The Impact of Temperature Trends on Short-Term Energy Demand

by Michael Morris

The past few years have witnessed unusually warm weather, as evidenced by both mild winters and hot summers. The most recent winter was the second warmest on record, and the summer of 1998 set new U.S. and worldwide temperature records. Climatologists have concluded that the recent spate of unusually warm weather is part of a warming trend that dates to 1965, and that this trend is likely to continue. The trend has also exhibited distinct seasonal and regional variations: winters have experienced a greater warming trend than other seasons, and the West has been more prone to warming than the rest of the Lower-48 states.

The analysis shows that the 30-year norms--the basis of weather-related energy demand projections--do not reflect the warming trend or its regional and seasonal patterns. Weather premises based on climate change result in lower energy demand projections. The concentration of the warming trend during the winter season results in a reduction of projected space-heating requirements exceeding increases in summer cooling demand that also result from the same trend.

The Livezey and Smith Findings

In a paper published in January 1999,[1] Robert Livezey and Thomas Smith (LS) of the National Oceanographic and Atmospheric Administration (NOAA) found evidence of a quantifiable warming trend starting in 1965. Their models were able to isolate other factors, including El Nino and La Nina episodes, in identifying that trend. LS estimated the average national warming trend to be 0.015 degrees Fahrenheit per year. In other words, average annual temperatures in the Lower-48 states have risen more than half a degree since the onset of the warming trend 34 years ago.

LS also identified widely divergent seasonal and regional patterns in the warming trend. **Figure 1** depicts the seasonal and regional nature of climate change. The bar graph shows that the upward temperature trend for the peak winter season averages 0.055 degrees Fahrenheit per year, more than three times that for the year as a whole. In contrast, fall temperatures have exhibited a slight cooling trend. The map of the Lower-48 states highlights the regional variation in annual temperature trends. Western and coastal areas have undergone even more pronounced warming than the national average, while some areas of the Deep South have exhibited mild cooling trends. **Figure 2** comprises examples of sharp regional divergences during different seasons compared to those observed on an annual basis.

These findings have prompted a review of the traditional approach to projecting weather-related energy demand based on 30-year averages. The analysis below attempts to corroborate the LS findings in terms of data used in generating short-term energy demand projections.

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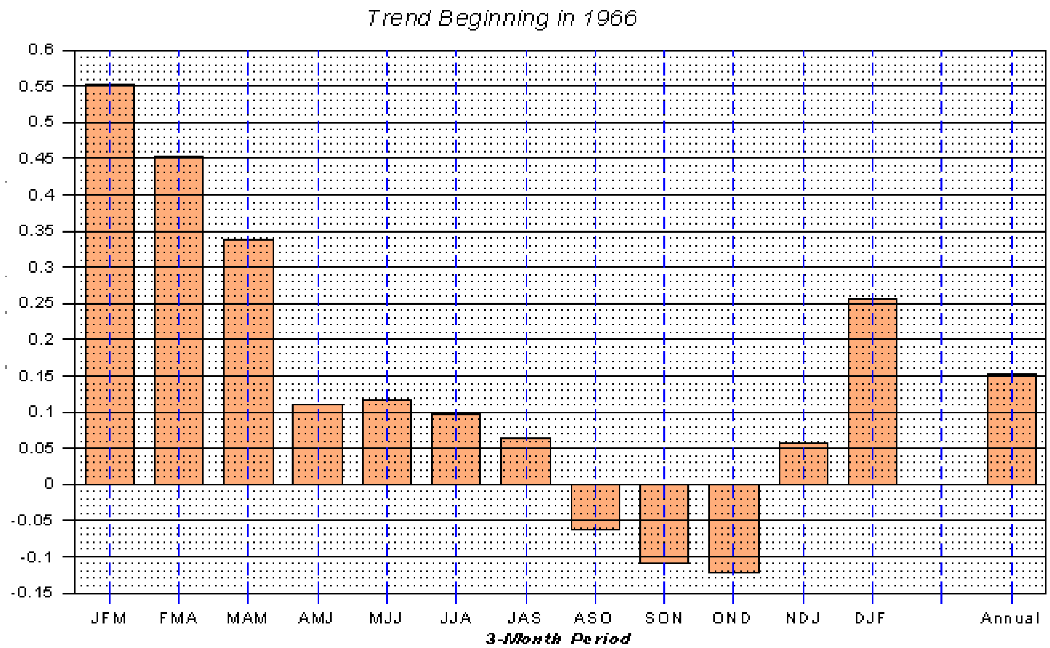
[1] Robert E. Livezey and Thomas M. Smith: "Covariability of Aspects of North American Climate with Global Sea Surface Temperatures on Interannual and Interdecadal Timescales." *Journal of Climate*, January 1999, pp. 289-302.

