# Energy Savings due to DST in British Columbia

AEIC Load Research Workshop

May 2007, Boston

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Business Systems Group

Power Smart

BC Hydro

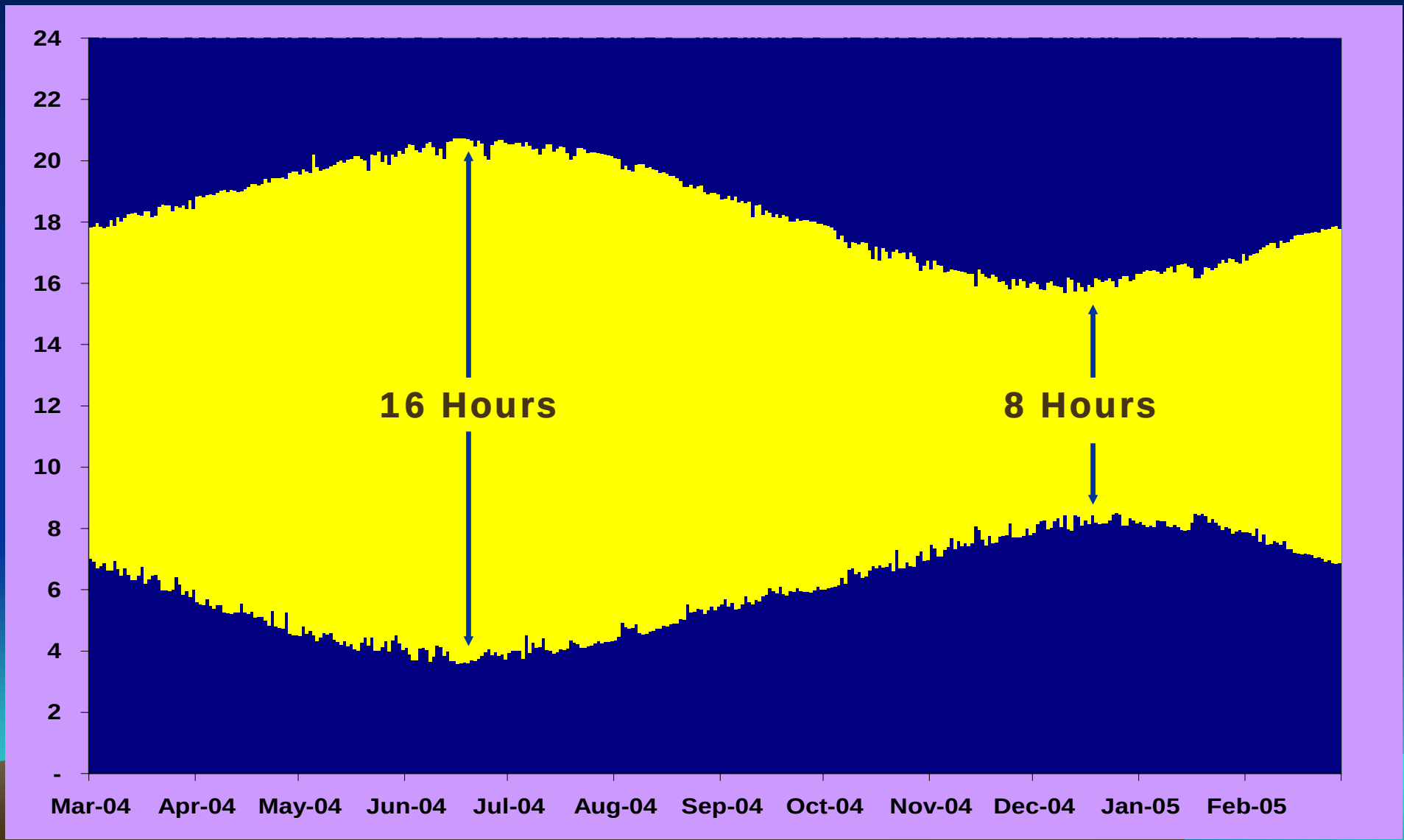
# Energy Savings due to DST in British Columbia

1. DST and Energy Savings – The Theory
2. Analyzing the Daily Load for a Year
3. Investigating the Start of DST (Mar-Apr)
4. Investigating the End of DST (Oct-Nov)
5. Model Results
6. 2007 DST Extension
7. Conclusion

# 1. DST and Energy Savings – The Theory

We chose the 12-month period March 1 2004 to February 28 2005

# Annual Sunshine Cycle PST



# DST Trivia Question #1

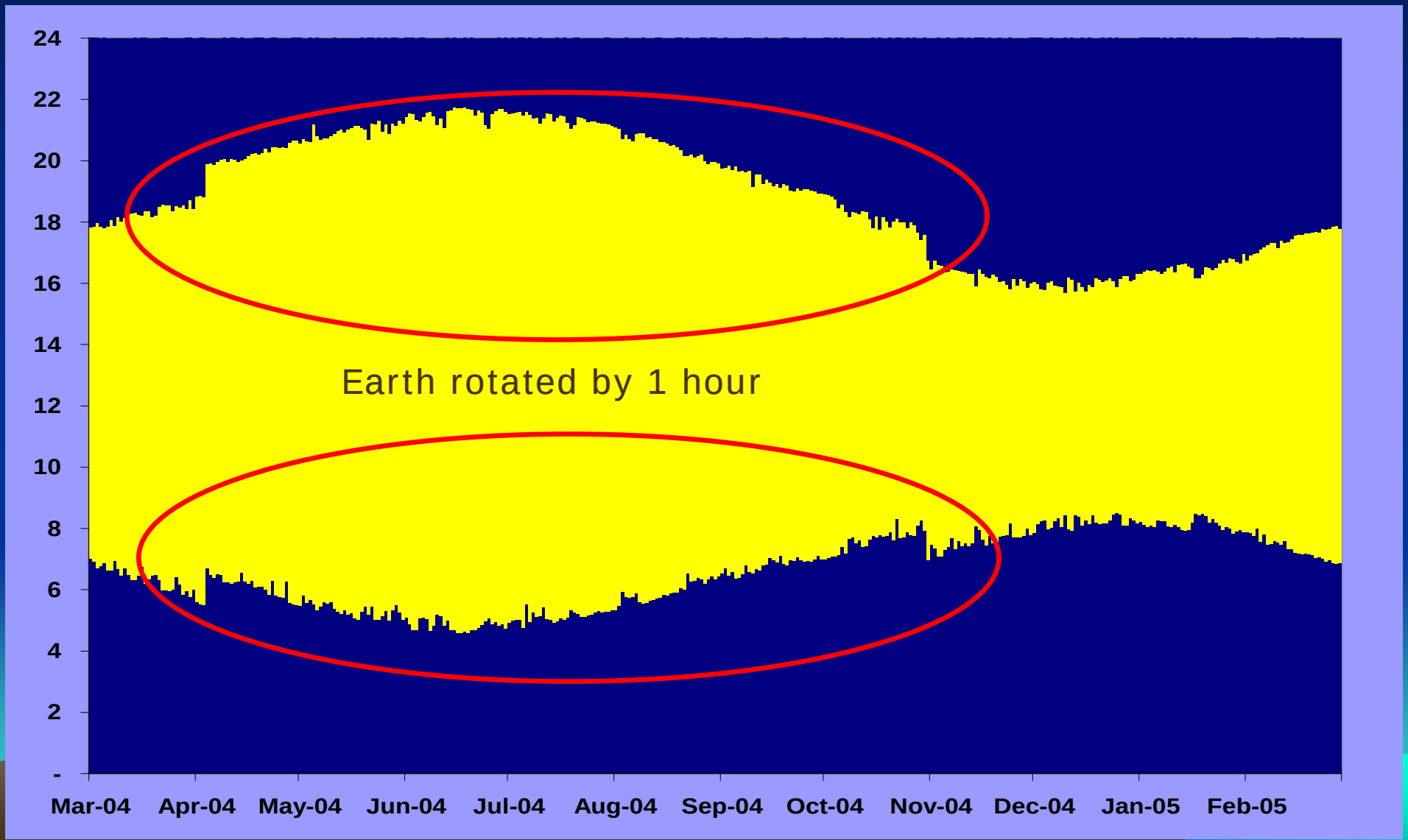
- How do you implement DST without resetting all your clocks forward and back by an hour ?

# DST Trivia Question #1

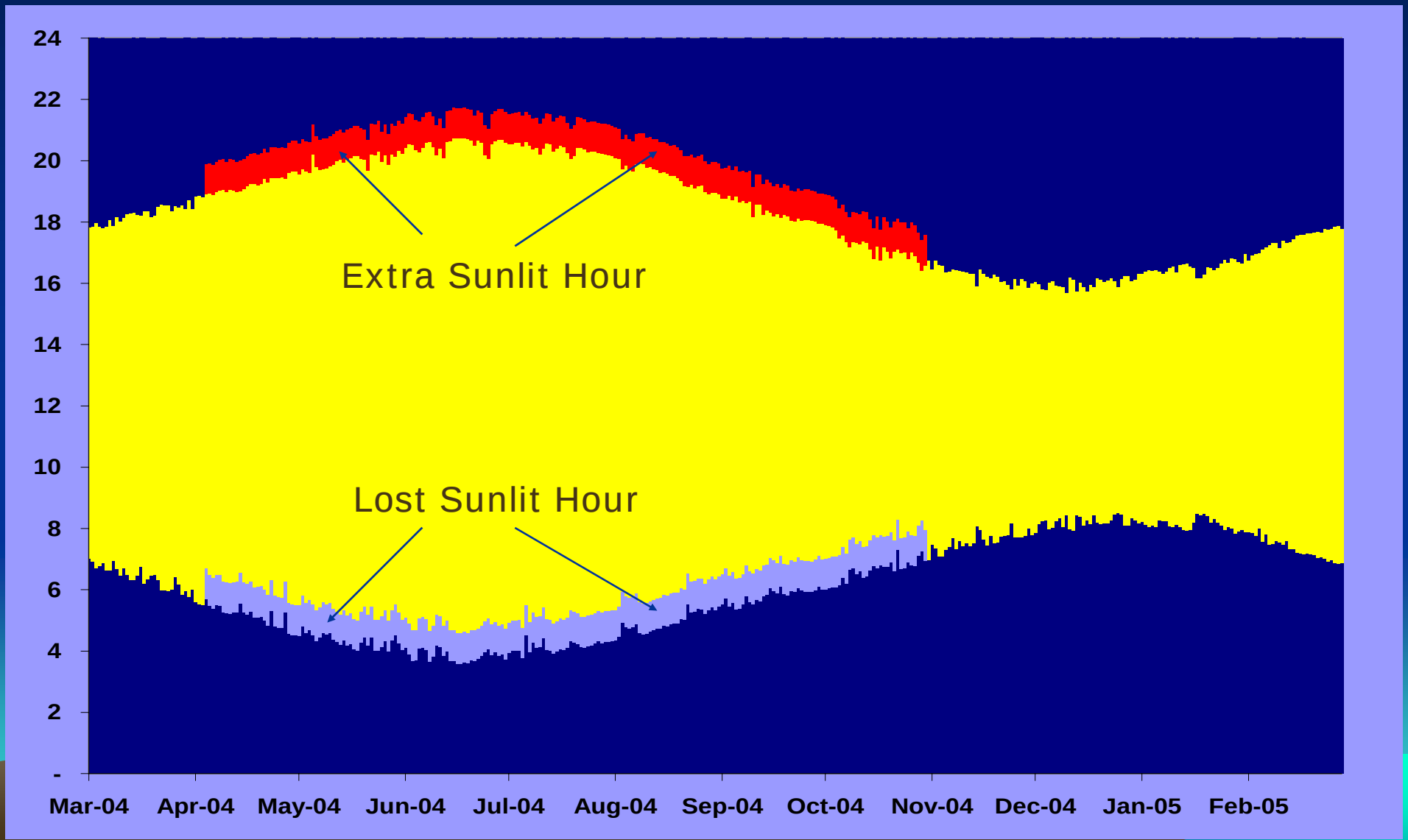
- How do you implement DST without resetting all your clocks forward and back by an hour ?

Simple – you rotate the earth forward and back by an hour….

