Forecasting Short Term Unhealthy Air Quality Using the 3 Hour Multipollutant AQHI Method for Mountain Valley Locations

- Where strong diurnal variation of air pollutant levels occurs as a function of local emissions and pollutant trapping.

- Based on an evaluation of 4 years of co-located meteorological data in Rutland Vermont and the 3 hour averaged Canadian AQHI Index.

Goals of this study.

- Forecasting air pollutant levels for Local emissions events in the wintertime for a northern appalachian mountain valley setting.
- **Approach :** An evaluation of surface meteorology at the measurement site is utilized to develop a forecaster's 'rules of thumb' unique to the measurement location.

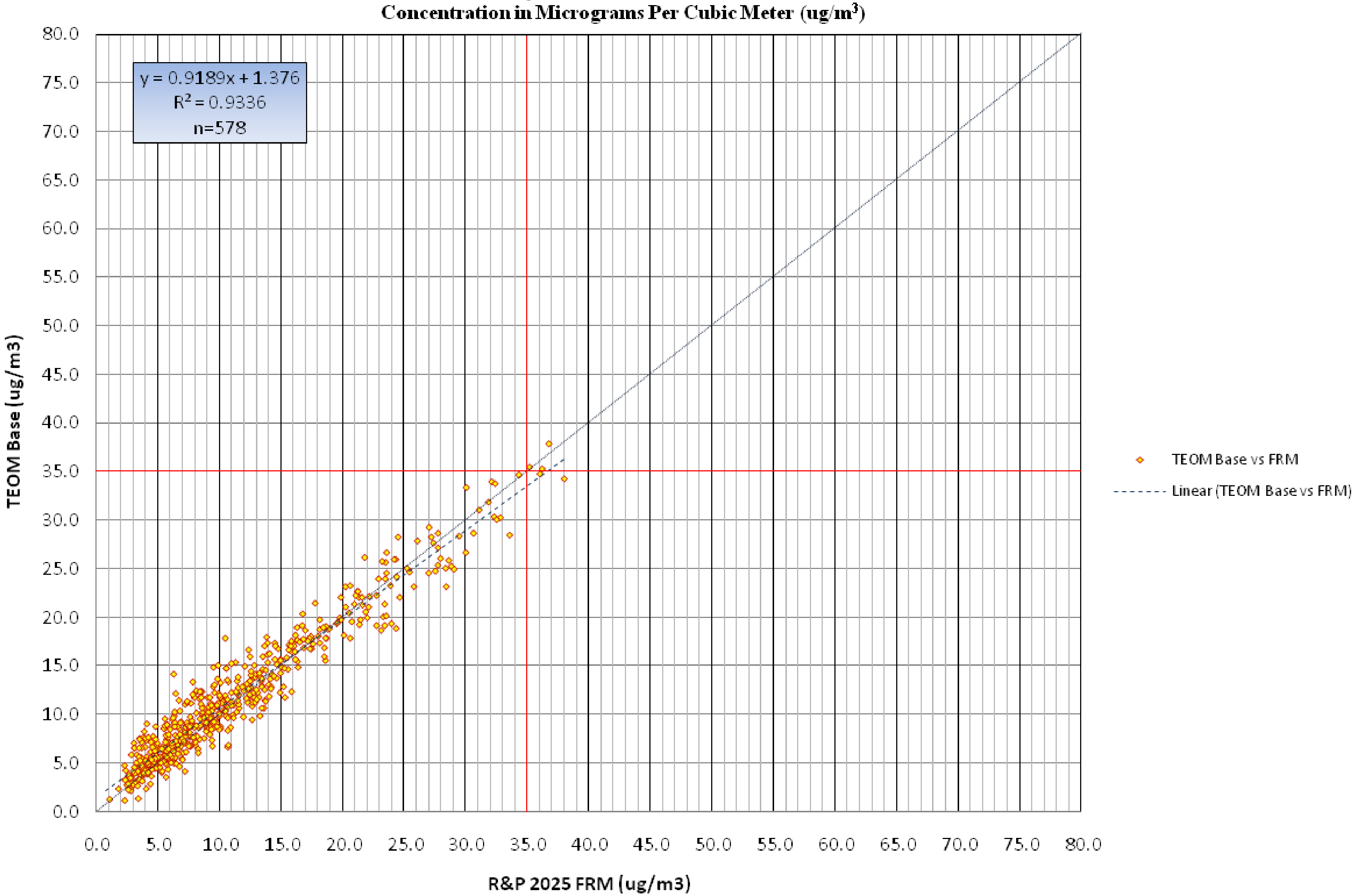
- Developing a capacity to issue the forecast in a sensible manner with respect to diurnal variation.
- **Approach :**The AQHI 3 hour Canadian Standard is an index calculated using PM2.5, NO2, and ozone concentrations that offers temporal resolution to capture diurnal variation.

- Examination of incidence of the EPA AQI versus Canadian AQHI Index Exceedances over the 4 year period.
- **Approach :** Comparative Calculations of Both Indices methods are performed for the period 2006 – 2009 in Rutland, Vermont, in a theoretical, non-regulatory exercise.

To achieve these goals a *microscale* approach is utilized – Appropriate for Local Pollutant Trapping.

- Using a 4 year contiguous data set (2006 – 2009), of co-located meteorological measurements in Rutland, Vermont.
- PM2.5, NO2, and Ozone are utilized (where ozone was supplied from a location about 100 km. in distance).
- PM2.5 – Using FDMSTEOM Base Measure (excludes semi volatiles - more similar to an FRM PM25 measure).
- Meteorological Association limited to Surface Temperature and surface wind speed.

Rutland TEOM Base Channel vs Rutland FRM
January 2004- March 2009



Northern Appalachian Characteristics Contributing to Local Pollutant Trapping

- In January through early March continental polar high pressure may become established over Northern New England /Southern Quebec featuring minimum overnight temperatures of -20 to -30 F in valley locations.
- These cold temps necessitate extensive heating (wood heat) – the primary source of PM25 emissions .
- Extensive cloudiness often prevails in November and December.
- The valley profiles are steep and tight with no valley floor breadth. On average, many valley locations do not receive direct sunlight for more than 6 hrs of the day as sun remains behind hillsides.

Worcester, Vermont – vertical differential in elevation about 3000 feet.

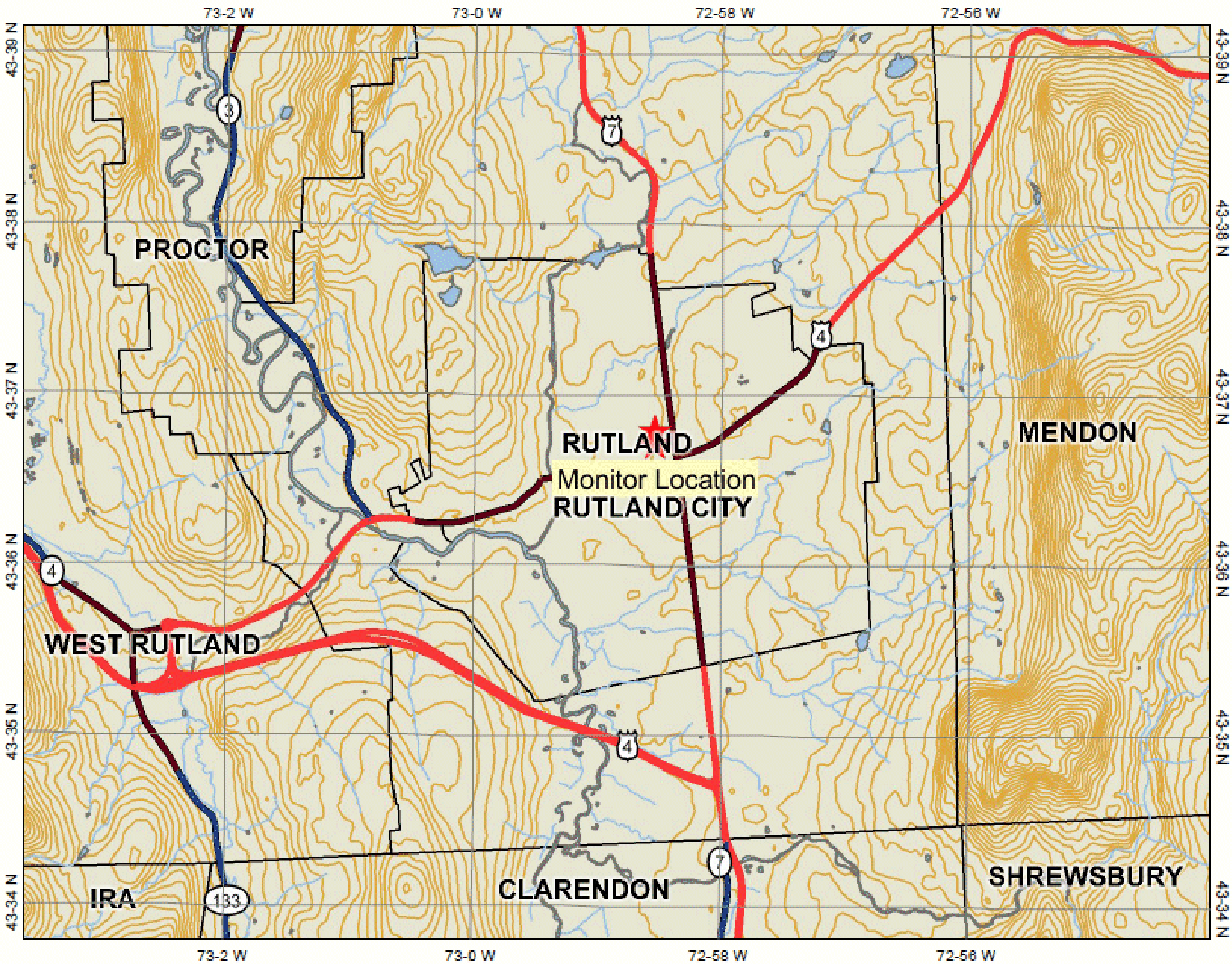
Microscale Study Location - Rutland, Vermont

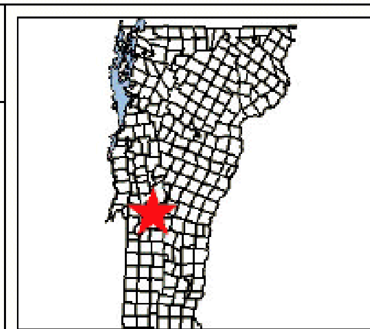
- Differential Elevation of about 2000 feet.
- Relatively broad valley floor for Vermont.
- Population about 20,000.
- Residential wood combustion is widespread.