Figure 1

National Temperature Trends by 3-Month Periods & Full Year



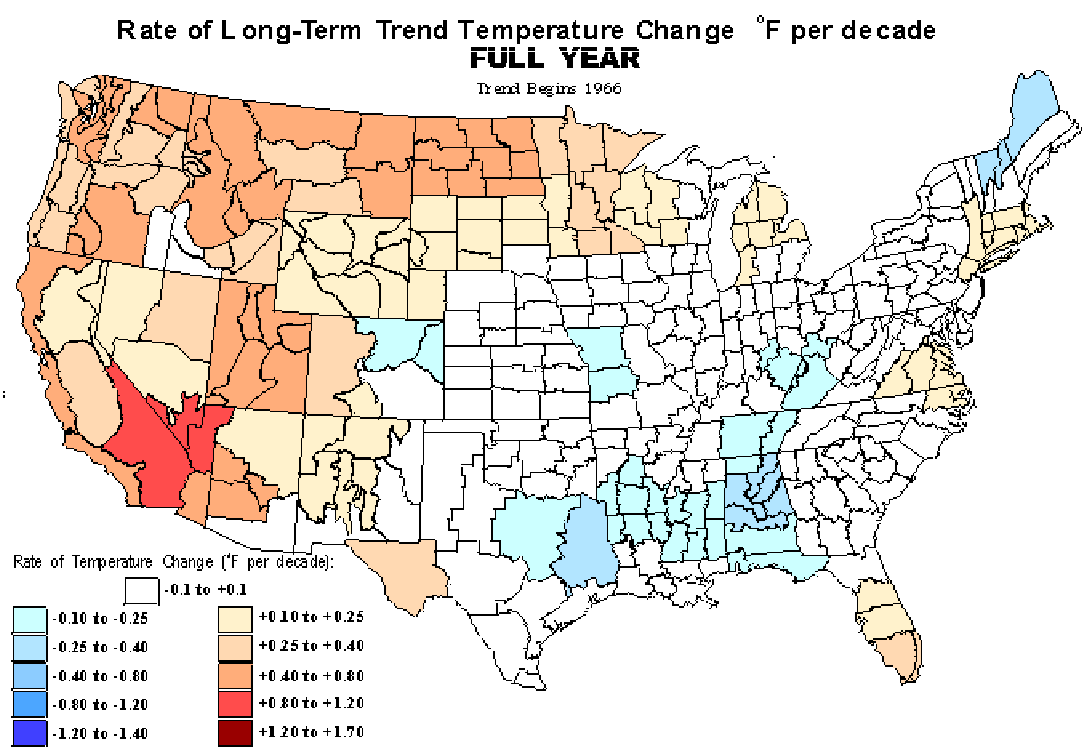
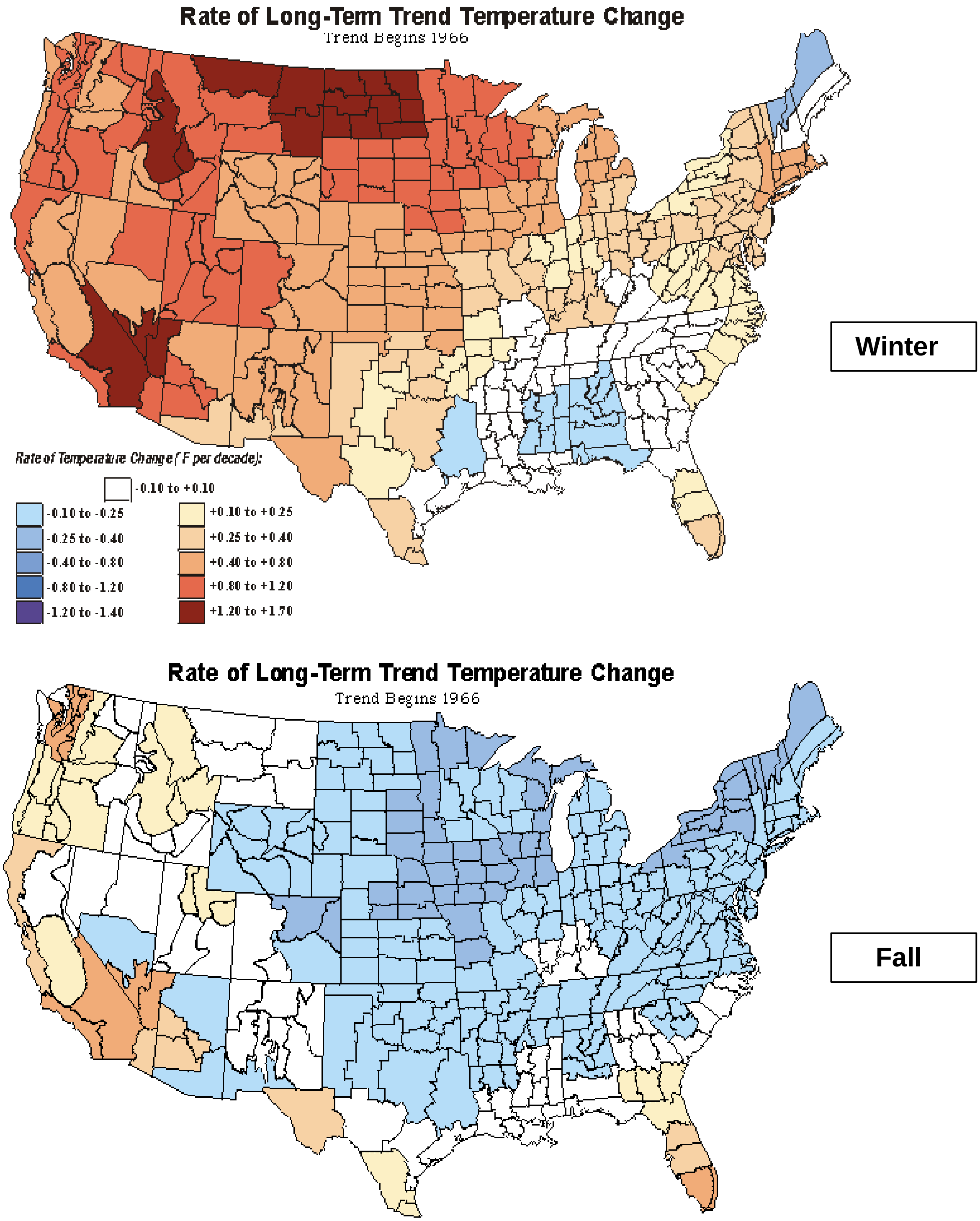