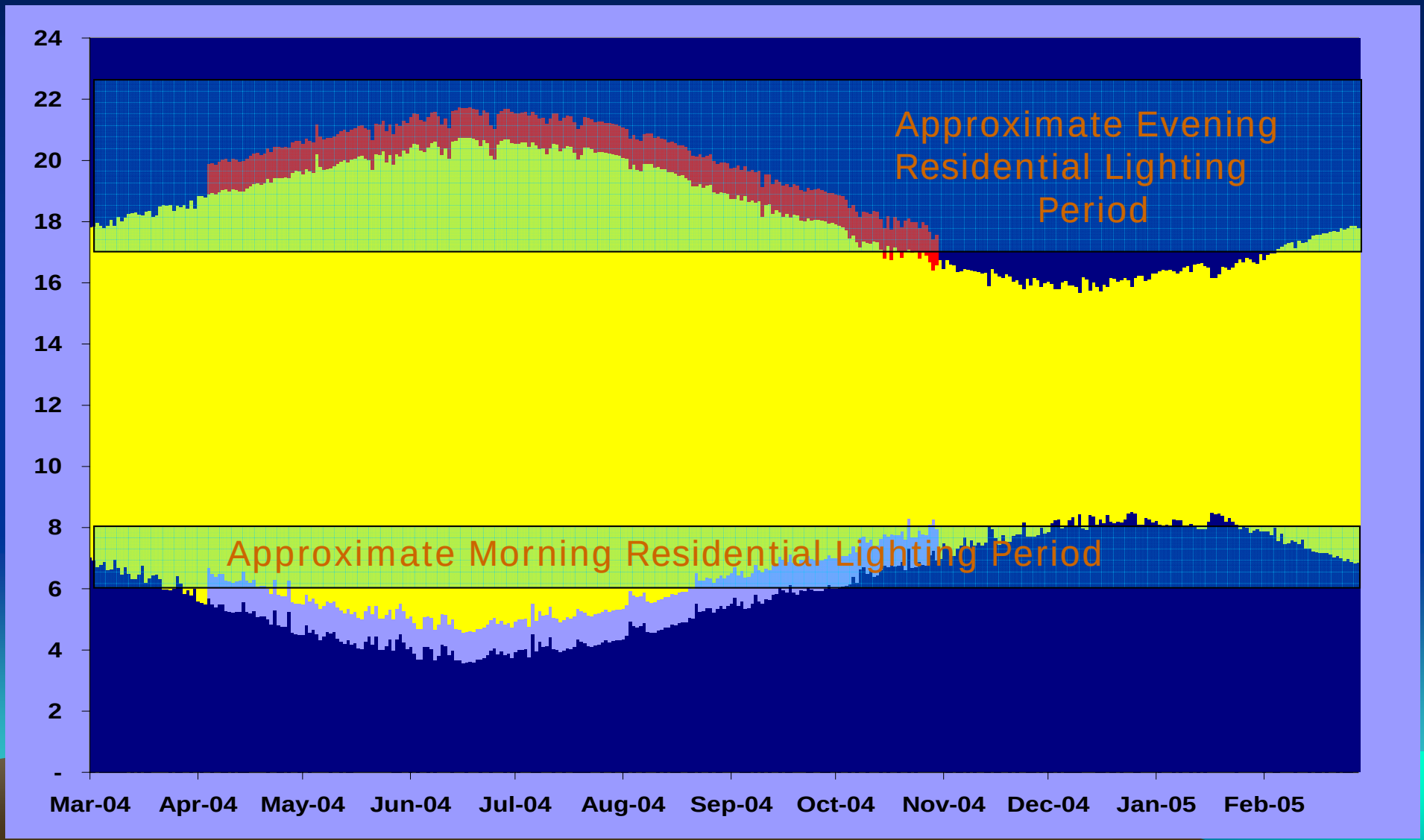
# Annual Sunshine Cycle PDT I



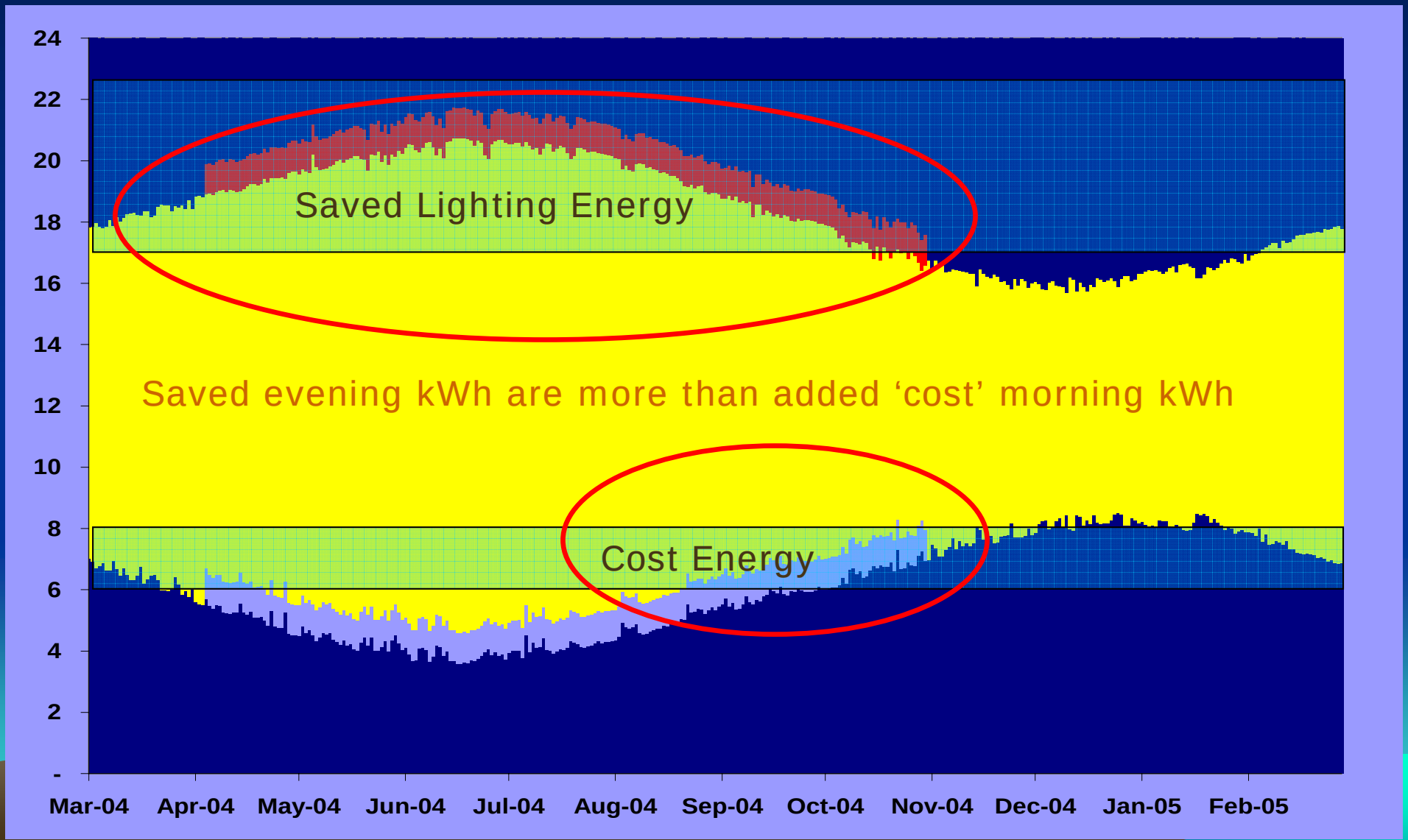
# Annual Sunshine Cycle PDT II



# Annual Sunshine Cycle PDT IIa



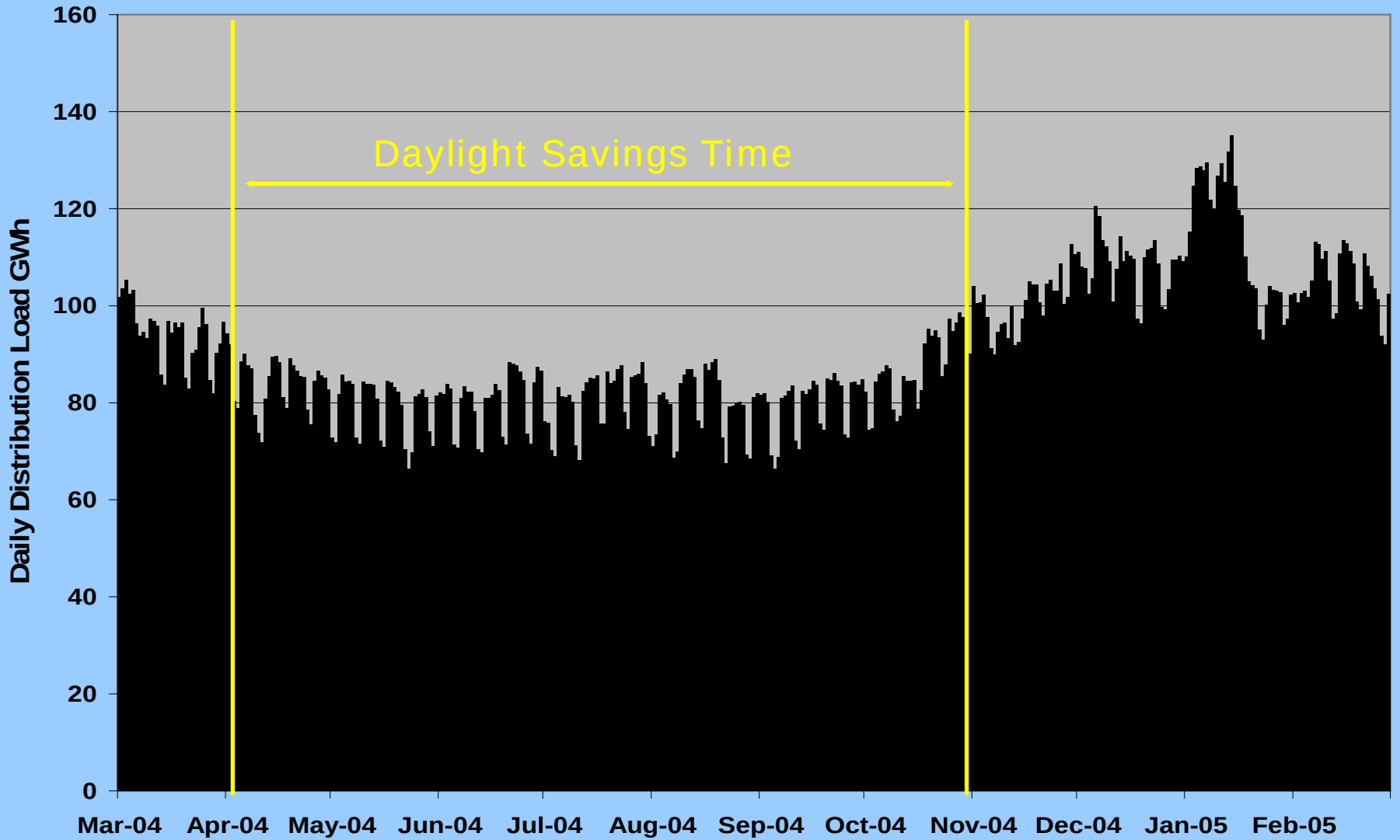
# Annual Sunshine Cycle PDT III



# 2. Analyzing the Daily Load for a Year

Distribution Load Shape estimated by aggregating the Load Research Rate Class load shapes and modelling the Street Lighting and Unmetered loads

# BC Hydro Distribution Load

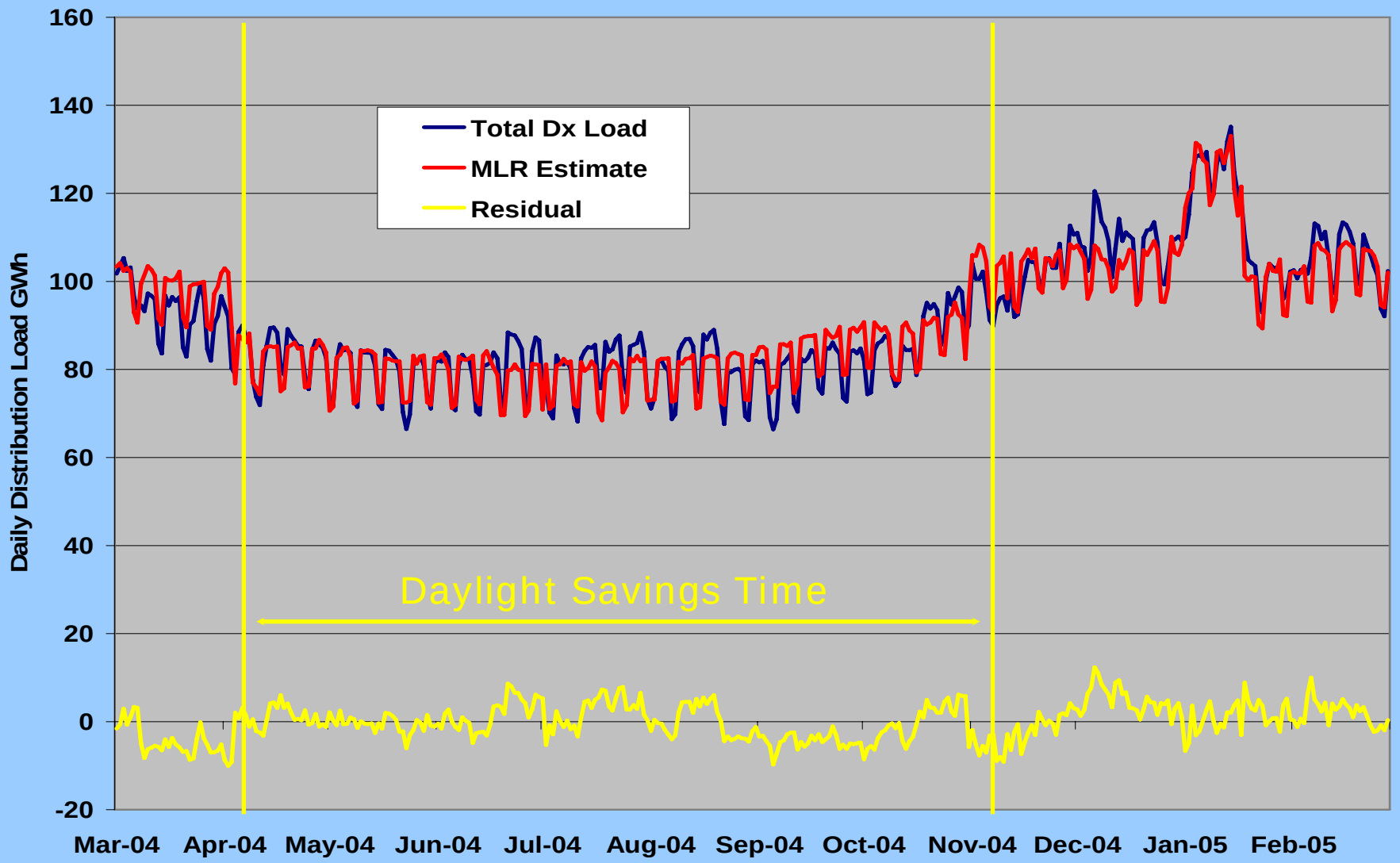


# MLR#1 – Total Dx Daily GWh

Multiple Linear Regression (with XLSTAT)