VERMONT

ANR Environmental Interest Locator

Vermont Agency of Natural Resources (ANR)





Legend

Major Roads
- US Highway
- Vermont State Highway
- Class One
- Interstate
- Class One
- Hydrography Lakes and Ponds (VHD 5k)
- Hydrography (VHD 5k)
- VT County Boundary
- VT Town Boundaries (No Fill)
- 50 foot Contour
- VT State Boundary (Fill)

VT State Plane Meters (NAD83)

0 6500 13000 19500 ft.

Map center: 461189, 123217

Scale: 1:69,448

URL: http://maps.vermont.gov/imf/sites/ANR_NATRESViewer/jsp/launch.jsp

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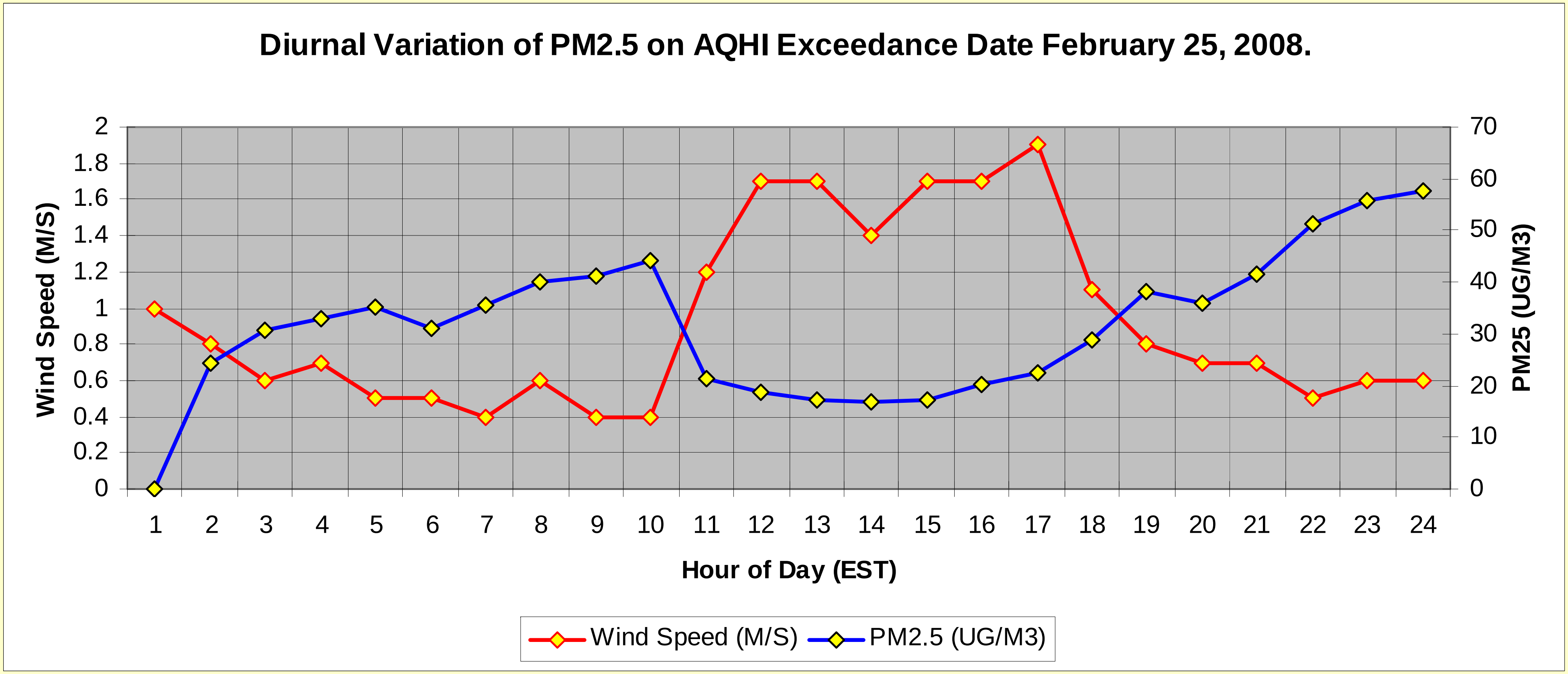
Strong Diurnal Variation of Air Pollutants in the mountain valley.

- a strong diurnal variation of PM2.5 levels often occurs which is very sensitive to fluctuations in the velocity of the surface wind field.
- Pollutant accumulation will continue until the surface winds nudge above about 1 M/S.
- In calm, high pressure conditions sufficient stirring of the surface winds occurs in association with morning break up of the thermal inversion.
- Canceling Effect on 24 Hour Average. The same conditions that are necessary for excessive pm2.5 buildup overnight cause a correspondingly greater drop during the hrs of the day when inversion breakup occurs (that is, stronger vertical mixing occurs during the daytime with the clear conditions).



Diurnal Variation of PM2.5 on AQHI Exceedance Date February 25, 2008.
Wind Speed (M/S)
PM25 (UG/M3)
Hour of Day (EST)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Wind Speed (M/S)
PM2.5 (UG/M3)

To capture diurnal variation an index with better temporal resolution is necessary.

- The AQHI 3 hour Canadian Standard is an index calculated using PM2.5, NO2, and ozone concentrations.

- The AQHI 3 hour Canadian Standard Provides temporal resolution that is sensitive to diurnal variation

- It is represented on a scale of 1 – 10, where 1 – 3 is good, 4 – 7 is moderate, above 7 unhealthy.

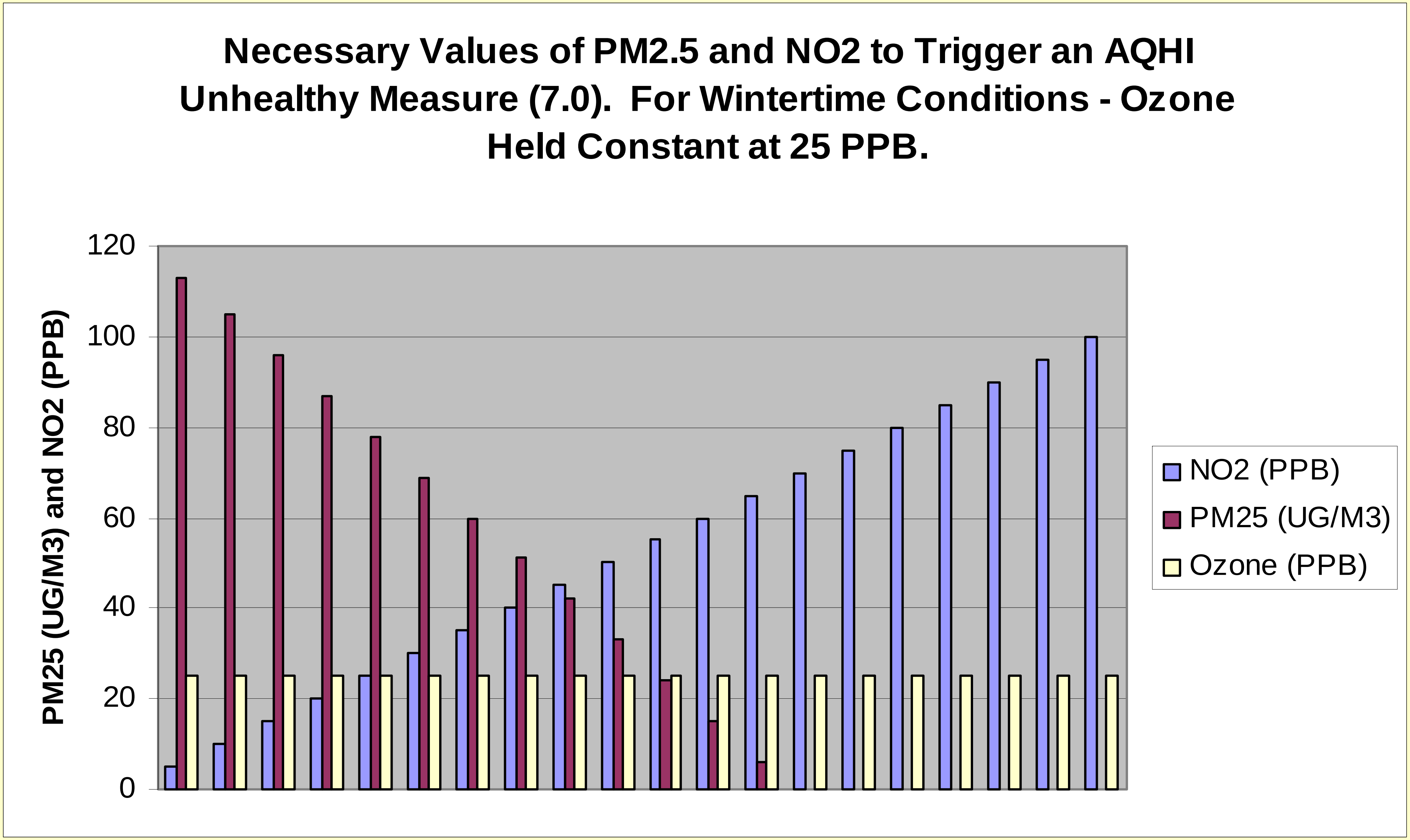
- Currently Canada relies on the CHRONOS model to calculate AQHI values on a gridded basis and uses the index to identify adverse air quality in real time.