Figure 2


Rate of Long-Term Trend Temperature Change
Trend Begins 1966
Rate of Temperature Change (°F per decade):
-0.10 to +0.10
-0.10 to -0.25
-0.25 to -0.40
-0.40 to -0.80
-0.80 to -1.20
-1.20 to -1.40
+0.10 to +0.25
+0.25 to +0.40
+0.40 to +0.80
+0.80 to +1.20
+1.20 to +1.70
Winter
Rate of Long-Term Trend Temperature Change
Trend Begins 1966
Fall

Data Requirements, Methodology and Results

In the *Short-Term Energy Outlook*, heating-degree days (HDD's) and cooling-degree days (CD's), published by NOAA, are regarded as robust estimators of heating- and cooling-related energy consumption. A heating- (cooling-) degree day is an index of coldness (warmth) in terms of average daily temperature being below (above) 65 degrees Fahrenheit. Statewide HDD and CDD aggregates are based on Census division population weights; regional and national series are weighted by population, residential heating fuel household type, and air-conditioning households. Population, residential fuel and air-conditioning weights are updated every 10 years in accordance with Census data. **Figure 3** comprises graphs of annual population-weighted data for the Lower-48 states based on available NOAA statistics. To aggregate winter seasons, HDD data were summed on a July-to-June basis. Both graphs depict a high degree of volatility and a lack of any consistent trend based on almost seven decades of data.

To verify the LS claim of a warming trend since 1965, the NOAA data were divided into three periods, the most recent comprising post-1965 data. The pre-1950 timeframe (Period I), which was excluded from the LS study, serves as a useful reference point in evaluating the LS claims based on the later periods. The 1950-1965 time-span (Period II), during which no apparent temperature trends were found by LS, and the post-1965 interval (Period III) constitute the frame of the LS study. For both data series, linear trend-lines were estimated for each of the three periods using least-square regression methods. **Figure 4** displays these trends and coefficients of determination, a standard measure of "goodness of fit."

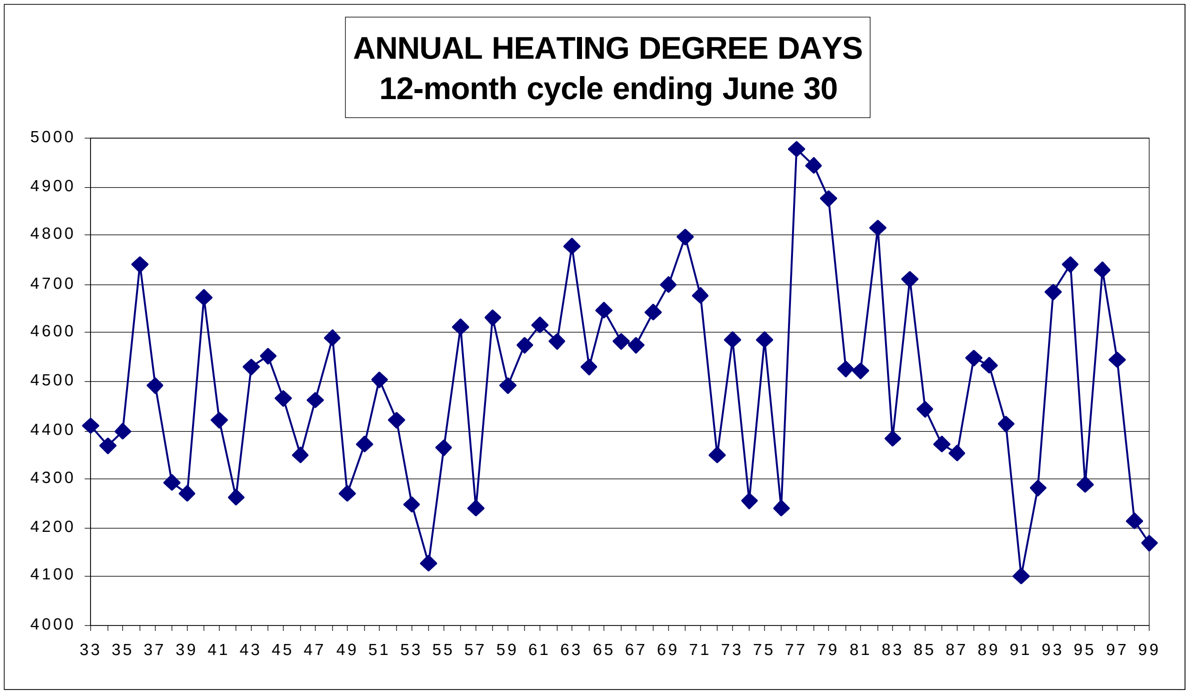
The trend estimates for Period III based on annual HDD and CDD data are consistent with the LS findings of a statistically significant warming trend since 1965. Because the LS finding of 0.015 degrees Fahrenheit per year falls within the confidence interval based on the analysis of HDD and CDD data, we accept that estimate as a valid population-weighted measure of warming for the Lower-48 states. The CDD- and HDD-based results show an estimated warming trend of 0.031 degrees Fahrenheit per year, or a cumulative increase of 1.06 degrees of warming since 1965, twice the LS estimate. But the HDD- and CDD-based results contain a 95-percent confidence interval that ranges from 0.009 to 0.053 degrees Fahrenheit. The LS trend estimate of 0.015 falls within that range. Although the first two periods revealed statistically significant trends for one of the series, Period III exhibited statistically significant trends for both heating and cooling were statistically significant, corroborating the presence of a warming trend during that interval.

The trend estimates, however, should be treated with caution. Period III comprises high volatility in both data series. Some of the coldest winters occurred during the earlier part of period, contributing to possible overstatement of the downward trend. That timeframe also witnessed the three coolest summers. Trends are also susceptible to the erratic nature of some of the most recent annual data. Absent the record high data-point for 1998, the CDD trend for Period III would have been much flatter.