- Y: Daily Distribution GWh
- X:
  - Daylight Hours
  - Average Daily Temperature
  - Daily Cloud Opacity (later removed)
  - Wind Speed (later removed)
  - Number of Accounts (later removed)
  - Weekday or Weekend/Holiday (1/0)
  - PDT or PST (1/0)
  - Two weeks in January 2005 Anomaly (1/0)

# MLR#1 – Total Dx Daily GWh



# MLR#1 – Goodness of Fit

| | |
|---|---|
| Observations | 365.000 |
| Sum of weights | 365.000 |
| DF | 358.000 |
| $R^2$ | 0.911 |
| Adjusted $R^2$ | 0.910 |
| MSE | 17.921 |
| RMSE | 4.233 |
| MAPE | 3.822 |
| DW | 0.438 |
| Cp | 7.000 |
| AIC | 1060.320 |
| SBC | 1087.620 |
| PC | 0.092 |

Good !

Good !

# MLR#1 – Analysis of Variance

Good !

Good !

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 6 | 66017.917 | 11002.986 | 613.958 | < 0.0001 |
| Error | 358 | 6415.861 | 17.921 | | |
| Corrected Total | 364 | 72433.778 | | | |

# MLR#1 – Model Parameters

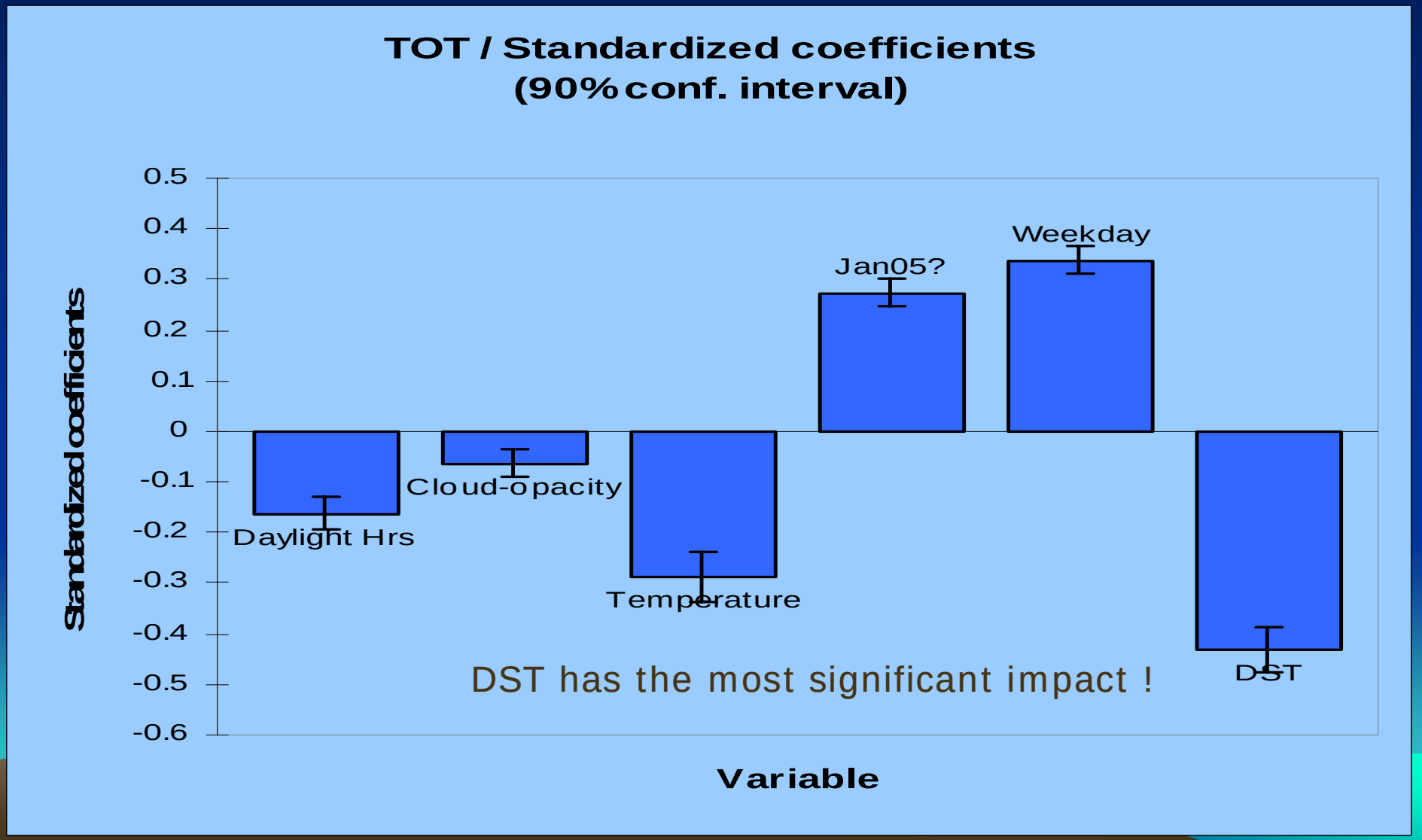
Good !

Good !

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 108.391 | 1.247 | 86.951 | < 0.0001 | 106.335 | 110.447 |
| Daylight Hrs | -0.742 | 0.086 | -8.645 | < 0.0001 | -0.884 | -0.601 |
| Cloud-opacity | -2.766 | 0.734 | -3.769 | 0.000 | -3.977 | -1.556 |
| Temperature | -0.680 | 0.068 | -9.943 | < 0.0001 | -0.793 | -0.567 |
| Jan05? | 18.350 | 1.200 | 15.287 | < 0.0001 | 16.370 | 20.330 |
| Weekday | 10.323 | 0.480 | 21.493 | < 0.0001 | 9.531 | 11.115 |
| DST | -12.304 | 0.758 | -16.239 | < 0.0001 | -13.554 | -11.055 |

Average Daily Load is about 12 GWh (>10%) lower
When DST is in effect !

# MLR#1 – Std Coefficients



# MLR#1 – Model Parameters

**Does this mean that DST saves 12 GWh a day,**

**or 2,520 GWh over a year (210 days of DST) ?**

**In other words, about 8% of Distribution GWh ?**

**Probably not……**

# MLR#1 – Correlation Matrix

**Because we have** **Multicollinearity!**

| Variables | Daylight Hrs | Cloud-opacity | Temperature | Jan05? | Weekday | DST | TOT |
|---|---|---|---|---|---|---|---|
| Daylight Hrs | **1.000** | -0.303 | 0.498 | -0.183 | 0.006 | 0.480 | -0.542 |
| Cloud-opacity | -0.303 | **1.000** | -0.232 | -0.014 | 0.037 | -0.250 | 0.169 |
| Temperature | 0.498 | -0.232 | **1.000** | -0.443 | 0.005 | 0.793 | -0.816 |
| Jan05? | -0.183 | -0.014 | -0.443 | **1.000** | -0.049 | -0.257 | 0.527 |
| Weekday | 0.006 | 0.037 | 0.005 | -0.049 | **1.000** | -0.012 | 0.326 |
| DST | 0.480 | -0.250 | 0.793 | -0.257 | -0.012 | **1.000** | -0.797 |
| TOT | -0.542 | 0.169 | -0.816 | 0.527 | 0.326 | -0.797 | **1.000** |

Temp and DST highly correlated, and both important to model

# MLR#2 – Dx Daily without DST

The obvious thing to do is to remove one of the highly correlated variables

We will remove DST and see what happens….

# MLR#2 Model Fit, Correlation

| | |
|---|---|
| Observations | 365.000 |
| Sum of weights | 365.000 |
| DF | 359.000 |
| $R^2$ | 0.846 |
| Adjusted $R^2$ | 0.844 |
| MSE | 31.036 |
| RMSE | 5.571 |
| MAPE | 5.224 |
| DW | 0.280 |
| Cp | 6.000 |
| AIC | 1259.779 |
| SBC | 1283.178 |
| PC | 0.159 |

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 61291.872 | 12258.374 | 394.973 | < 0.0001 |
| Error | 359 | 11141.907 | 31.036 | | |
| Corrected Total | 364 | 72433.778 | | | |

Good fit, no correlation issues

| Variables | Daylight Hrs | Cloud-opacity | Temperature | Jan05? | Weekday | TOT |
|---|---|---|---|---|---|---|
| Daylight Hrs | **1.000** | -0.303 | 0.498 | -0.183 | 0.006 | -0.542 |
| Cloud-opacity | -0.303 | **1.000** | -0.232 | -0.014 | 0.037 | 0.169 |
| Temperature | 0.498 | -0.232 | **1.000** | -0.443 | 0.005 | -0.816 |
| Jan05? | -0.183 | -0.014 | -0.443 | **1.000** | -0.049 | 0.527 |
| Weekday | 0.006 | 0.037 | 0.005 | -0.049 | **1.000** | 0.326 |
| TOT | -0.542 | 0.169 | -0.816 | 0.527 | 0.326 | **1.000** |

# MLR#2 Comparison to MLR#1

Model including DST:

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 108.391 | 1.247 | 86.951 | < 0.0001 | 106.335 | 110.447 |
| Daylight Hrs | -0.742 | 0.086 | -8.645 | < 0.0001 | -0.884 | -0.601 |
| Cloud-opacity | -2.766 | 0.734 | -3.769 | 0.000 | -3.977 | -1.556 |
| Temperature | -0.680 | 0.068 | -9.943 | < 0.0001 | -0.793 | -0.567 |
| Jan05? | 18.350 | 1.200 | 15.287 | < 0.0001 | 16.370 | 20.330 |
| Weekday | 10.323 | 0.480 | 21.493 | < 0.0001 | 9.531 | 11.115 |
| DST | -12.304 | 0.758 | -16.239 | < 0.0001 | -13.554 | -11.055 |

Model without DST:

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 112.373 | 1.608 | 69.866 | < 0.0001 | 109.720 | 115.025 |
| Daylight Hrs | -0.937 | 0.112 | -8.373 | < 0.0001 | -1.121 | -0.752 |
| Cloud-opacity | -2.077 | 0.964 | -2.154 | 0.032 | -3.667 | -0.487 |
| Temperature | -1.479 | 0.063 | -23.633 | < 0.0001 | -1.582 | -1.376 |
| Jan05? | 15.269 | 1.560 | 9.789 | < 0.0001 | 12.697 | 17.842 |
| Weekday | 10.454 | 0.632 | 16.542 | < 0.0001 | 9.412 | 11.496 |

Removing DST has a dramatic effect on the Temperature Value

# MLR#3 – Multicollinearity

Can we prove that **Multicollinearity!** affects the model results ?

We can test this theory by replacing the DST variable with another that is highly correlated with temperature but probably does not affect daily GWh significantly……

After much consideration, the variable AndyBeerDay was chosen for this role. Andy is known to often enjoy a cold one on a hot day but he rarely has beer on a cold day.

# MLR#3 – AndyBeerDay I

| | |
|---|---|
| Observations | 365.000 |
| Sum of weights | 365.000 |
| DF | 358.000 |
| $R^2$ | 0.879 |
| Adjusted $R^2$ | 0.877 |
| MSE | 24.519 |
| RMSE | 4.952 |
| MAPE | 4.438 |
| DW | 0.396 |
| Cp | 7.000 |
| AIC | 1174.726 |
| SBC | 1202.026 |
| PC | 0.126 |

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 6 | 63656.081 | 10609.347 | 432.704 | < 0.0001 |
| Error | 358 | 8777.698 | 24.519 | | |
| Corrected Total | 364 | 72433.778 | | | |

We have a good model here, so what can we deduce ?