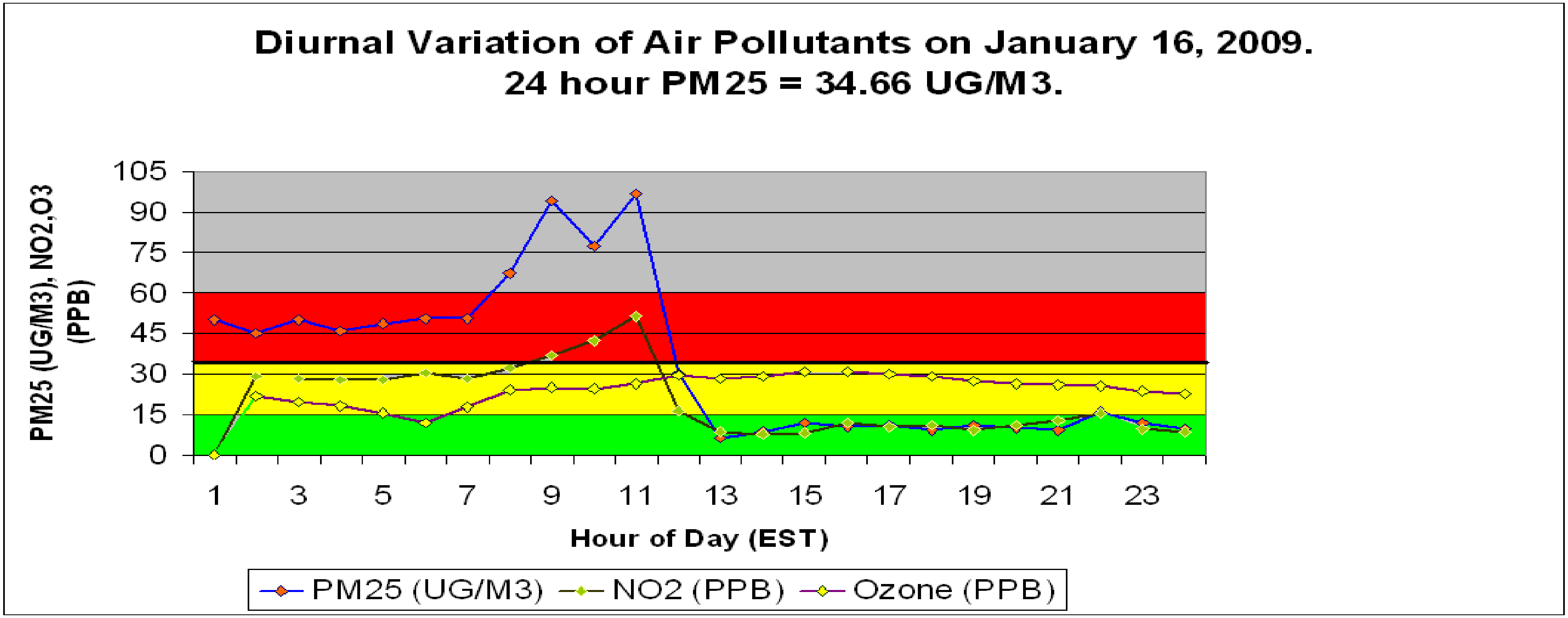
- Vermont is applying the AQHI method in a valley location subject to local pollutant accumulation.

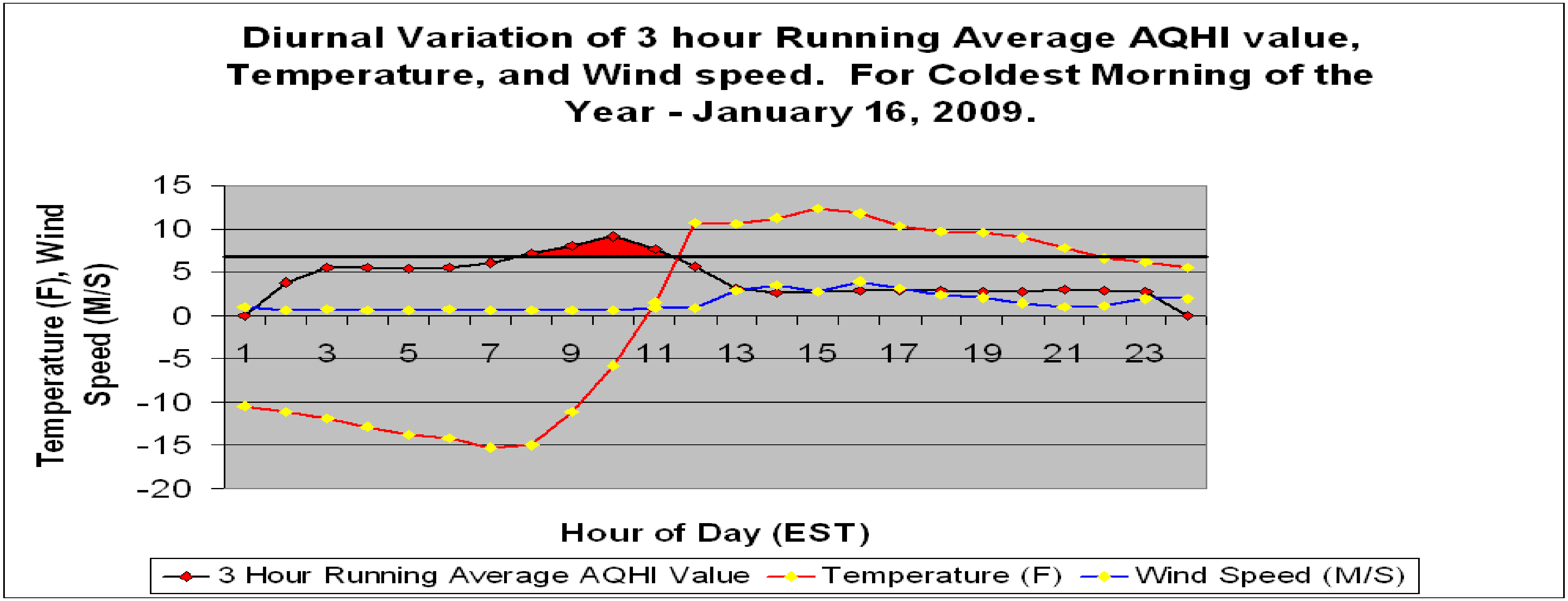
To capture diurnal variation an index with better temporal resolution is necessary.

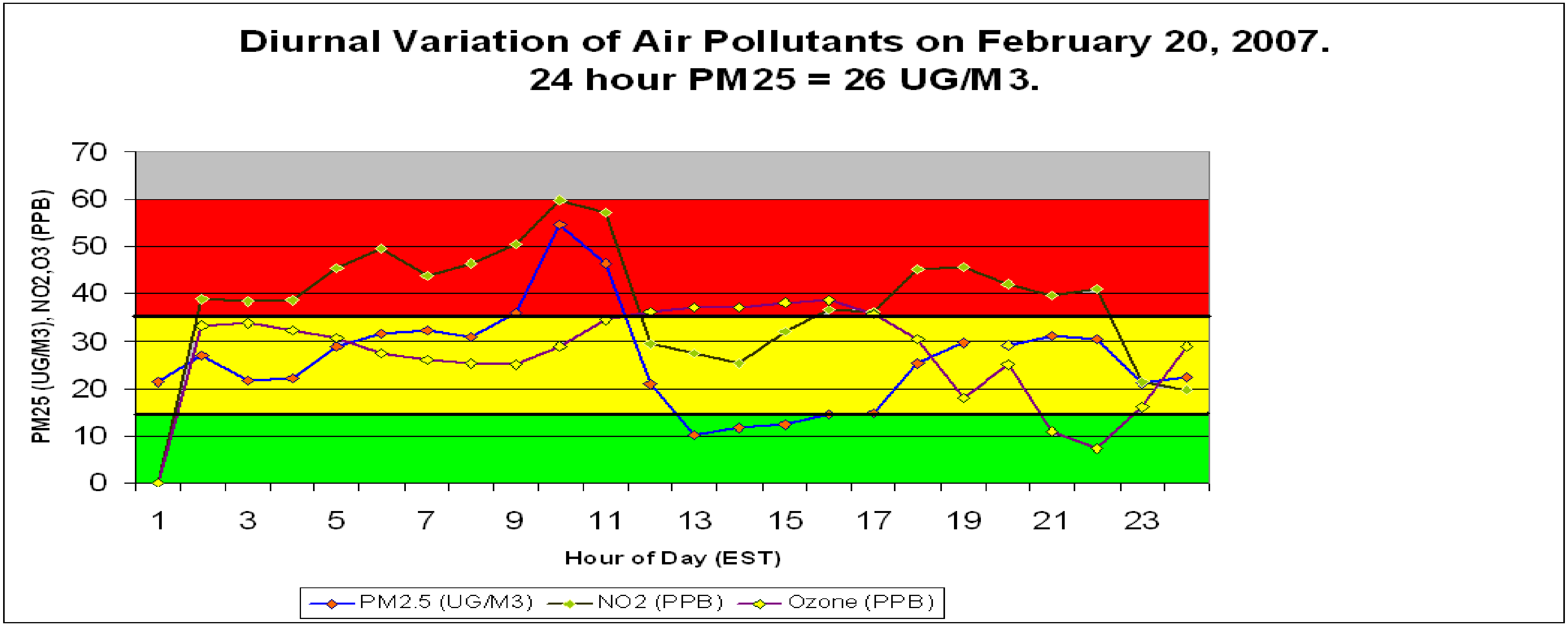
- It is a standard based on mortality studies. Literature concludes it is valid for irritant effects as well.
- NO2 – serves as a marker of other hazardous air contaminants from auto emissions which adversely effect human health.
- Literature cautions it may be inadequate for local pollutant accumulation of pm25 (therefore a temporary stopgap).
- 2 formulations for the AQHI calculation are available, annual and cold season, but annual formulation, which includes ozone, is recommended.
- The AQHI Annual Equation :

- PM2.5 AQHI = 10/10.4*(100*(e^0.000871*NO2)-1 + e^(0.000537*O3) – 1 + e(0.000487*PM25) -1))