In addition, the short-term nature of the timeframes renders these findings vulnerable to future shifts in temperature trends as well as pending revisions to early 1999 HDD data. In particular, NOAA's conversion of temperature data to HDD and CDD data may have introduced spurious trends not apparent in the temperature data itself, such as the cooling trend in the HDD series during period II. It results largely from data-points near both ends of the period. Indeed, the

LS study does not acknowledge the presence of that cooling trend due to the brevity of that timeframe. The occurrence of that short-lived cooling trend immediately prior to period of

Figure 3



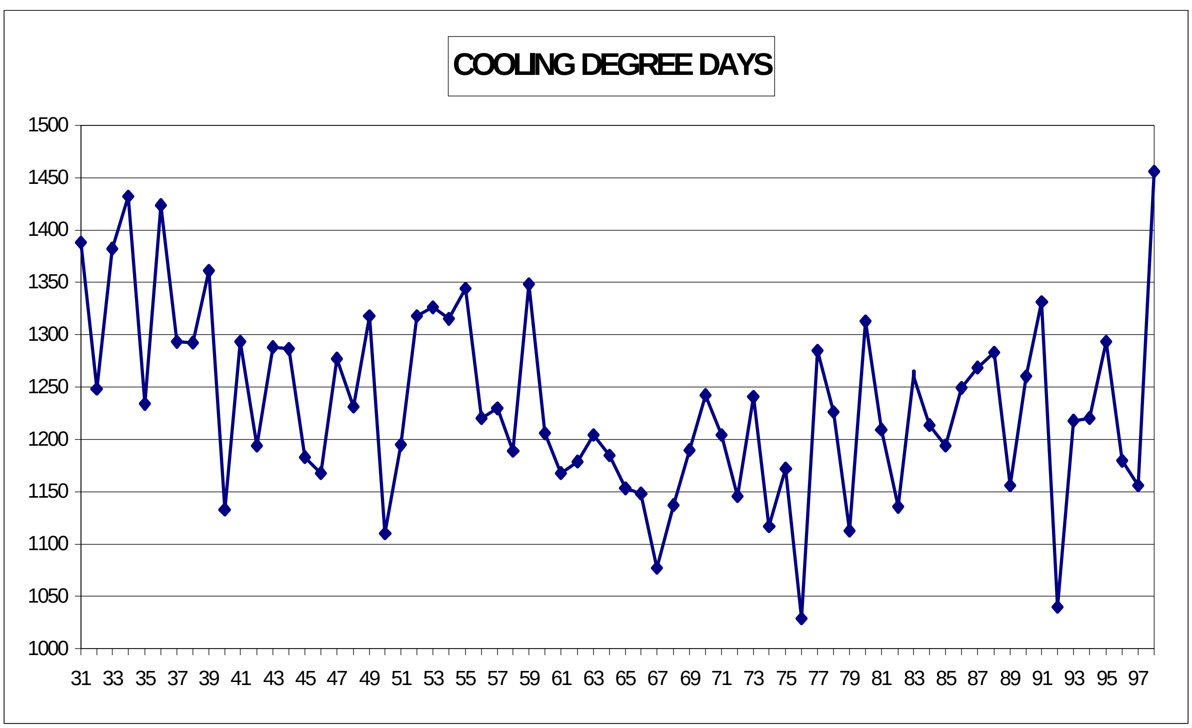
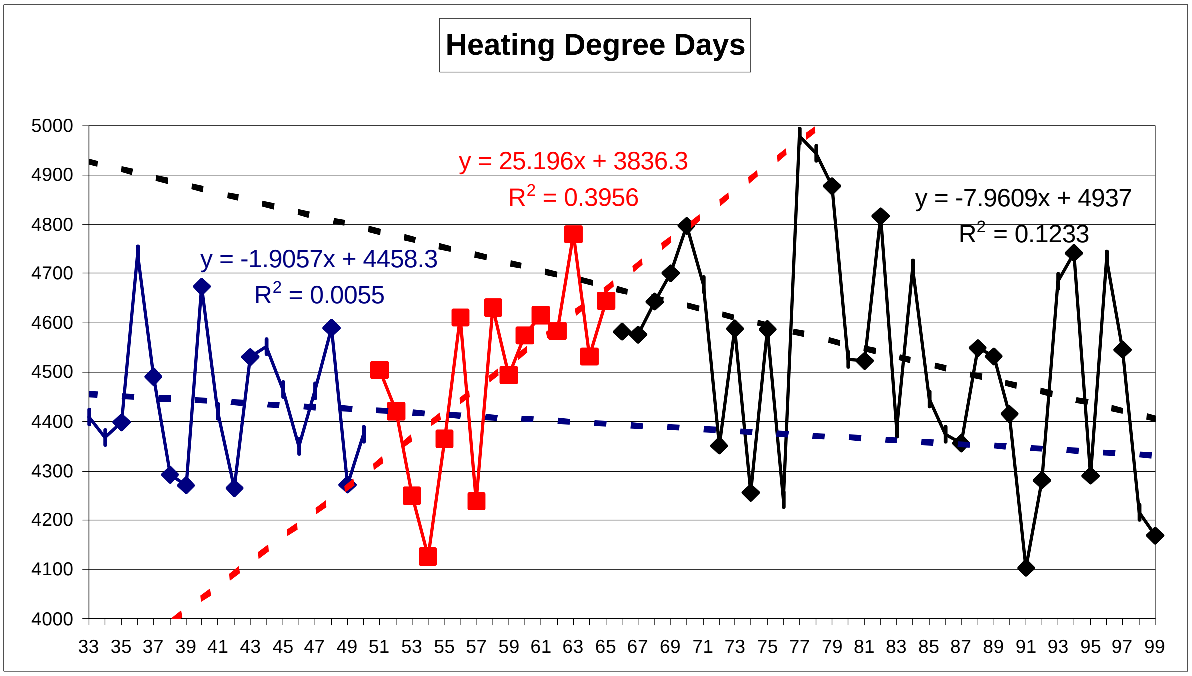
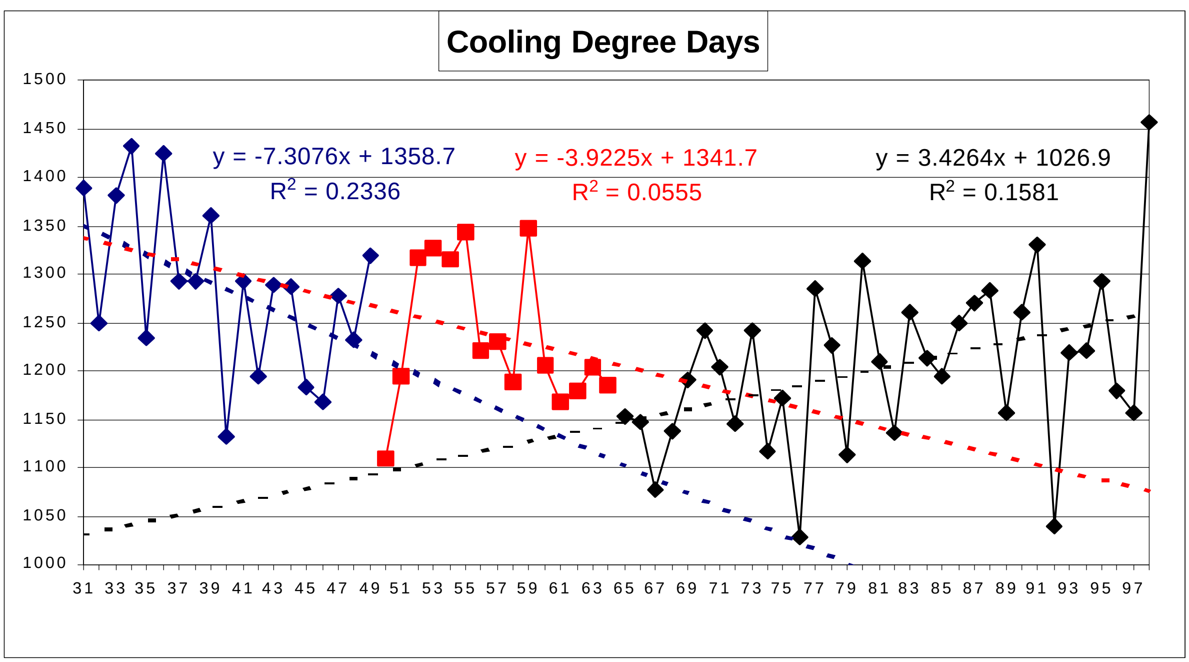