# MLR#3 – AndyBeerDay II

| | |
|---|---|
| Observations | 365.000 |
| Sum of weights | 365.000 |
| DF | 358.000 |
| $R^2$ | 0.879 |
| Adjusted $R^2$ | 0.877 |
| MSE | 24.519 |
| RMSE | 4.952 |
| MAPE | 4.438 |
| DW | 0.396 |
| Cp | 7.000 |
| AIC | 1174.726 |
| SBC | 1202.026 |
| PC | 0.126 |

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 6 | 63656.081 | 10609.347 | 432.704 | < 0.0001 |
| Error | 358 | 8777.698 | 24.519 | | |
| Corrected Total | 364 | 72433.778 | | | |

Well, it looks like we can conclude that on days when Andy has a beer, BC Hydro saves between 8 and 11 GWh, with a high level of confidence. *Send the beer truck !*

At 1 beer for 10 GWh, this DSM program passes all the tests – TRC, UCT, HIC etc wish eesh

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 108.130 | 1.493 | 72.403 | < 0.0001 | 105.668 | 110.593 |
| Daylight Hrs | -0.809 | 0.100 | -8.069 | < 0.0001 | -0.975 | -0.644 |
| Cloud-opacity | -2.495 | 0.858 | -2.908 | 0.004 | -3.910 | -1.080 |
| Temperature | -0.798 | 0.089 | -8.979 | < 0.0001 | -0.945 | -0.652 |
| Jan05? | 19.033 | 1.438 | 13.232 | < 0.0001 | 16.661 | 21.405 |
| Weekday | 10.325 | 0.562 | 18.376 | < 0.0001 | 9.398 | 11.251 |
| AndyBeerDay | -9.524 | 0.970 | -9.820 | < 0.0001 | -11.123 | -7.924 |

# MLR#3 – Correlation Matrix

**Multicollinearity!**

| Variables | Daylight Hrs | Cloud-opacity | Temperature | Jan05? | Weekday | AndyBeerDay | TOT |
|---|---|---|---|---|---|---|---|
| Daylight Hrs | **1.000** | -0.303 | 0.498 | -0.183 | 0.006 | 0.485 | -0.542 |
| Cloud-opacity | -0.303 | **1.000** | -0.232 | -0.014 | 0.037 | -0.254 | 0.169 |
| Temperature | 0.498 | -0.232 | **1.000** | -0.443 | 0.005 | 0.826 | -0.816 |
| Jan05? | -0.183 | -0.014 | -0.443 | **1.000** | -0.049 | -0.225 | 0.527 |
| Weekday | 0.006 | 0.037 | 0.005 | -0.049 | **1.000** | -0.017 | 0.326 |
| AndyBeerDay | 0.485 | -0.254 | 0.826 | -0.225 | -0.017 | **1.000** | -0.758 |
| TOT | -0.542 | 0.169 | -0.816 | 0.527 | 0.326 | -0.758 | **1.000** |

Temp and AndyBeerDay highly correlated, and both important to model

# MLR#3 – Conclusion

We need both Temperature and DST as variables in the model, and the regression can establish a relationship between DST and load, but *cannot distinguish* the DST effect from the Temperature effect because these parameters are highly correlated with each other.

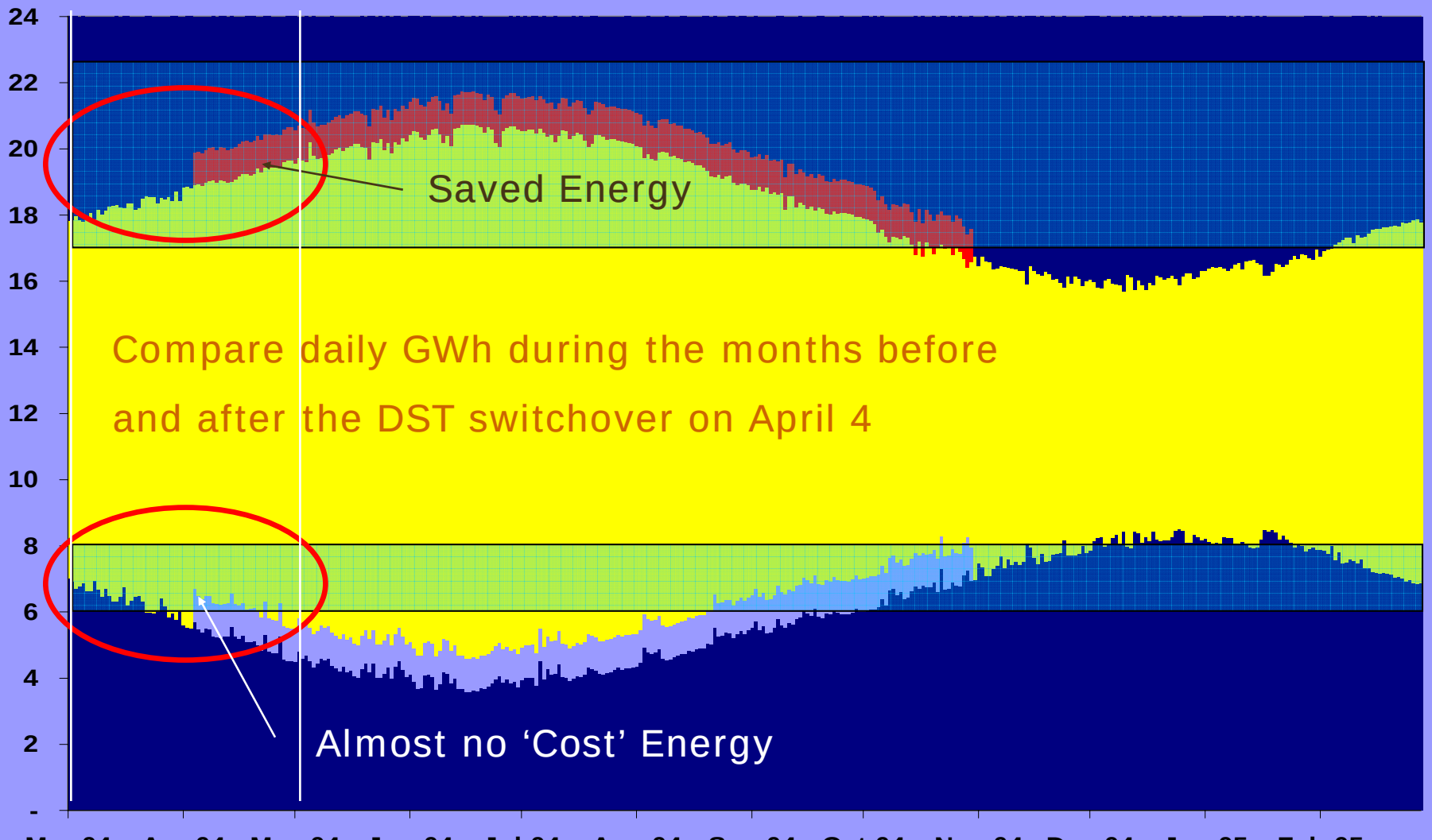
So we will abandon this approach for now because of…..

**Multicollinearity!**

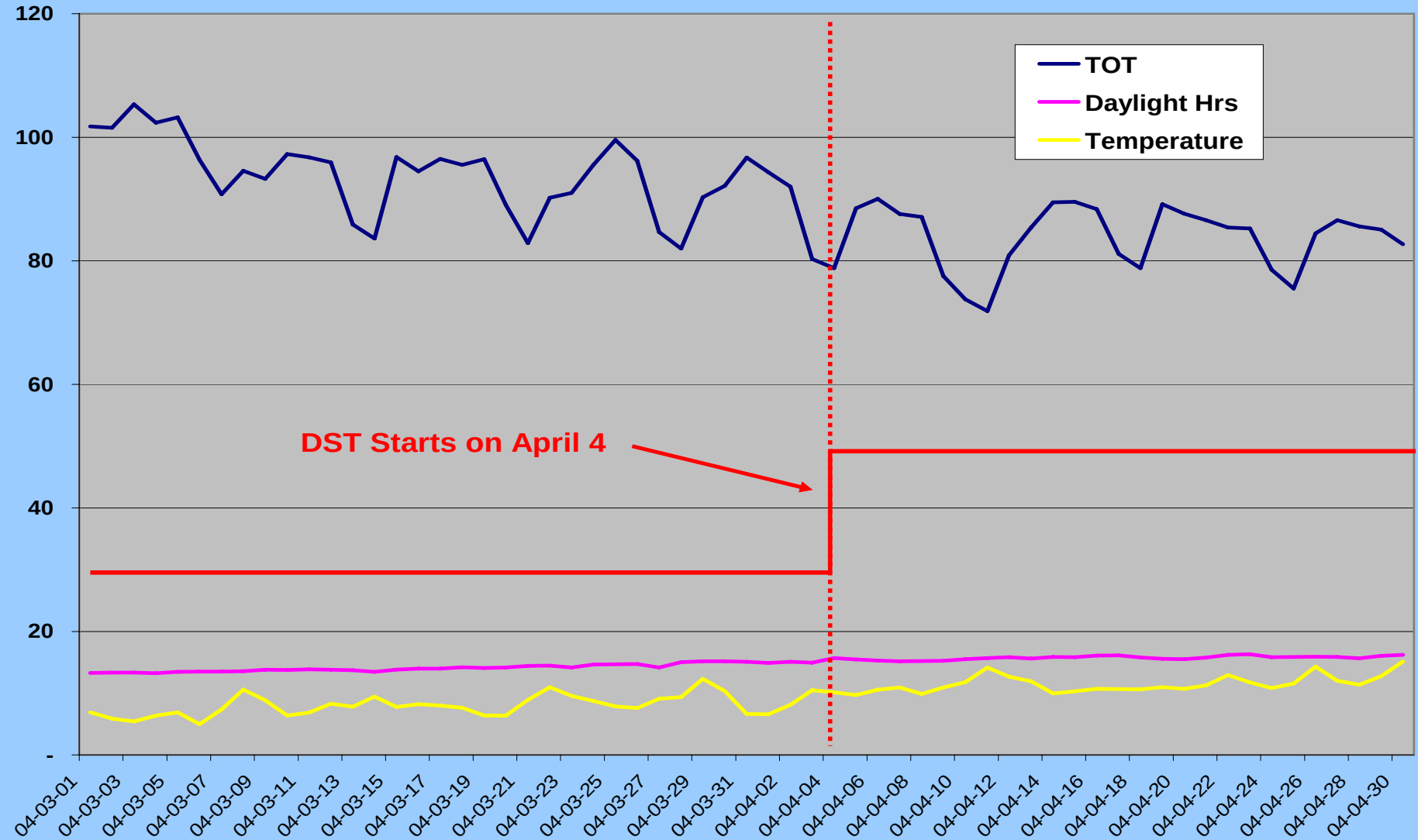
# 3. Investigating the DST Switching Times