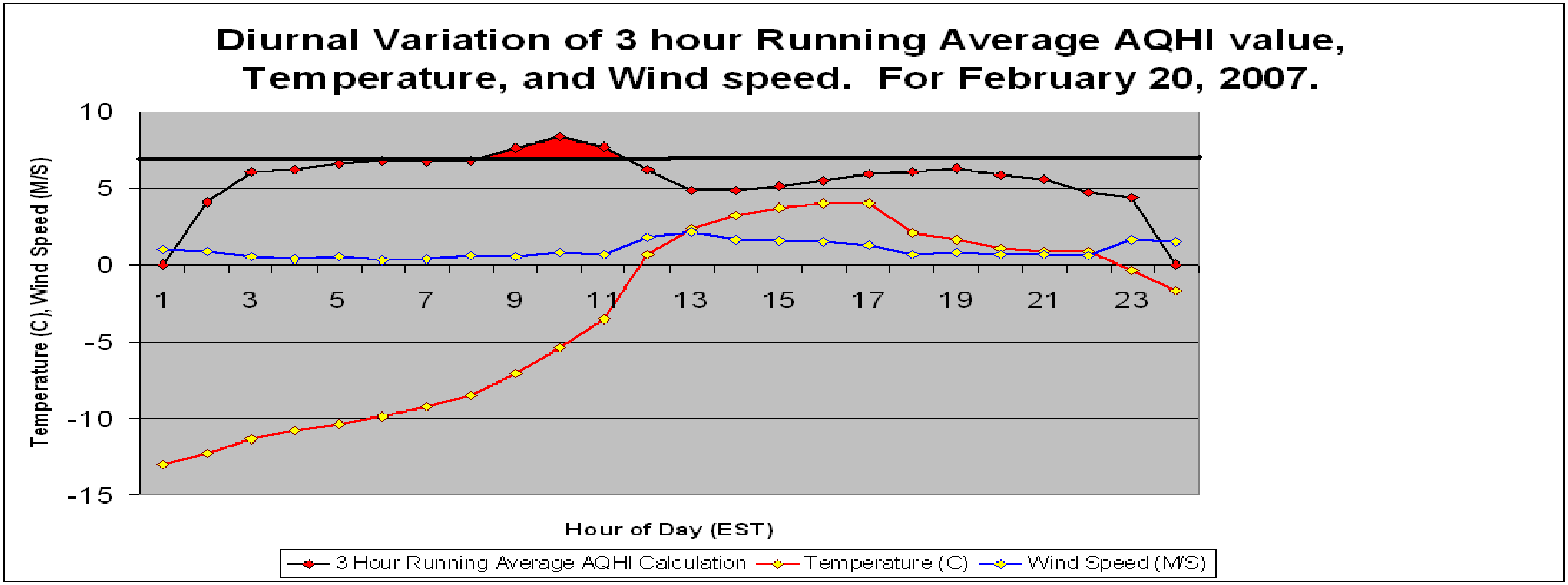

Necessary Values of PM2.5 and NO2 to Trigger an AQHI Unhealthy Measure (7.0). For Wintertime Conditions - Ozone Held Constant at 25 PPB.
PM25 (UG/M3) and NO2 (PPB)
120
100
80
60
40
20
0
NO2 (PPB)
PM25 (UG/M3)
Ozone (PPB)


Diurnal Variation of Air Pollutants on January 16, 2009.
24 hour PM25 = 34.66 UG/M3.
PM25 (UG/M3), NO2,O3 (PPB)
105
90
75
60
45
30
15
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day (EST)
PM25 (UG/M3)
NO2 (PPB)
Ozone (PPB)


Diurnal Variation of 3 hour Running Average AQHI value, Temperature, and Wind speed. For Coldest Morning of the Year - January 16, 2009.
Temperature (F), Wind Speed (M/S)
15
10
5
0
-5
-10
-15
-20
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day (EST)
3 Hour Running Average AQHI Value
Temperature (F)
Wind Speed (M/S)



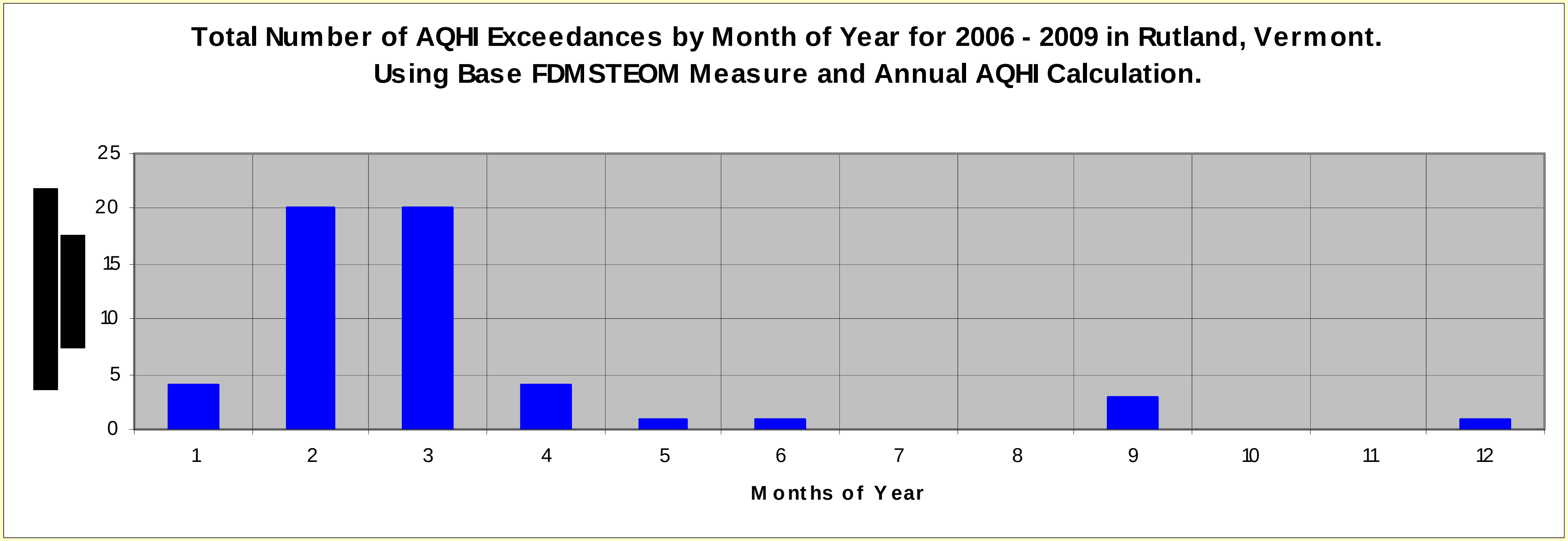
Diurnal Variation of Air Pollutants on February 20, 2007.
24 hour PM25 = 26 UG/M3.
PM25 (UG/M3), NO2,O3 (PPB)
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day (EST)
PM2.5 (UG/M3)
NO2 (PPB)
Ozone (PPB)