Figure 4: Periodic Trend Results





warming, however, means that pronounced warming trend based on HDD data may in part reflect a correction of the upward bias of the previous cooling trend. If so, it would account for some of the difference between the LS model results and HDD- and CDD-based regression results.

In contrast to the findings in the LS study, our model was unable to verify the extent to which impacts of El Nino and La Nina episodes affected HDD or CDD readings because of data complexities and differences in modeling techniques. Although these occurrences have often influenced readings, such as during last year, several instances of weather neutrality during El Nino and La Nina occurrences were recorded. Conversely, instances of unusually cold weather, such as those cited above, were generally not associated with any La Nina episodes. Moreover, 1976 and 1977, whose winters were the coldest during since early 1930's, witnessed significant El Nino episodes. But these episodes occurred in the Western Pacific, contributing to the diversion of normal weather patterns and, subsequently, larger and colder arctic air masses lingering over the North American continent.

Seasonal and Regional Characteristics

In addition to verifying a national warming trend, the results of our study also corroborate most of the distinct seasonal and regional patterns inherent in that trend. **Table 1** summarizes and compares national population-weighted seasonal patterns based on both LS and the HDD/CDD-based methodologies. **Figure 5** illustrates one example of regional trends, and how it differs from the national trend.

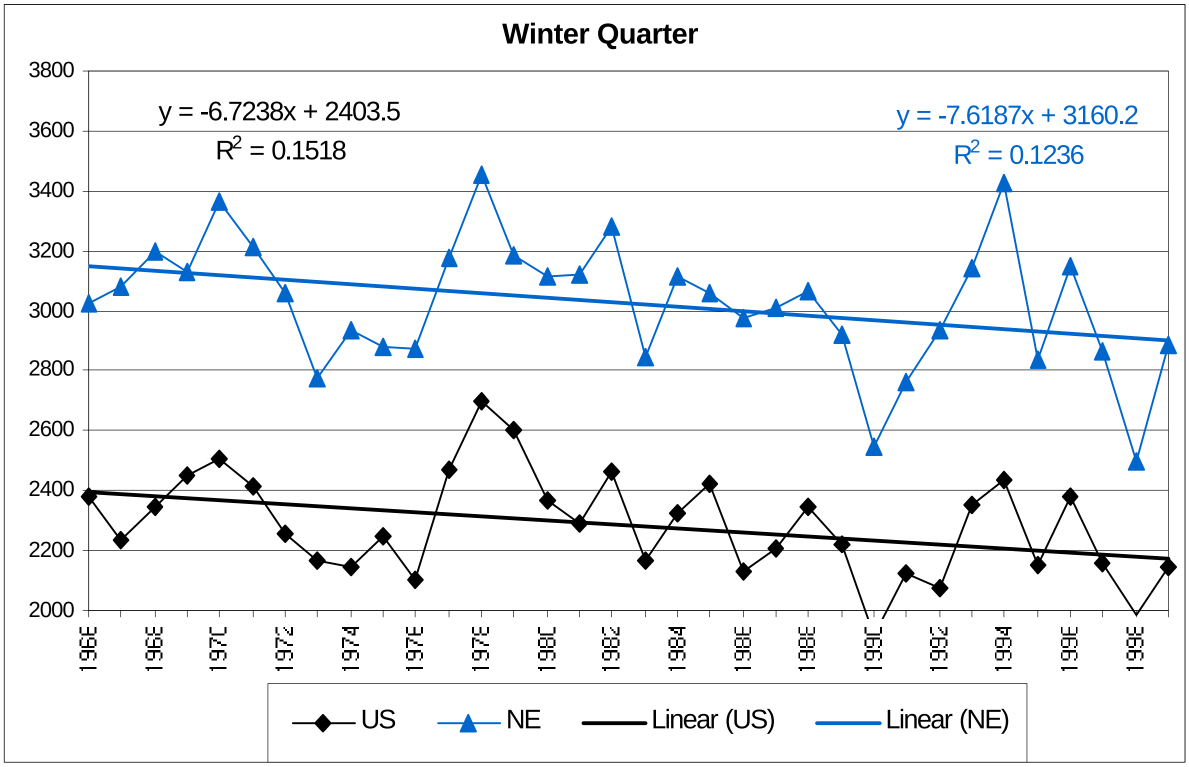
Table 1
Seasonal Temperature Trends for the Lower-48
(Degrees Fahrenheit Per Year)

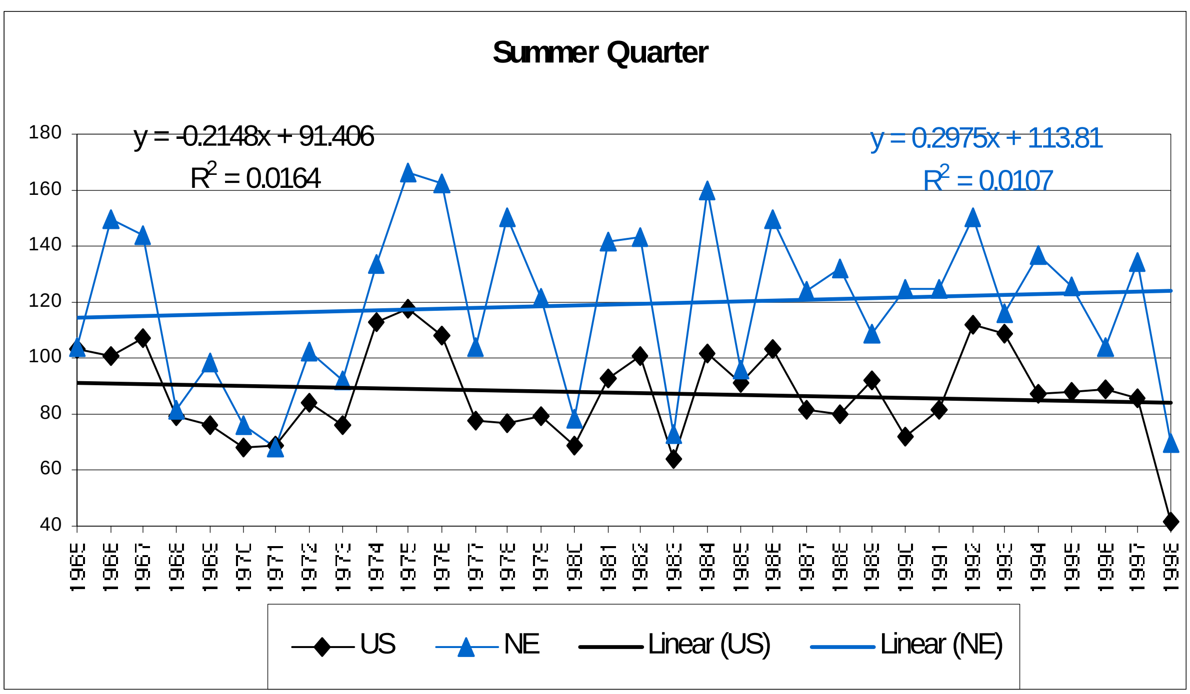
	Q1	Q2	Q3	Q4	Year
LS	.055	.011	.006	-.006	.015
HDD/CDD	.031	.011	.007	.007	.015