The start of DST: March - April

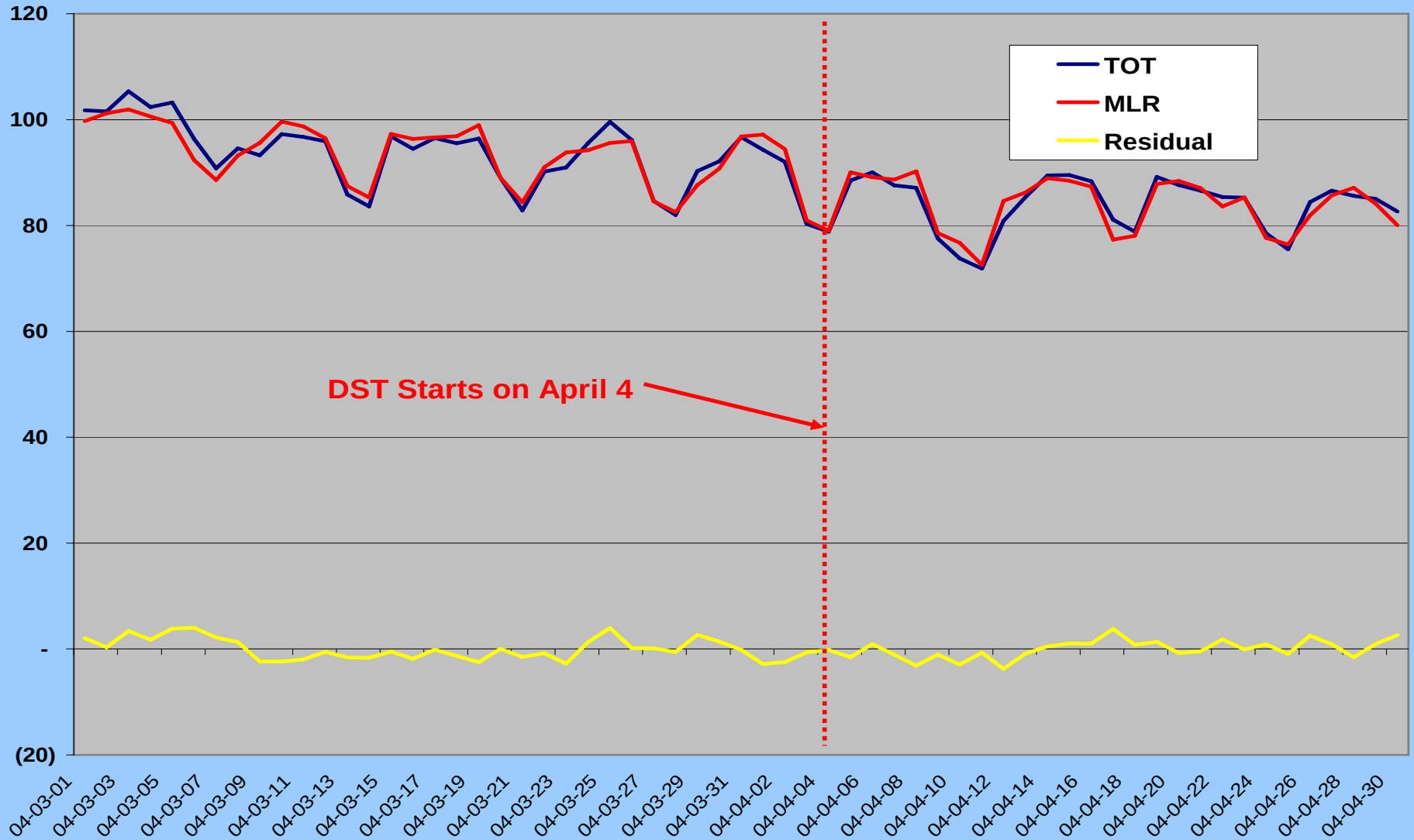
# Annual Sunshine Cycle PDT IV



# MLR#4 – Some Variables



# MLR#4 – Modelled Daily Load



# MLR#4 – Fit and Parameters

| | |
|---|---|
| Observations | 61.000 |
| Sum of weigh | 61.000 |
| DF | 56.000 |
| $R^2$ | 0.936 |
| Adjusted $R^2$ | 0.931 |
| MSE | 3.958 |
| RMSE | 1.990 |
| MAPE | 1.738 |
| DW | 1.075 |
| Cp | 5.000 |
| AIC | 88.705 |
| SBC | 99.260 |
| PC | 0.075 |

| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 4 | 3242.813 | 810.703 | 204.820 | < 0.0001 |
| Error | 56 | 221.655 | 3.958 | | |
| Corrected Tot | 60 | 3464.468 | | | |

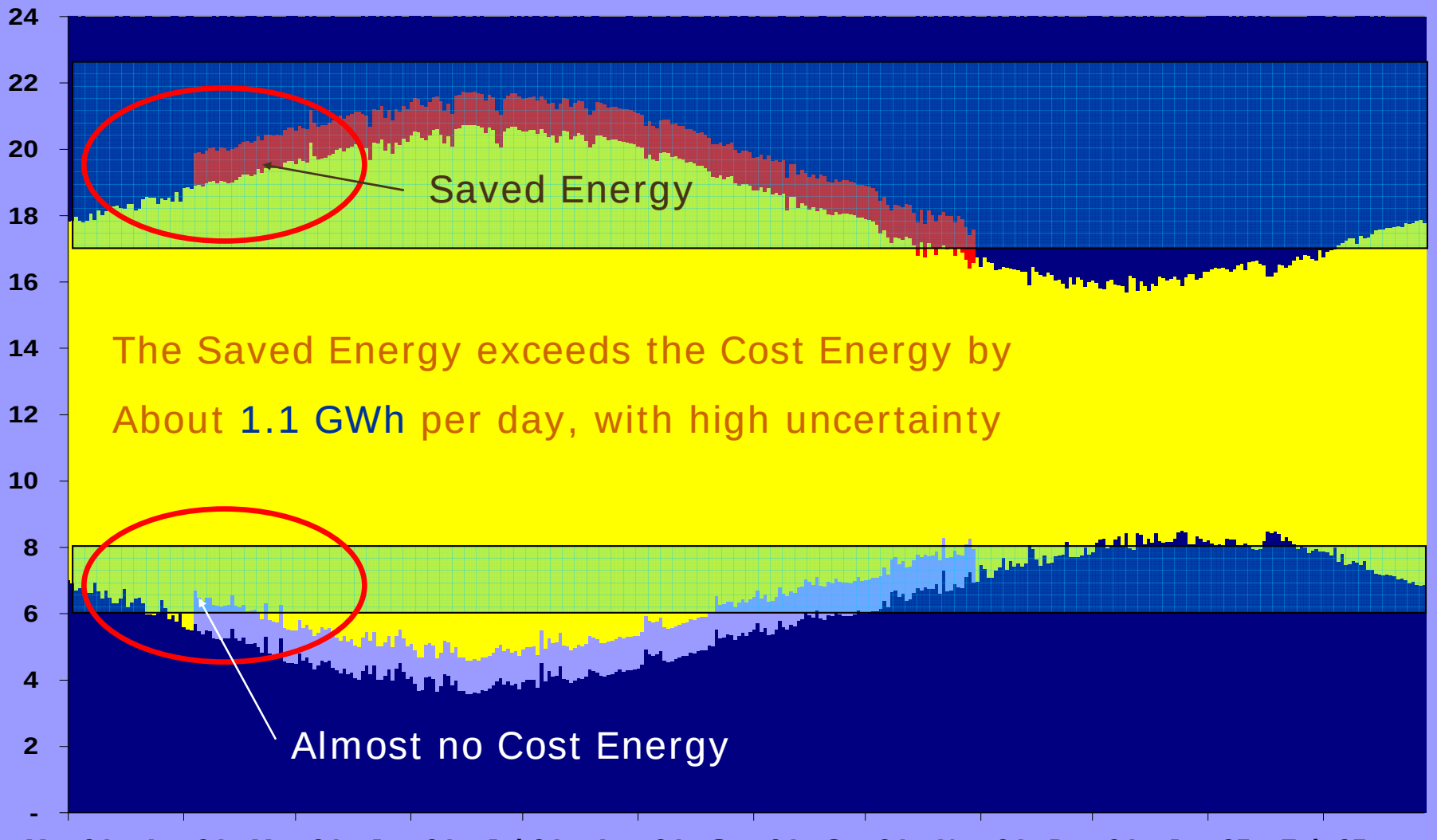
We have a good model, and DST is the weakest variable, not really significant

With no morning energy 'cost', the estimated evening DST saving is about 1.1 GWh a day with a high degree of uncertainty

Considerably less than 12 GWh per day !

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 124.712 | 7.489 | 16.653 | < 0.0001 | 112.186 | 137.237 |
| Daylight Hrs | -1.807 | 0.571 | -3.167 | 0.002 | -2.762 | -0.853 |
| Temperature | -1.603 | 0.186 | -8.612 | < 0.0001 | -1.915 | -1.292 |
| DST | -1.108 | 0.994 | -1.115 | 0.270 | -2.771 | 0.554 |
| Weekday | 9.966 | 0.569 | 17.512 | < 0.0001 | 9.014 | 10.917 |