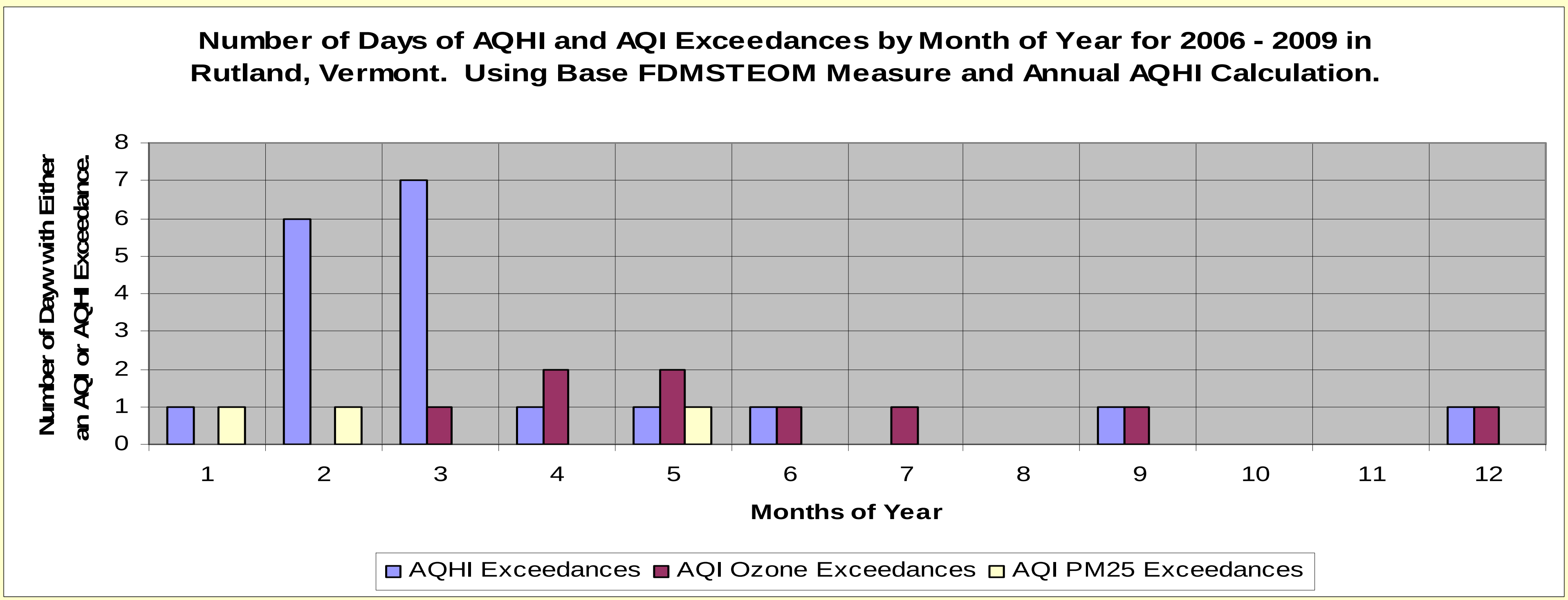


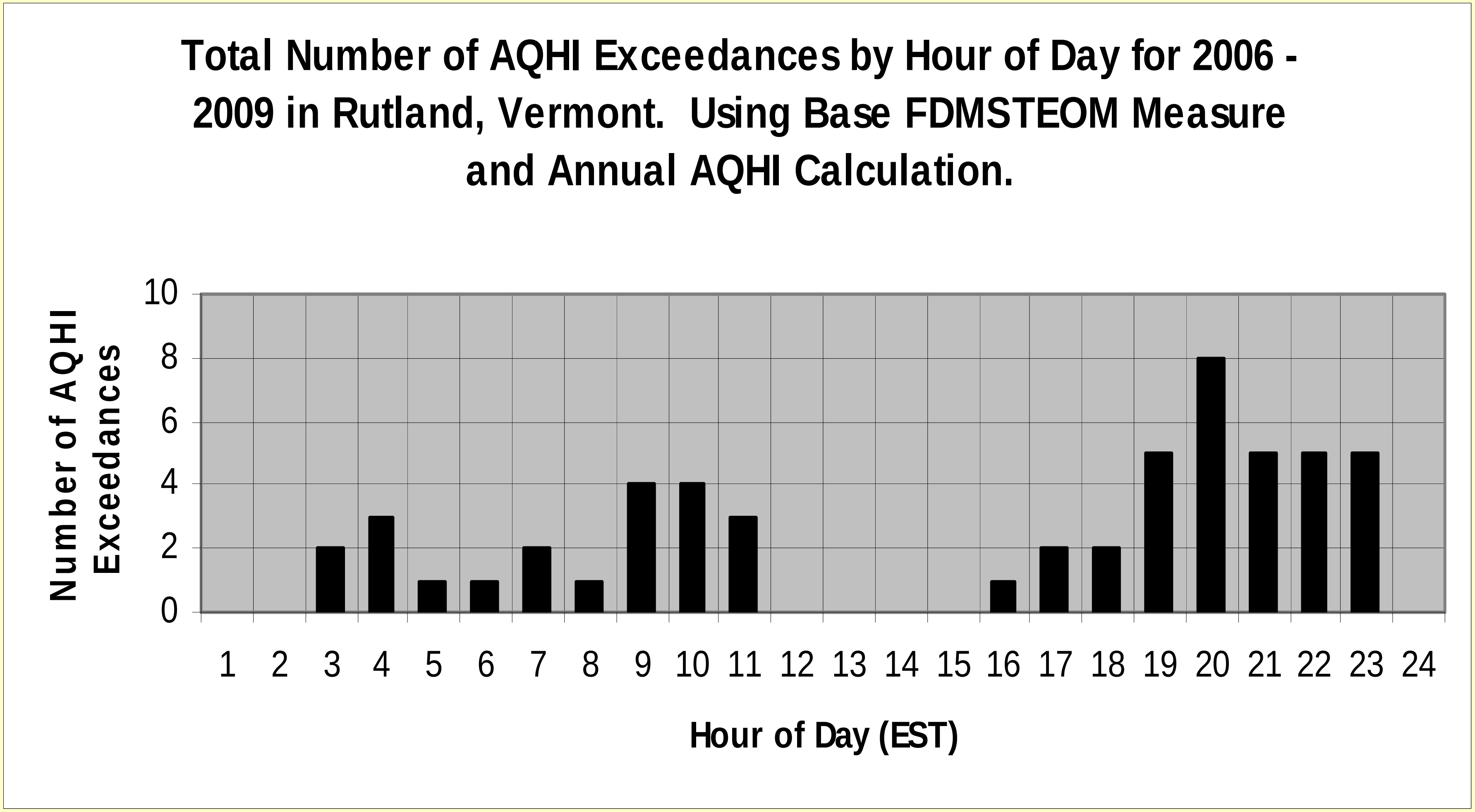
Diurnal Variation of 3 hour Running Average AQHI value, Temperature, and Wind speed. For February 20, 2007.
Temperature (C), Wind Speed (M/S)
10
5
0
-5
-10
-15
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day (EST)
3 Hour Running Average AQHI Calculation
Temperature (C)
Wind Speed (M/S)

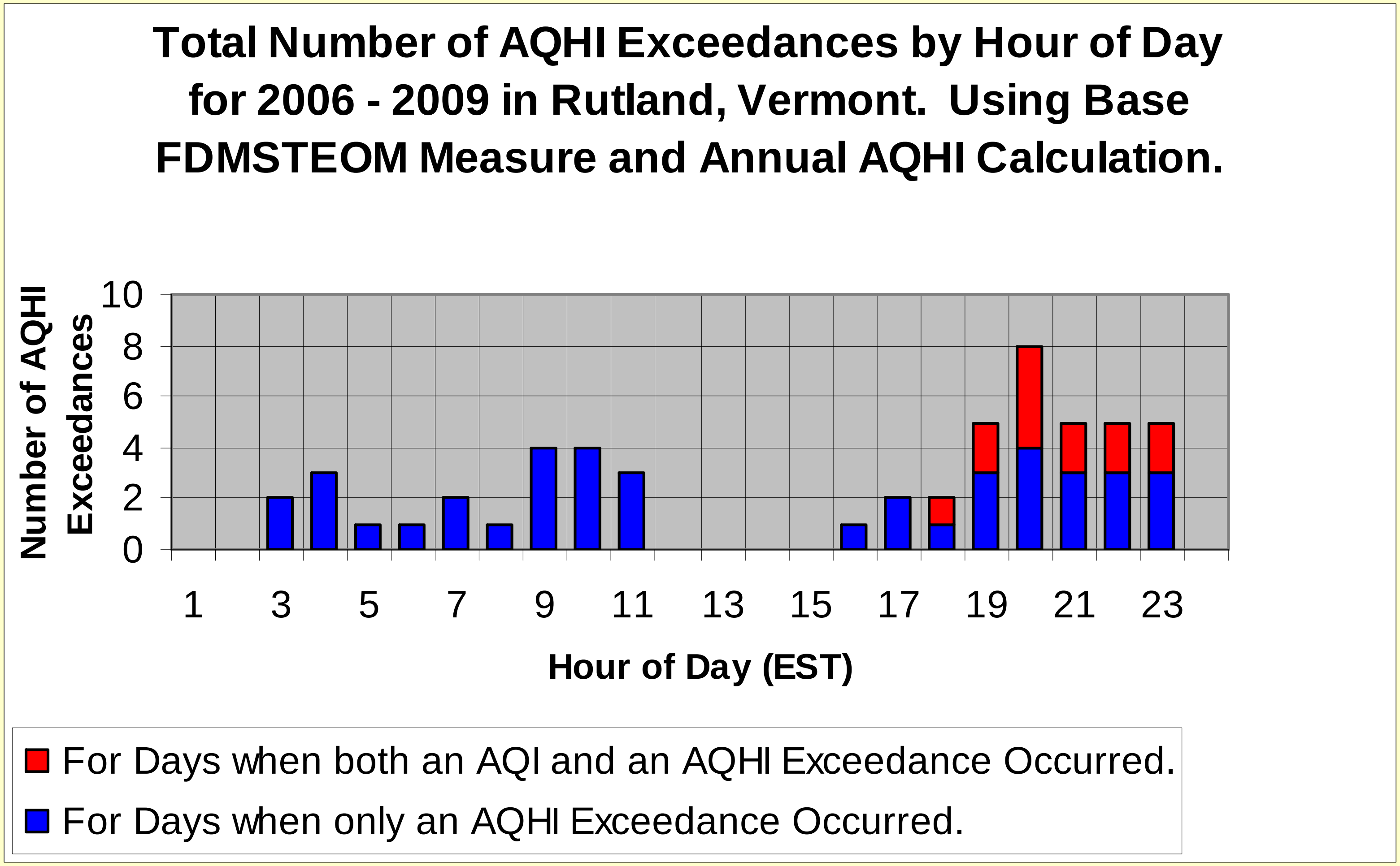
Examination of incidence of AQI vs. AQHI Exceedances for 2006 – 2009 in Rutland, Vermont.

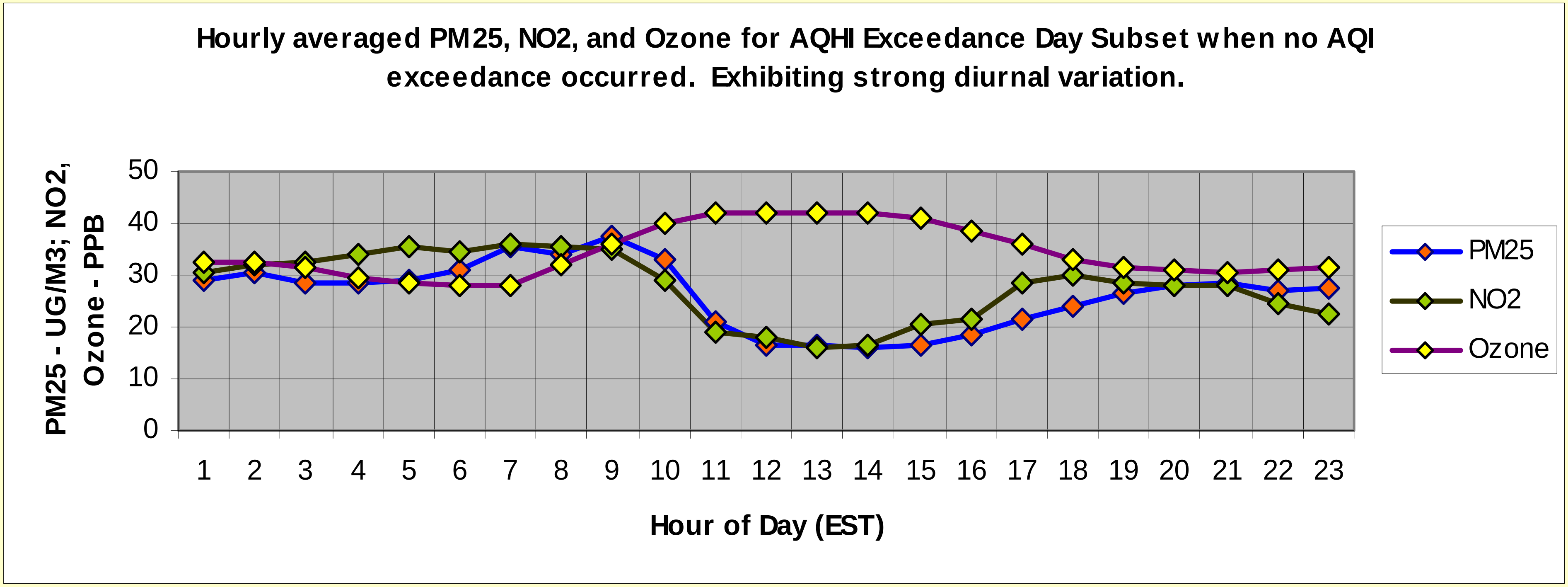
- Using 75 PPB for 8 hour Average ozone for AQI exceeding 100.
- Using 35 UG/M3 for 24 hour PM25 average for AQI exceeding 100.
- Both compared against the Canadian AQHI index threshold of 7.
- Examining Diurnal and Annual exceedance patterns.
- Examining associated averaged daily pollutant values.