Consistent with the LS findings, combined HDD and CDD results indicate that the warming trend in the first quarter is far greater than the national average. The cooling trend in the fourth quarter, however, is more visible in the LS results than in the HDD/CDD-based trends. (The latter found a weaker cooling trend, which is obscured by the quarterly aggregation).
In the upper graph of Figure 5, a warming trend is evident in the Northeast as well as for the Lower-48 states. But in the Northeast, where the weather is colder than the national average, the trend is more pronounced. The lower graph, on the other hand, reveals a slight cooling trend in the Northeast in the summer, during which a slight warming trend dominates national weather patterns. For the Lower-48 states, a seasonal cooling trend is evident in the fourth quarter.

Figure 5

U.S. and Northeastern Seasonal Trends





Comparison of Periodic Averages

In addition to deriving the validity of trends, this analysis comprised statistical tests of averages of heating and cooling degree data based on several benchmark timeframes, including those of NOAA as well as those of LS, and whether differences between these averages were statistically significant. **Tables 2** and **3** provide complete data for HDD and CDD series, respectively. As in Figure 2, HDD data refer to 12-month cycles ending in June. The tables comprise statistics resulting from tests of significance between averages. In each Table, column 1 contains the complete data series. Columns 2 through 4 denote Periods I, II, and III, upon which the trend analysis above was based. Despite the statistical significance of some of the trends, the differences between the Period I, II, and III averages for either the HDD or CDD series were not only statistically insignificant, but also suggestive of a *cooling* trend over seven decades. Starting with the 1941-70 period, the two subsequent updates to the NOAA 30-year norms have also resulted in a spurious cooling trend. That observation highlights the shortcomings of relying on long-term averages without regard for inter-temporal trends.