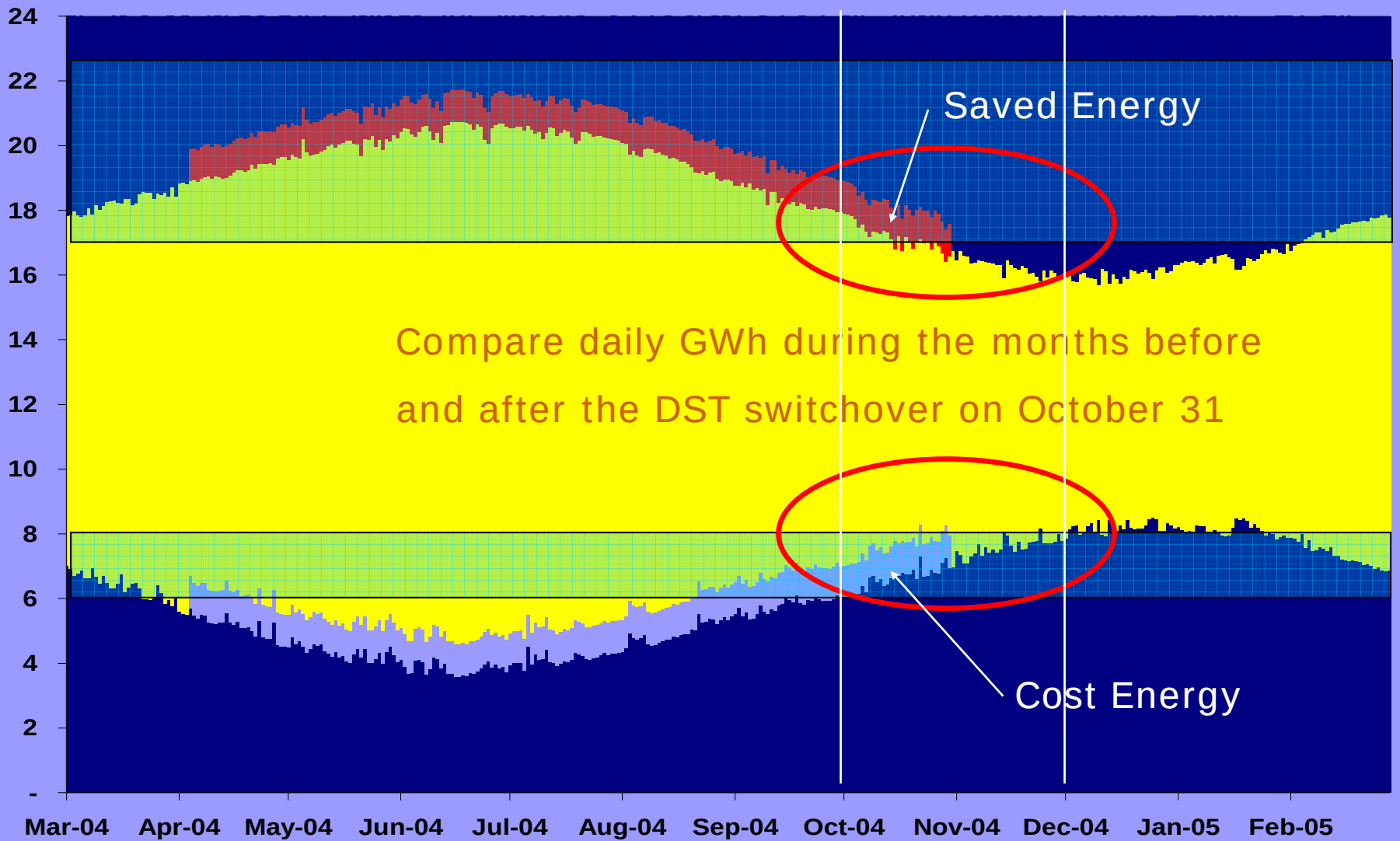
# Annual Sunshine Cycle PDT V



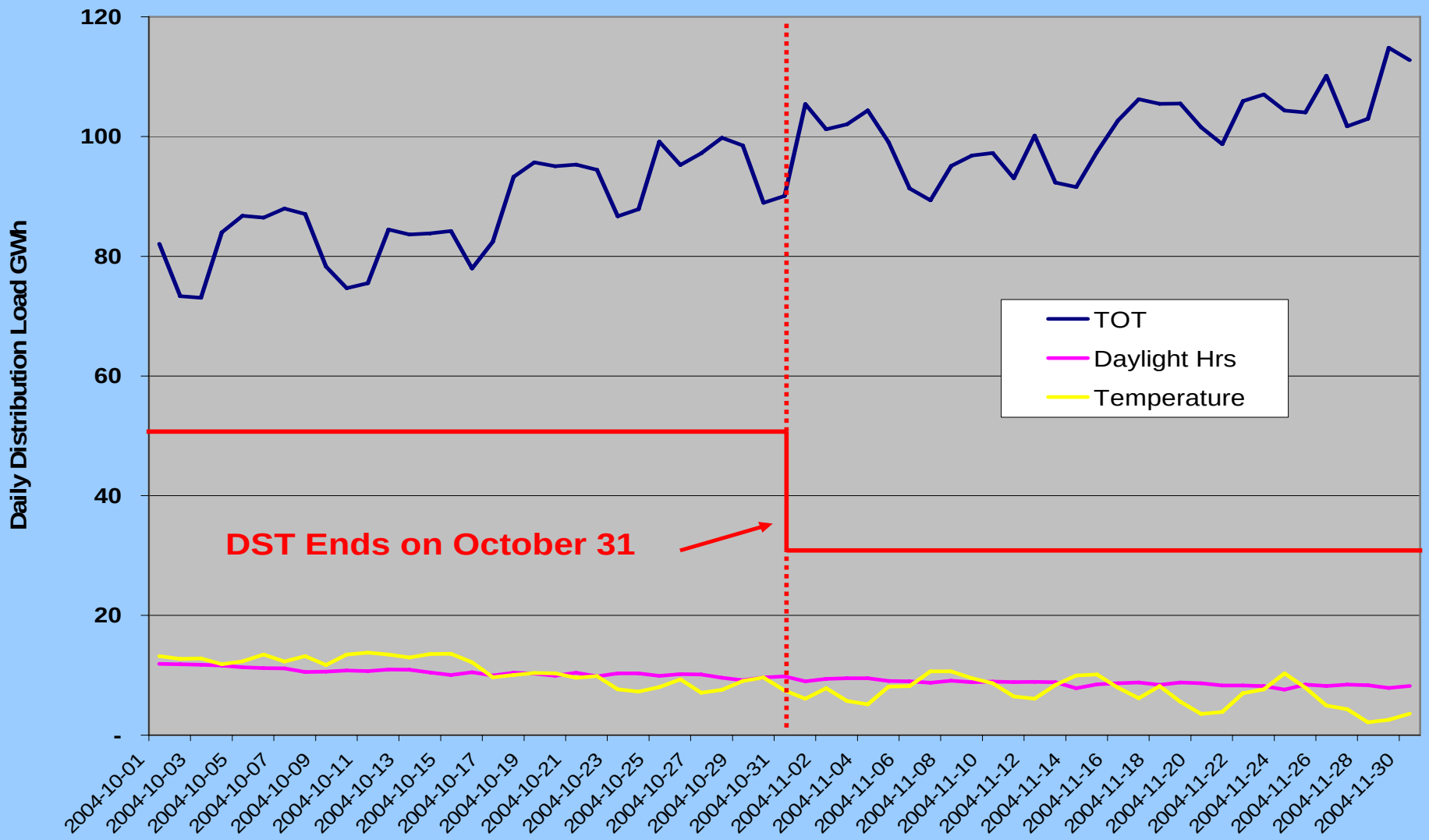
# 4. Investigating the DST Switching Times

The end of DST: October - November

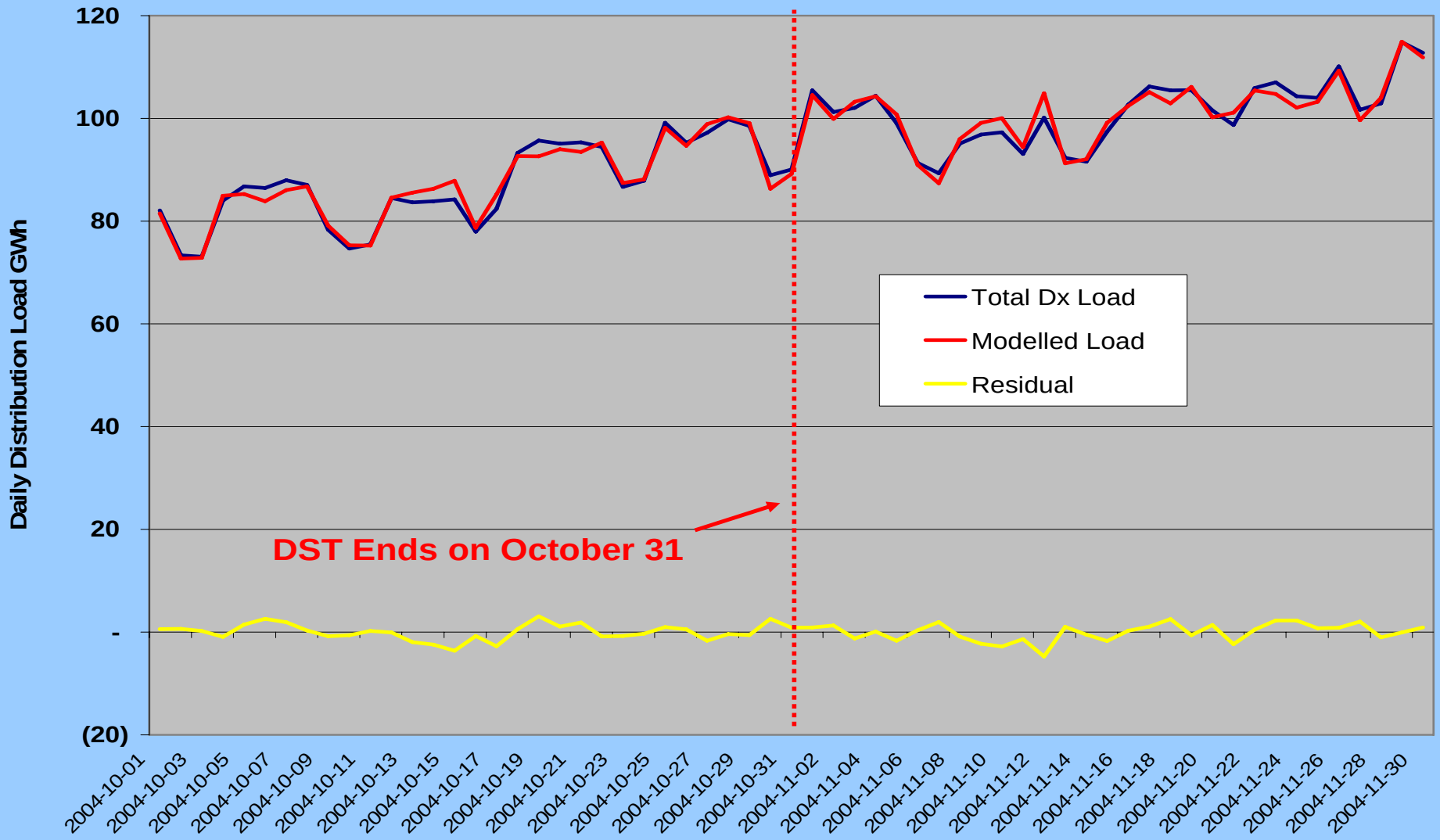
# Annual Sunshine Cycle PDT VI



# MLR#5 – Some Variables



# MLR#5 – Modelled Daily Load



# MLR#5 – Fit and Parameters

| | |
|---|---|
| Observations | 61.000 |
| Sum of weights | 61.000 |
| DF | 56.000 |
| $R^2$ | 0.973 |
| Adjusted $R^2$ | 0.971 |
| MSE | 2.880 |
| RMSE | 1.697 |
| MAPE | 1.400 |
| DW | 1.381 |
| Cp | 5.000 |
| AIC | 69.315 |
| SBC | 79.870 |
| PC | 0.031 |

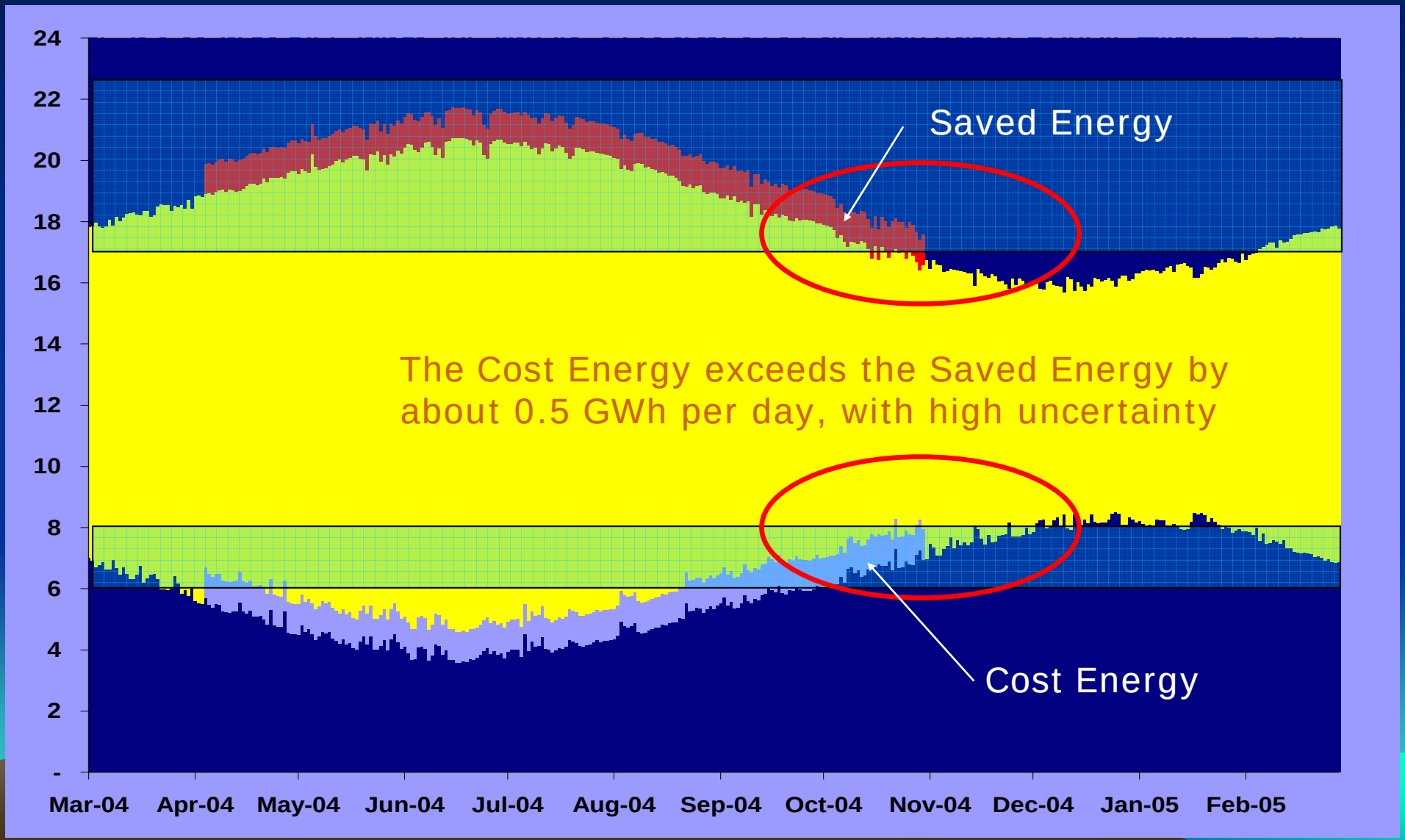
| Source | DF | Sum of squares | Mean squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 4 | 5884.927 | 1471.232 | 510.786 | < 0.0001 |
| Error | 56 | 161.298 | 2.880 | | |
| Corrected Total | 60 | 6046.225 | | | |

Very good model, and DST effect is not significant. The model indicates *increased* load on DST days of about 0.5 GWh, with great uncertainty

This implies that , if the estimate of evening savings of 1.1 GWh is accepted, then the morning 'cost' is about 1.6 GWh per day

| Source | Value | Standard error | t | Pr > \|t\| | Lower (90%) | Upper (90%) |
|---|---|---|---|---|---|---|
| Intercept | 138.697 | 3.280 | 42.288 | < 0.0001 | 133.211 | 144.182 |
| Daylight Hrs | -3.708 | 0.397 | -9.347 | < 0.0001 | -4.371 | -3.044 |
| Temperature | -1.770 | 0.104 | -16.952 | < 0.0001 | -1.944 | -1.595 |
| DST | 0.473 | 0.821 | 0.576 | 0.567 | -0.901 | 1.846 |
| Weekday | 9.886 | 0.466 | 21.228 | < 0.0001 | 9.107 | 10.665 |