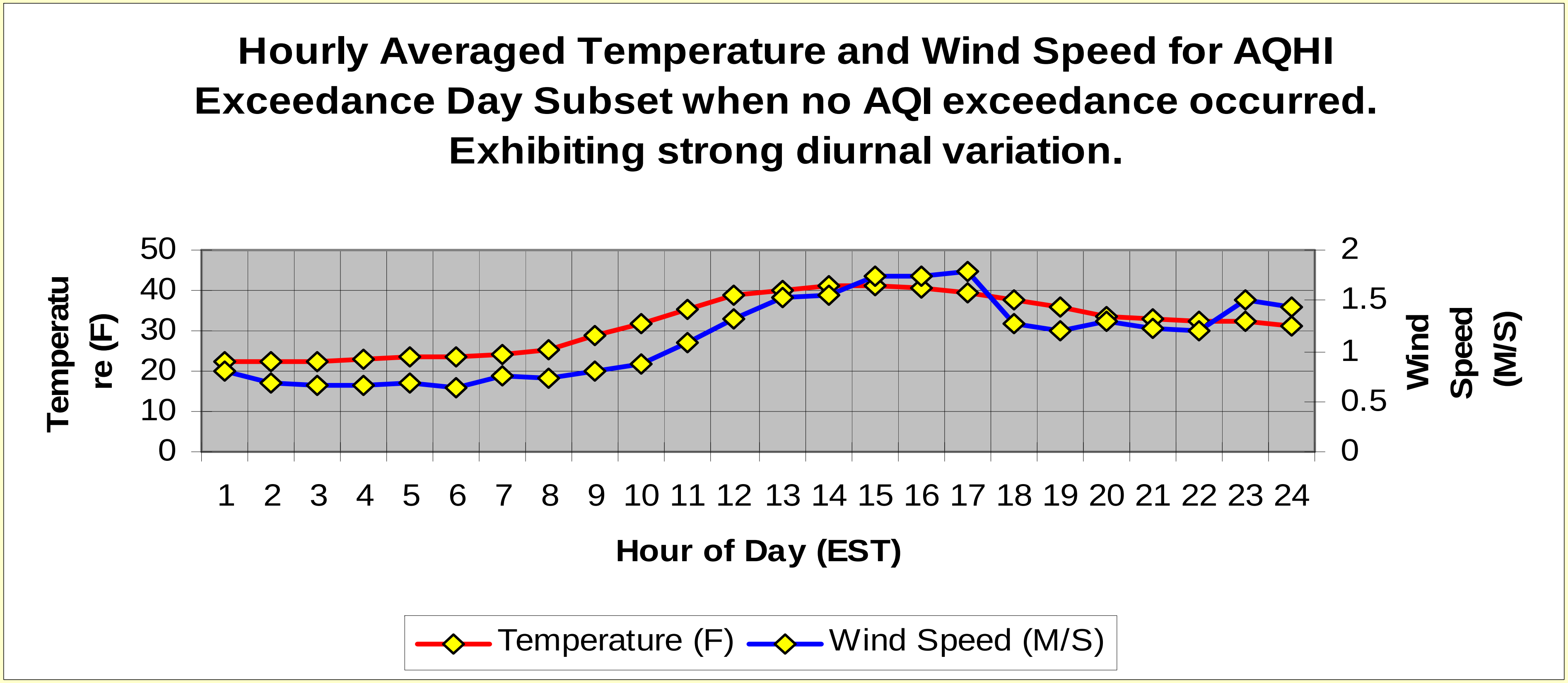

Total Number of AQHI Exceedances by Month of Year for 2006 - 2009 in Rutland, Vermont.
Using Base FDMSTEOM Measure and Annual AQHI Calculation.
[redacted]
0
5
10
15
20
25
1
2
3
4
5
6
7
8
9
10
11
12
Months of Year

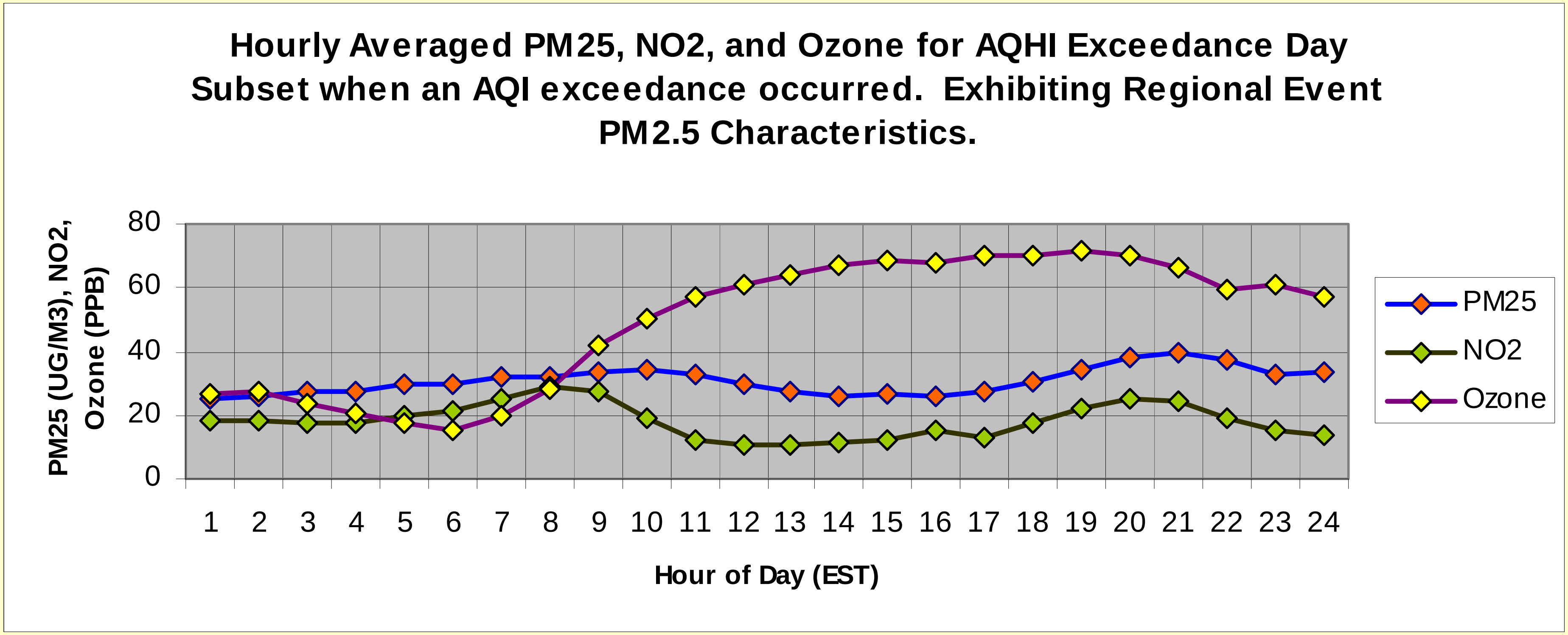

Number of Days of AQHI and AQI Exceedances by Month of Year for 2006 - 2009 in Rutland, Vermont. Using Base FDMSTEOM Measure and Annual AQHI Calculation.
Number of Dayswith Either an AQI or AQHI Exceedance.
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11
12
Months of Year
AQHI Exceedances
AQI Ozone Exceedances
AQI PM25 Exceedances

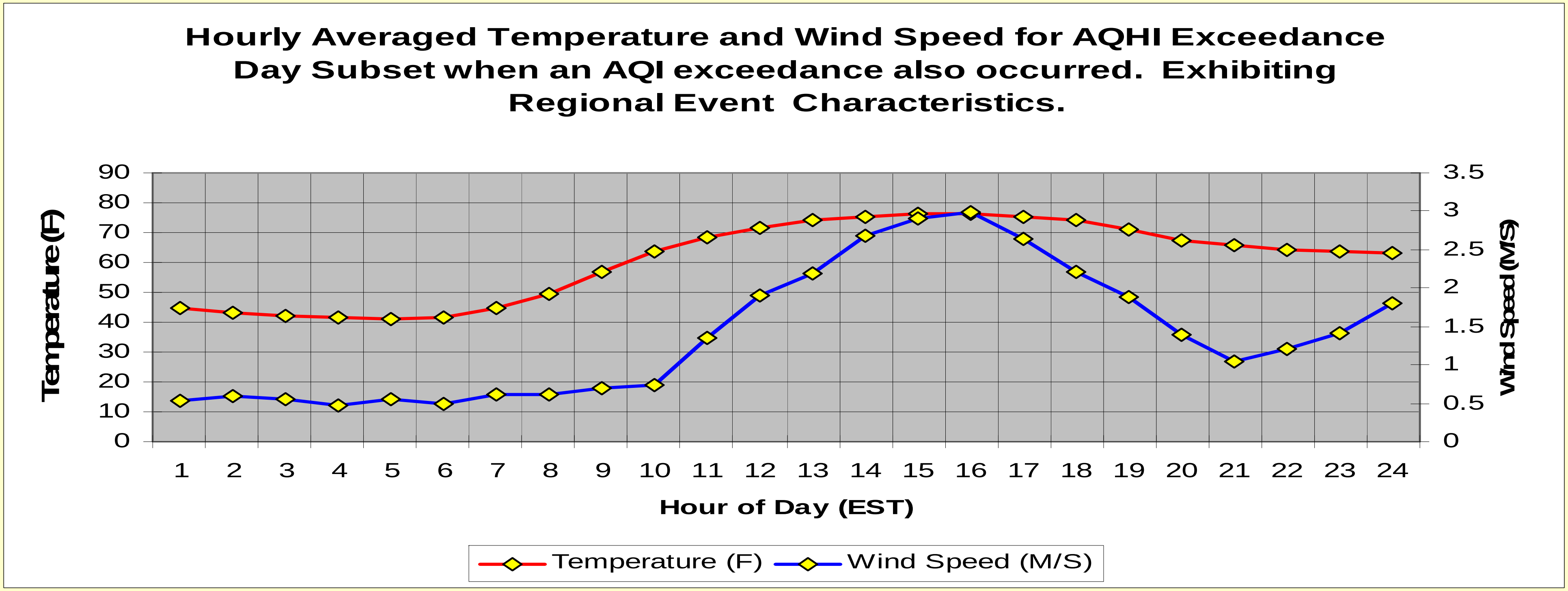

Total Number of AQHI Exceedances by Hour of Day for 2006 - 2009 in Rutland, Vermont. Using Base FDMSTEOM Measure and Annual AQHI Calculation.
Number of AQHI Exceedances
Hour of Day (EST)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