In contrast, the data in columns 5-8 in both Tables suggest the presence of a warming trend since the mid-1960's. Substituting averages based on the latest 30-year timeframe (Column 7) for those of the NOAA timeframe (Column 5) would lower the HDD norms by 1.0 percent, and raise the CDD norms by 1.8 percent. The insertion of HDD and CDD averages based on 1990's data alone (column 8) would have an even more dramatic impact on weather-related energy demand: HDD's would be 2.5 percent lower than the NOAA norms; the CDD average would be 2.8 percent higher. Although these results do not meet conventional statistical tests of significance due to the volatility of the data in as well as the short time-span of the 1990's data, they are consistent with the warming trend. But it should be noted that these results do not fully account for the *magnitude* of that trend due to the lagged effect of the averaging process.

In addition, periodic averages based on *seasonal* (October-March HDD and April-September CDD) and *peak* (Q1 HDD and Q3 CDD) averages lead to similar conclusions about the (in)validity of periodic averages as weather premises.

The Impact of the Warming Trend on the Upcoming Winter and Summer Seasons

Inserting the new weather premises into the *Outlook* model results in substantial seasonal shifts in U.S. energy demand projections as well as a net reduction in demand for the 12-month cycle that combines both winter and summer seasons. These results, based on the August 1999 release of the *Outlook*, are summarized in **Table 4**. For the heating season, the impact of milder winters results in lower energy demand for almost all fuels and all sectors. With the exception of electric utility demand, summer results generally show small declines in residential and commercial space-heating demand, due largely to reduced residential demand for heating fuels in the spring.

TABLE 2
U.S. ANNUAL HEATING DEGREE DAYS: A PERIODIC ANALYSIS

	1	2	3	4	5	6	7	8
	Total Frame 1932 - 99	Period I 1932 - 50	Period II 1950 - 65	Period III 1965 - 99	30-yr Bench 1961 - 91	Truncated 8 1961 - 69	Latest 30- 1969 - 99	Post Bench 1991 - 99
1931 - 32	*	*						
1932 - 33	4409	4409						
1933 - 34	4368	4368						
1934 - 35	4398	4398						
1935 - 36	4741	4741						
1936 - 37	4491	4491						
1937 - 38	4292	4292						
1938 - 39	4270	4270						
1939 - 40	4674	4674						
1940 - 41	4421	4421						
1941 - 42	4264	4264						
1942 - 43	4531	4531						
1943 - 44	4551	4551						
1944 - 45	4465	4465						
1945 - 46	4350	4350						
1946 - 47	4462	4462						
1947 - 48	4590	4590						
1948 - 49	4272	4272						
1949 - 50	4374	4374						
1950 - 51	4505		4505					
1951 - 52	4421		4421					
1952 - 53	4250		4250					
1953 - 54	4126		4126					
1954 - 55	4365		4365					
1955 - 56	4611		4611					
1956 - 57	4239		4239					
1957 - 58	4631		4631					
1958 - 59	4494		4494					
1959 - 60	4574		4574					
1960 - 61	4616		4616					
1961 - 62	4584		4584		4584	4584		
1962 - 63	4779		4779		4779	4779		
1963 - 64	4531		4531		4531	4531		
1964 - 65	4645		4645		4645	4645		
1965 - 66	4582			4582	4582	4582		
1966 - 67	4576			4576	4576	4576		
1967 - 68	4643			4643	4643	4643		
1968 - 69	4701			4701	4701	4701		
1969 - 70	4797			4797	4797		4797	
1970 - 71	4678			4678	4678		4678	
1971 - 72	4351			4351	4351		4351	
1972 - 73	4588			4588	4588		4588	
1973 - 74	4255			4255	4255		4255	
1974 - 75	4587			4587	4587		4587	
1975 - 76	4241			4241	4241		4241	
1976 - 77	4979			4979	4979		4979	
1977 - 78	4944			4944	4944		4944	
1978 - 79	4877			4877	4877		4877	
1979 - 80	4526			4526	4526		4526	
1980 - 81	4523			4523	4523		4523	
1981 - 82	4816			4816	4816		4816	
1982 - 83	4385			4385	4385		4385	
1983 - 84	4712			4712	4712		4712	
1984 - 85	4445			4445	4445		4445	
1985 - 86	4374			4374	4374		4374	
1986 - 87	4355			4355	4355		4355	
1987 - 88	4548			4548	4548		4548	
1988 - 89	4532			4532	4532		4532	
1989 - 90	4415			4415	4415		4415	
1990 - 91	4103			4103	4103		4103	
1991 - 92	4281			4281			4281	4281
1992 - 93	4684			4684			4684	4684
1993 - 94	4741			4741			4741	4741
1994 - 95	4290			4290			4290	4290
1995 - 96	4730			4730			4730	4730
1996 - 97	4546			4546			4546	4546
1997 - 98	4216			4216			4216	4216
1998 - 99	4169			4169			4169	4169
MEAN	**4499.8**	**4440.2**	**4491.4**	**4535.0**	**4569.1**	**4630.2**	**4522.9**	**4457.1**
STDEV	197.0	137.8	179.1	225.7	208.2	79.9	237.4	243.4
Date Range	1932 - 99	1932 – 50	1950 - 65	1965 - 99	1961 - 91	1961 - 69	1969 - 99	1991 - 99
N	67	18	15	34	30	8	30	8
Reference						1991 - 99	1961 - 91	1961 - 91
N						8	30	30
MEANDIF (A)						-173.1	46.2	112.0
STDDIF (B)						96.8	58.6	88.4
T-STAT (A / B)						-1.79	0.79	1.27

Leap-year February HDDs are adjusted by the factor 28/29

*Data for the first NOAA annual cycle (1931-32), are excluded. At 3923, it is 576 HDD's (almost 3 standard deviations) below the mean. Its inclusion would result in a spurious upward trend for the Period I timeframe.