# Annual Sunshine Cycle PDT VII



# 5. Model Results

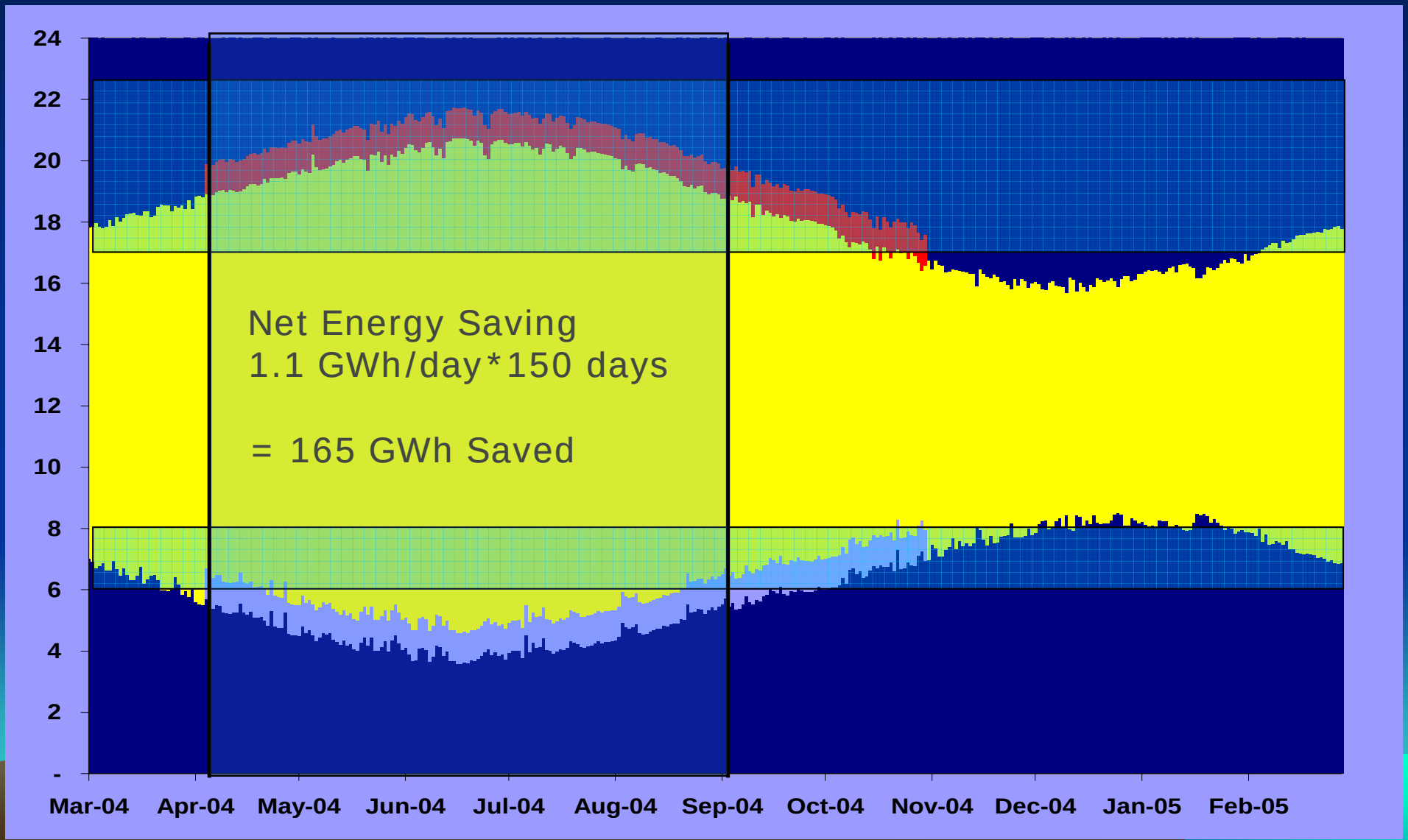
# 5. Model Results

- The 210 days of DST can be divided into a period with additional morning ‘Cost’ energy and a period with no additional morning ‘Cost’ energy.

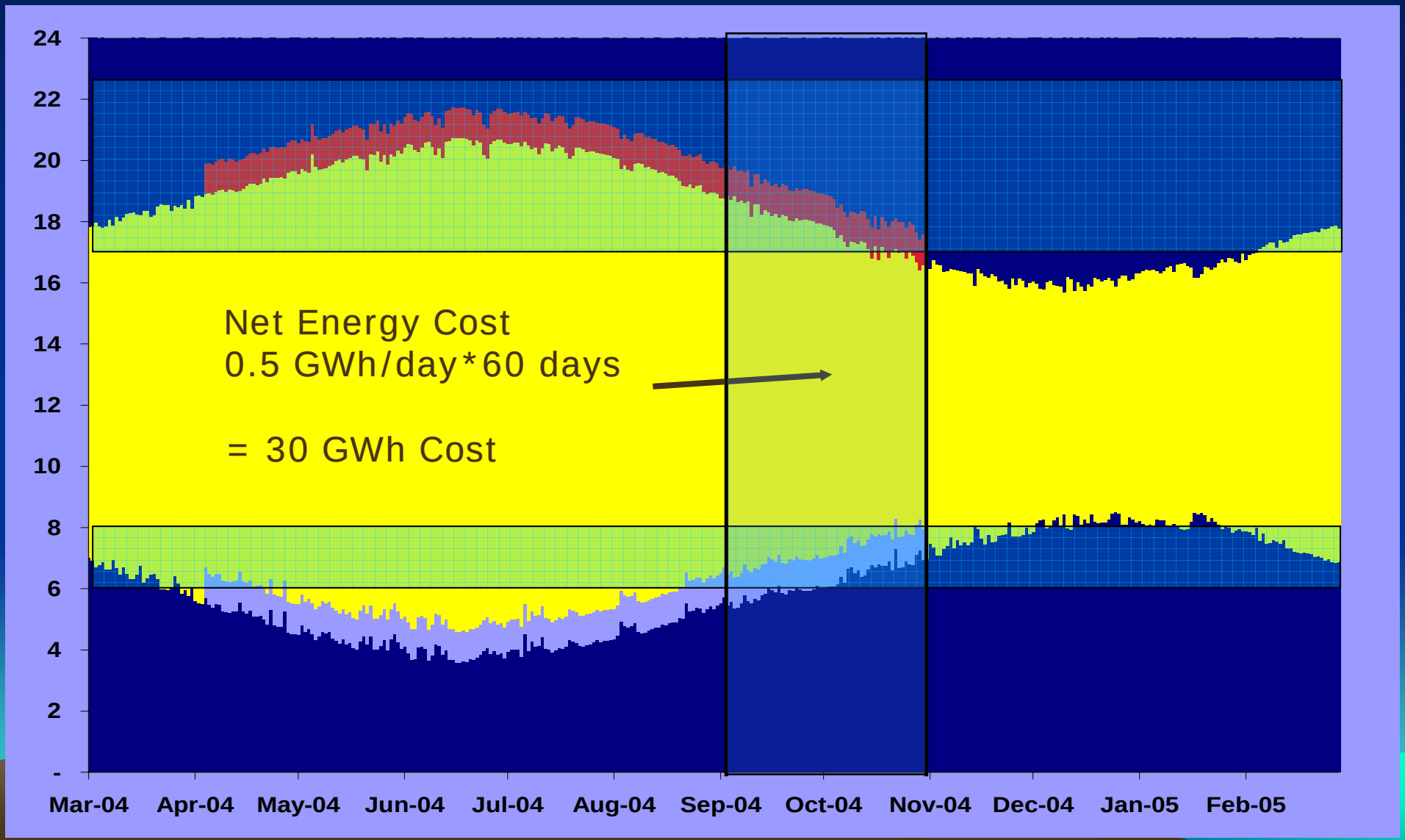
- When we have no morning ‘Cost’ energy, DST saves about 1.1 GWh per day in the evenings

- When DST causes additional morning lighting load, this exceeds the evening saving by about 0.5 GWh per day