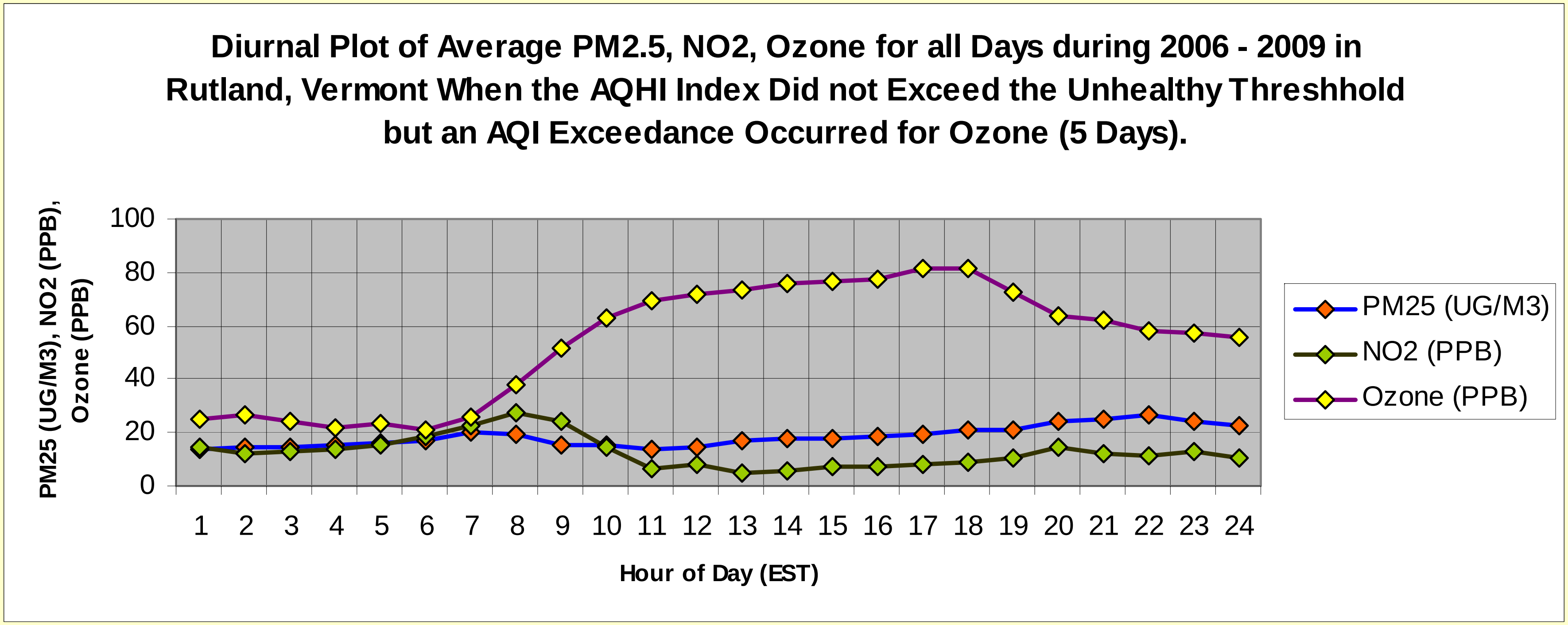

Total Number of AQHI Exceedances by Hour of Day for 2006 - 2009 in Rutland, Vermont. Using Base FDMSTEOM Measure and Annual AQHI Calculation.
Number of AQHI Exceedances
0
2
4
6
8
10
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day (EST)
For Days when both an AQI and an AQHI Exceedance Occurred.
For Days when only an AQHI Exceedance Occurred.

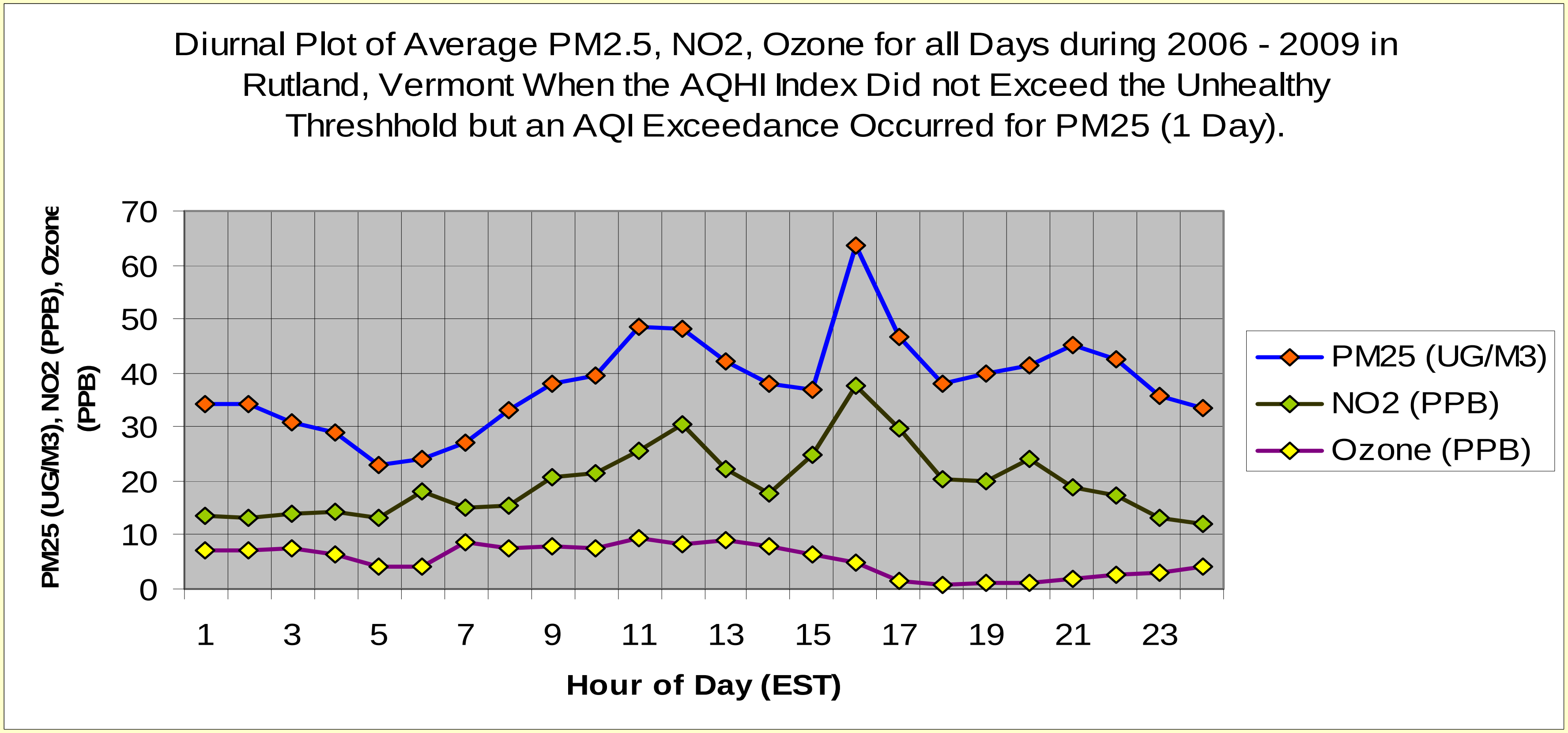

Hourly averaged PM25, NO2, and Ozone for AQHI Exceedance Day Subset when no AQI exceedance occurred. Exhibiting strong diurnal variation.
PM25 - UG/M3; NO2, Ozone - PPB
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of Day (EST)
PM25
NO2
Ozone


Hourly Averaged Temperature and Wind Speed for AQHI Exceedance Day Subset when no AQI exceedance occurred. Exhibiting strong diurnal variation.
Temperature (F)
0
10
20
30
40
50
Wind Speed (M/S)
0
0.5
1
1.5
2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
Temperature (F)
Wind Speed (M/S)


Hourly Averaged PM25, NO2, and Ozone for AQHI Exceedance Day Subset when an AQI exceedance occurred. Exhibiting Regional Event PM2.5 Characteristics.
PM25 (UG/M3), NO2, Ozone (PPB)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
PM25
NO2
Ozone

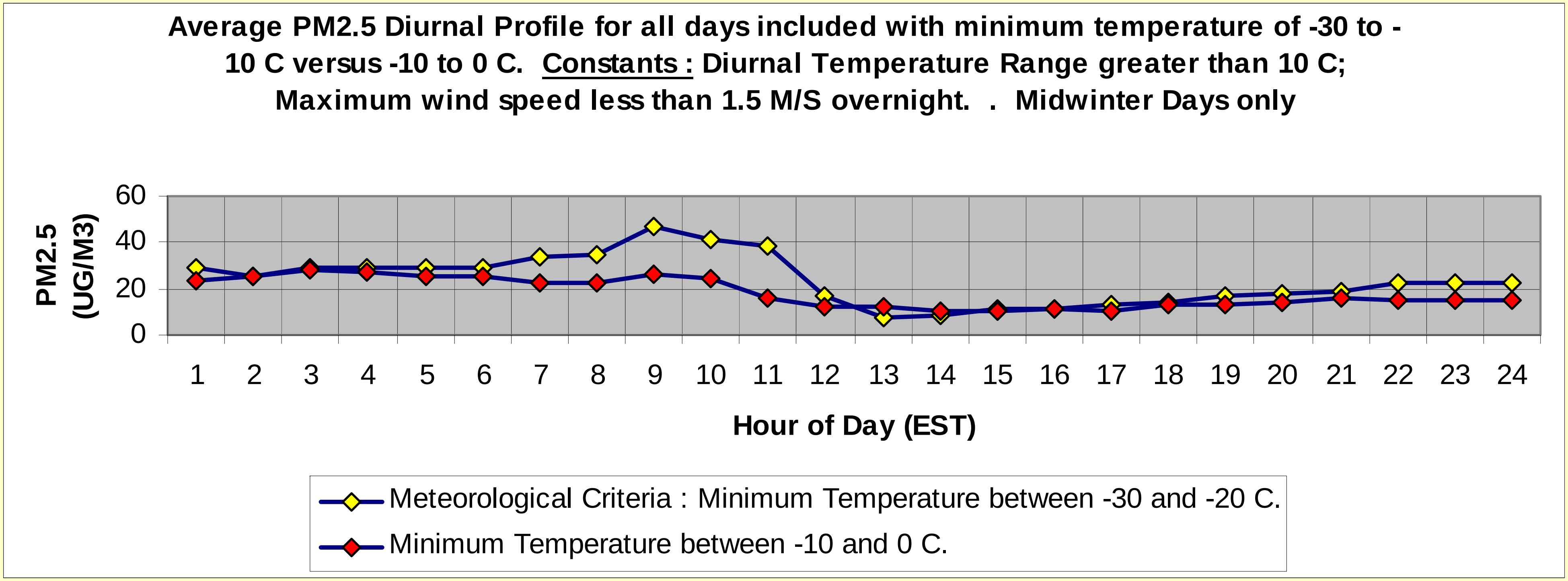

Hourly Averaged Temperature and Wind Speed for AQHI Exceedance Day Subset when an AQI exceedance also occurred. Exhibiting Regional Event Characteristics.
Temperature (F)
90
80
70
60
50
40
30
20
10
0
3.5
3
2.5
2
1.5
1
0.5
0
Wind Speed (M/S)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
Temperature (F)
Wind Speed (M/S)

