Lost Lake (5 stations), 5. Stratton Park, 6. Waverly, 7. Keenesburg

Work schedules have not yet permitted processing of the data recorded in this low-priority effort, but casual inspections indicate that wind speeds at sites numbers 2-6 are substantially stronger than those observed at the official Fort Collins weather station (e.g., peak gusts in one typical storm of > 60 mps vs. 38 mps). Such recorded differences are of interest in connection with possibilities for wind-energy exploitation. They are of importance because they have served to substantiate high-country winds 2 to 3 times stronger than the speeds predicted in warnings by weather forecasters serving the Front Range. The 1975-76 winter observations at sites numbers 1-6 helped provoke improvements in wind warnings, which years of importunings by area residents based on seaman's eye reports could not prompt.

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