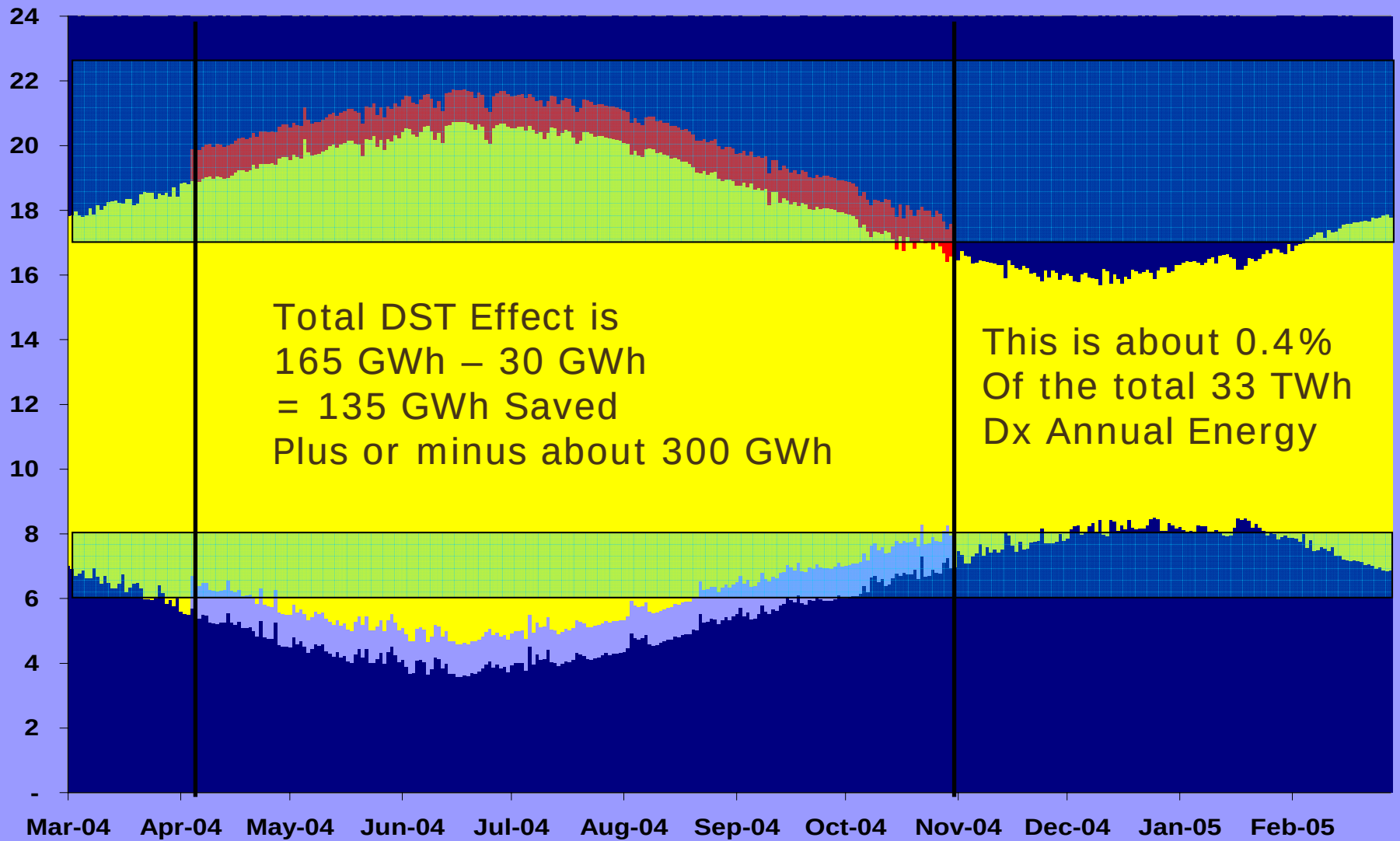
# DST Saving when no Cost



# DST Saving when Cost



# Overall Annual DST Savings



# 6. 2007 DST Extensions

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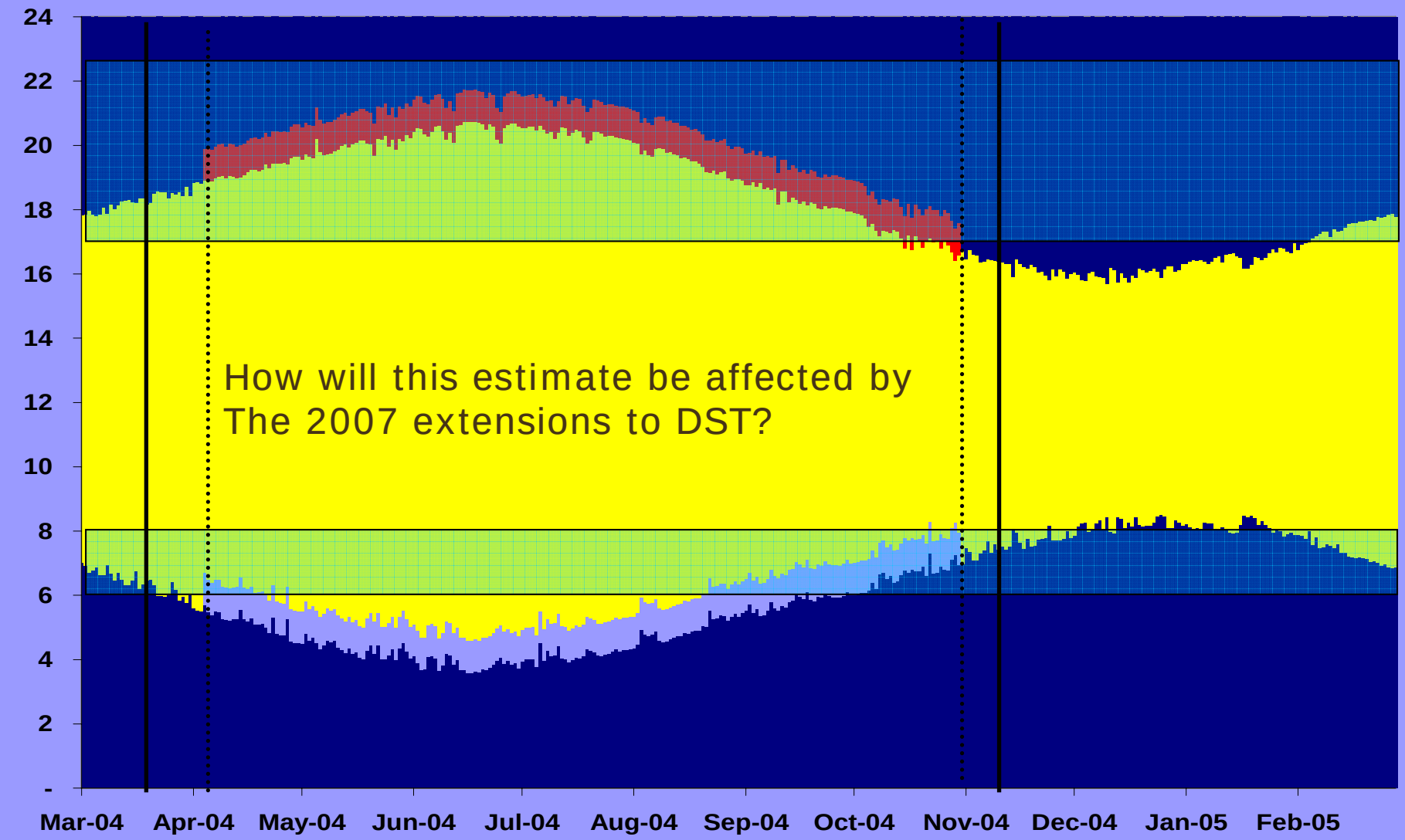
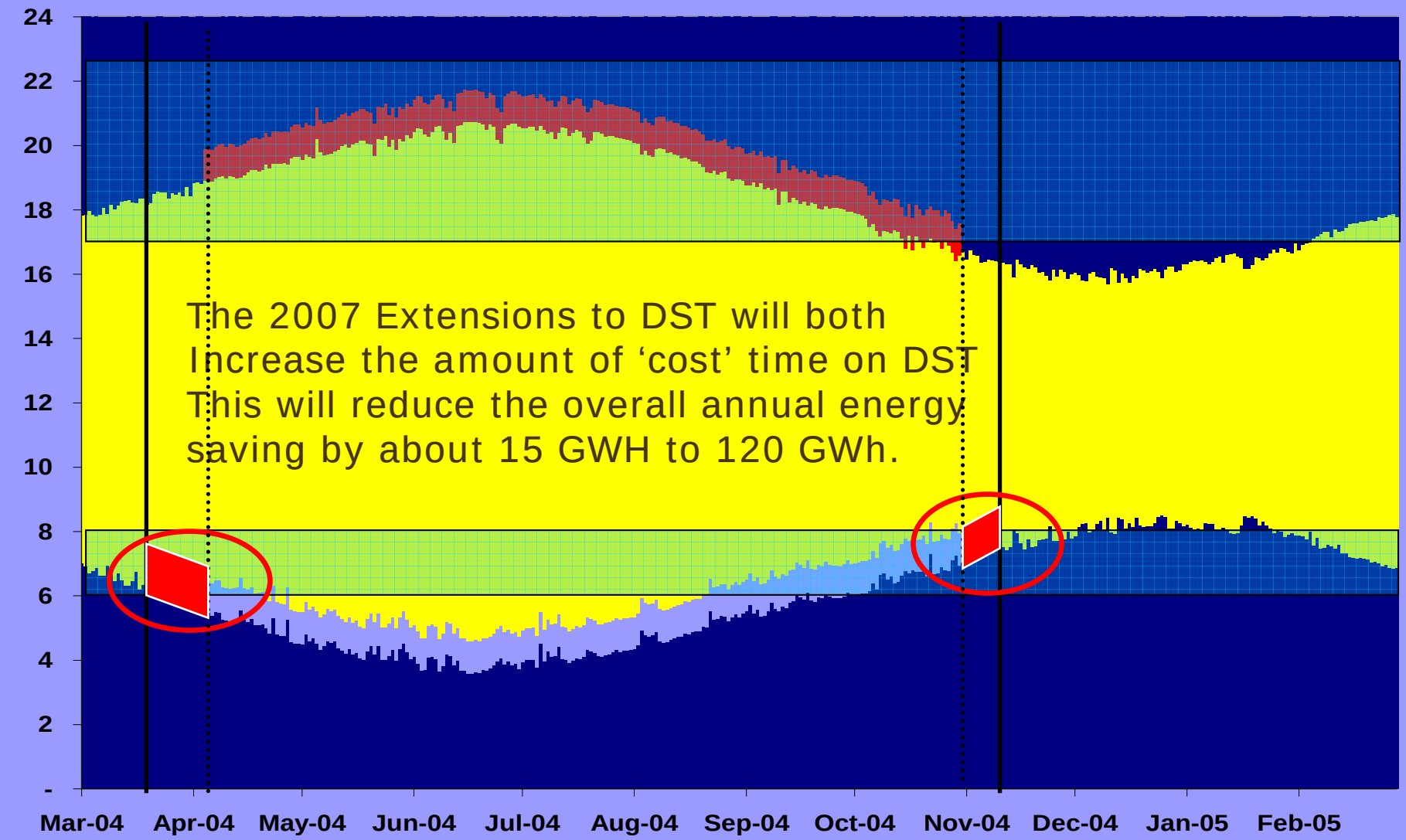
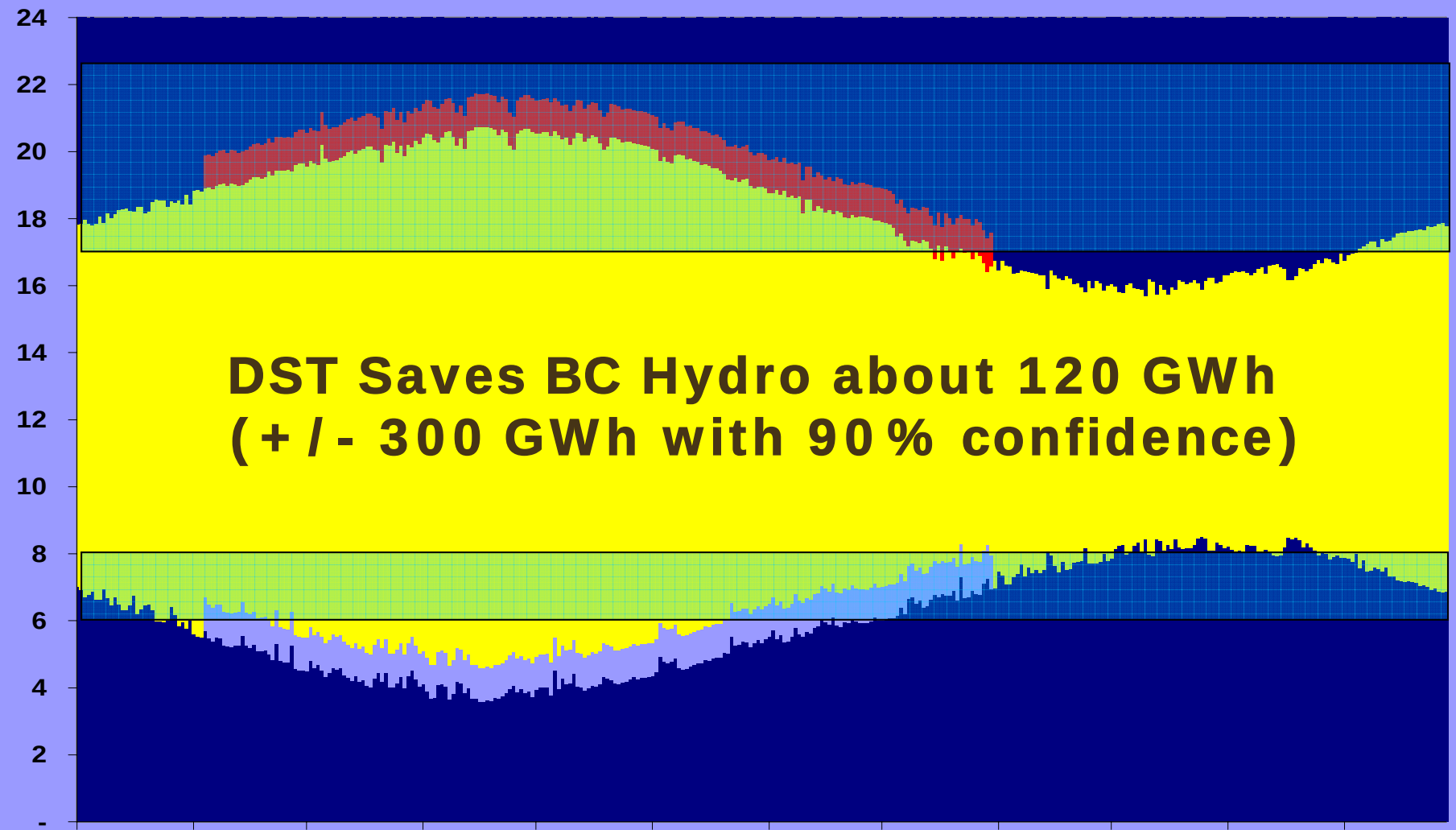


# 2007 DST Extensions

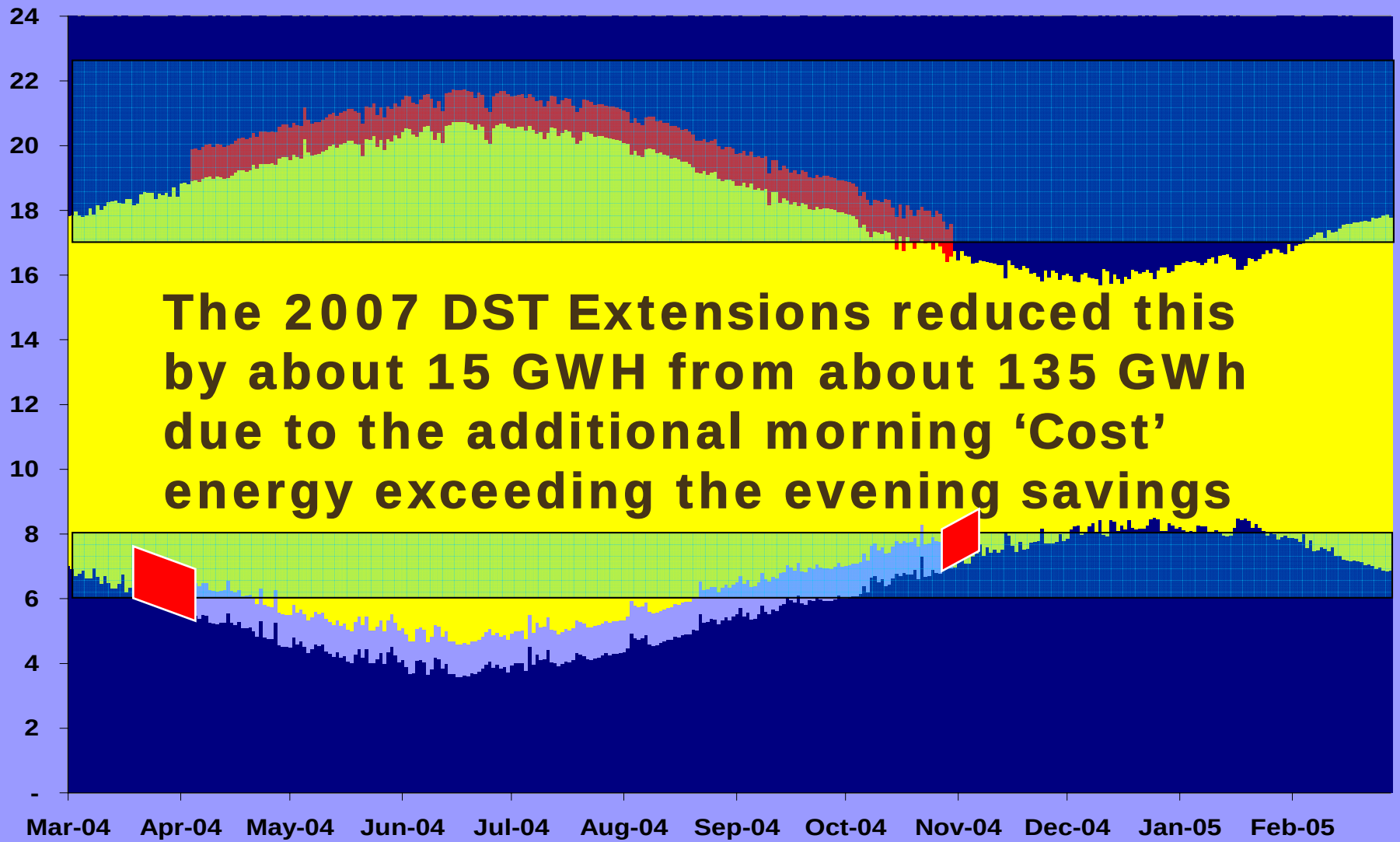


# 6. Conclusion

# Conclusion I



# Conclusion II



# The End – Questions ?

Watch for the forthcoming attraction:

"Where is the Energy Saved by DST?"