TABLE 3
U.S. ANNUAL COOLING DEGREE DAYS: A PERIODIC ANALYSIS

Leap-year February HDDs are adjusted by the factor 28/29

	1	2	3	4	5	6	7	8
	Total Frame 1931 - 98	Period I 1931 - 49	Period II 1950 - 64	Period III 1965 - 98	30-yr Bench 1961 - 90	Truncated 8 1961 - 68	Latest 30-yr 1969 - 98	Post Bench 1991 - 98
1931	1388	1388						
1932	1248	1248						
1933	1382	1382						
1934	1432	1432						
1935	1234	1234						
1936	1424	1424						
1937	1293	1293						
1938	1292	1292						
1939	1361	1361						
1940	1133	1133						
1941	1293	1293						
1942	1194	1194						
1943	1288	1288						
1944	1287	1287						
1945	1183	1183						
1946	1168	1168						
1947	1277	1277						
1948	1232	1232						
1949	1318	1318						
1950	1110		1110					
1951	1195		1195					
1952	1318		1318					
1953	1326		1326					
1954	1315		1315					
1955	1344		1344					
1956	1221		1221					
1957	1230		1230					
1958	1189		1189					
1959	1348		1348					
1960	1206		1206					
1961	1168		1168		1168	1168		
1962	1179		1179		1179	1179		
1963	1204		1204		1204	1204		
1964	1185		1185		1185	1185		
1965	1153			1153	1153	1153		
1966	1148			1148	1148	1148		
1967	1077			1077	1077	1077		
1968	1137			1137	1137	1137		
1969	1190			1190	1190		1190	
1970	1242			1242	1242		1242	
1971	1204			1204	1204		1204	
1972	1146			1146	1146		1146	
1973	1241			1241	1241		1241	
1974	1117			1117	1117		1117	
1975	1172			1172	1172		1172	
1976	1029			1029	1029		1029	
1977	1285			1285	1285		1285	
1978	1226			1226	1226		1226	
1979	1113			1113	1113		1113	
1980	1313			1313	1313		1313	
1981	1209			1209	1209		1209	
1982	1136			1136	1136		1136	
1983	1260			1260	1260		1260	
1984	1214			1214	1214		1214	
1985	1194			1194	1194		1194	
1986	1249			1249	1249		1249	
1987	1269			1269	1269		1269	
1988	1283			1283	1283		1283	
1989	1156			1156	1156		1156	
1990	1260			1260	1260		1260	
1991	1331			1331			1331	1331
1992	1040			1040			1040	1040
1993	1218			1218			1218	1218
1994	1220			1220			1220	1220
1995	1293			1293			1293	1293
1996	1180			1180			1180	1180
1997	1156			1156			1156	1156
1998	1456			1456			1456	1456
MEAN	**1233.5**	**1285.6**	**1235.8**	**1203.4**	**1191.9**	**1156.4**	**1213.3**	**1236.7**
STDEV	89.2	85.1	74.5	85.8	65.1	38.7	85.9	125.0
Date Range	1931 - 98	1931 - 49	1950 - 64	1965 - 98	1961 - 90	1961 - 68	1969 - 98	1991 - 98
N	68	19	15	34	30	8	30	8
Reference						1991 - 99	1961 - 90	1961 - 90
N						8	30	30
MEANDIF (A)						80.3	-21.4	-44.8
STDDIF (B)						49.5	20.0	33.3
T-STAT (A / B)						1.62	-1.07	-1.34

TABLE 4

CHANGES IN ENERGY DEMAND DUE TO WARMING TREND: 1999Q4 TO 2000Q3
(PERCENT)

	1999Q4	2000Q1	Winter	2000Q2	2000Q3	Summer	Total
Total Primary Energy	-0.04	-1.03	-0.55	-0.08	0.19	0.06	-0.26
Petroleum Products							
Distillate	-0.16	-1.11	-0.65	-0.15	-0.01	-0.08	-0.37
Residual Fuel Oil	-0.34	-3.12	-1.80	0.05	1.28	0.67	-0.71
LPG	-0.11	-0.98	-0.55	-0.07	-0.03	-0.05	-0.32
Total Petroleum	-0.06	-0.47	-0.26	-0.02	-0.04	-0.03	-0.15
Natural Gas	-0.07	-2.39	-1.39	-0.42	0.37	-0.04	-0.83
Coal	-0.02	-0.82	-0.42	0.09	0.53	0.32	-0.05
Electricity							
Fossil Fuel Generation	-0.03	-1.14	-0.59	0.23	0.91	0.59	0.03
Total Sales	-0.01	-0.73	-0.38	0.14	0.60	0.39	0.01

Reflecting equal and offsetting shifts in seasonal electricity demand, the increase in fossil fuel consumption by electric utilities during the cooling season is virtually the same as the decline during the heating season, leaving utility demand for these fuels virtually unchanged for the 12-month cycle. But fuel demand patterns vary: the hike in natural gas consumption by electric utilities far exceeds the winter season decline. Coal and oil demand by electric utilities also increase in the summer season to meet the additional generation requirement, but that increase in those fuels is offset by a sizable decline in the winter.