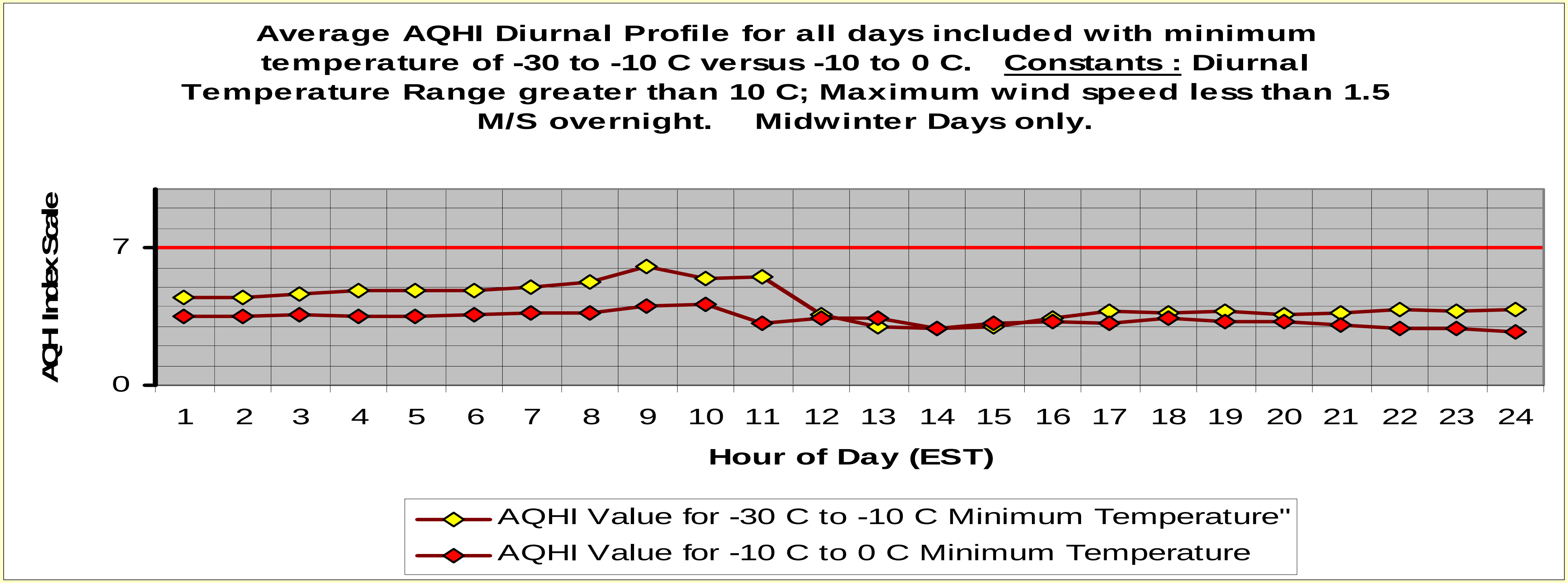

Diurnal Plot of Average PM2.5, NO2, Ozone for all Days during 2006 - 2009 in Rutland, Vermont When the AQHI Index Did not Exceed the Unhealthy Threshhold but an AQI Exceedance Occurred for Ozone (5 Days).
PM25 (UG/M3), NO2 (PPB), Ozone (PPB)
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
PM25 (UG/M3)
NO2 (PPB)
Ozone (PPB)

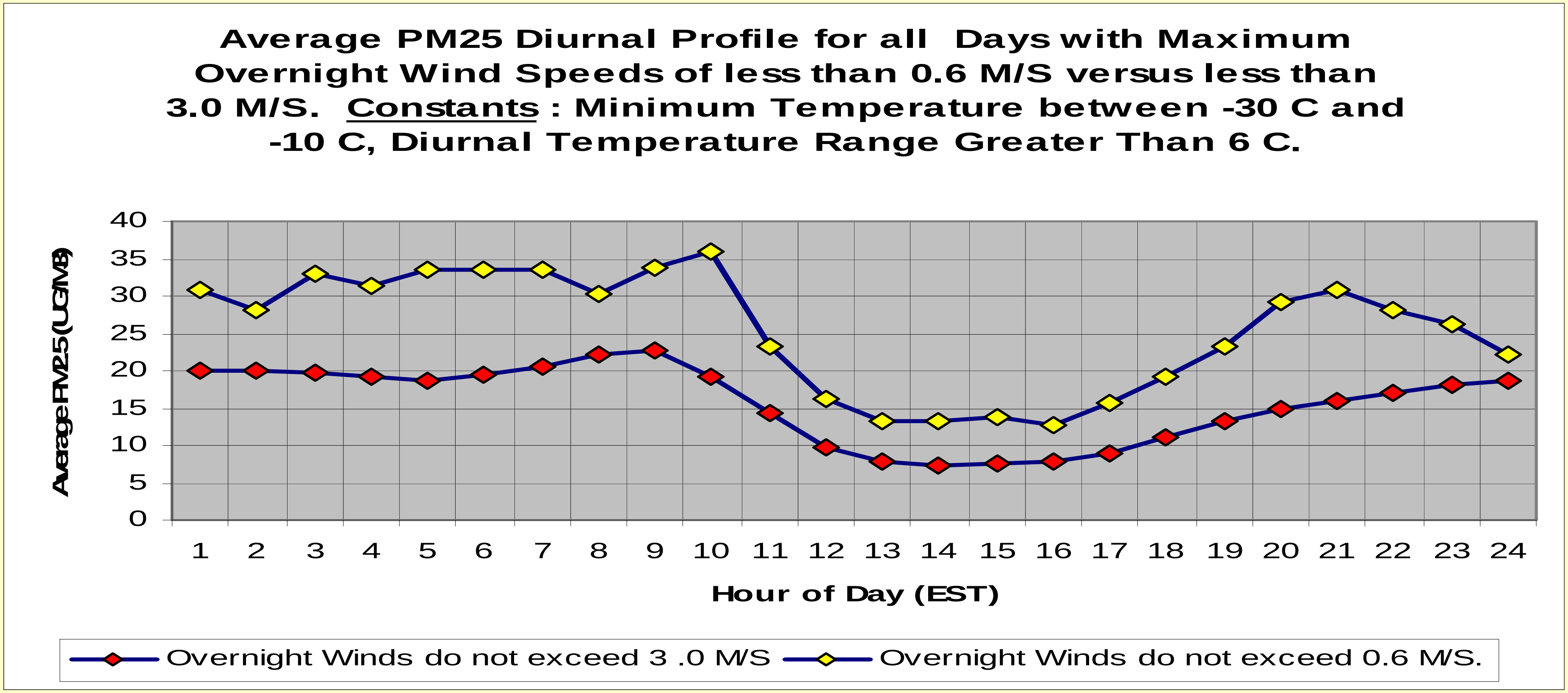

Diurnal Plot of Average PM2.5, NO2, Ozone for all Days during 2006 - 2009 in Rutland, Vermont When the AQHI Index Did not Exceed the Unhealthy Threshhold but an AQI Exceedance Occurred for PM25 (1 Day).
PM25 (UG/M3), NO2 (PPB), Ozone (PPB)
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23
Hour of Day (EST)
PM25 (UG/M3)
NO2 (PPB)
Ozone (PPB)

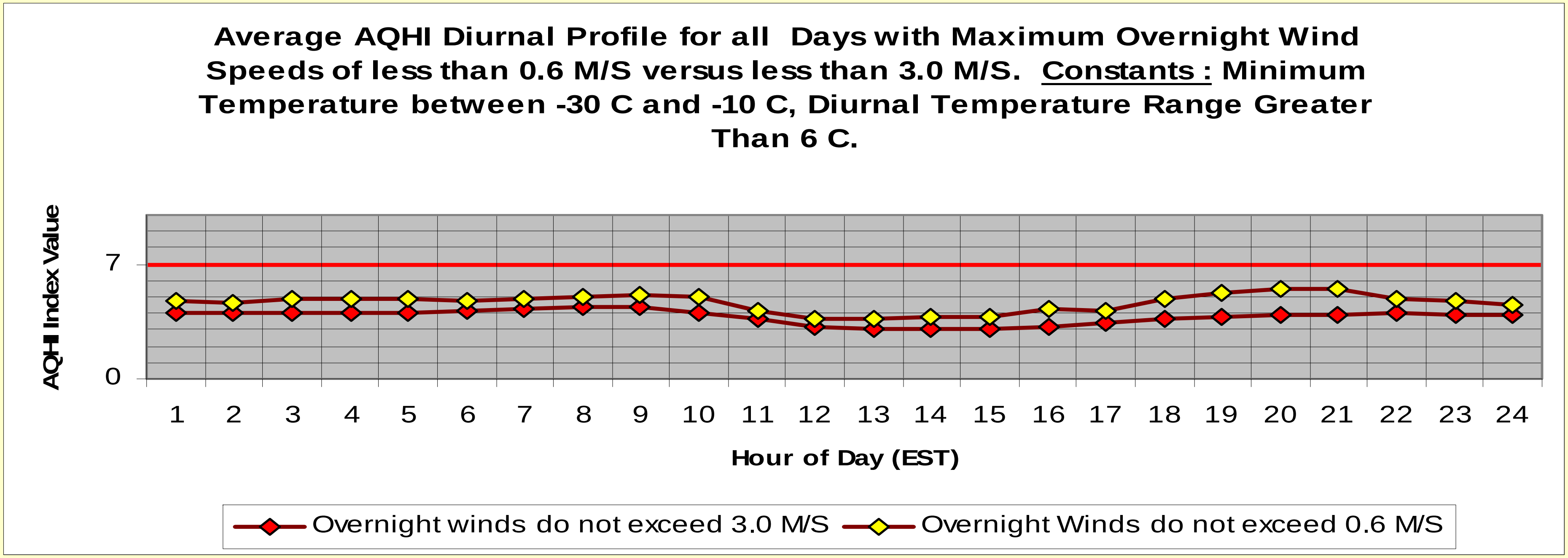
Developing a forecaster's rules of thumb for Rutland, Vermont.

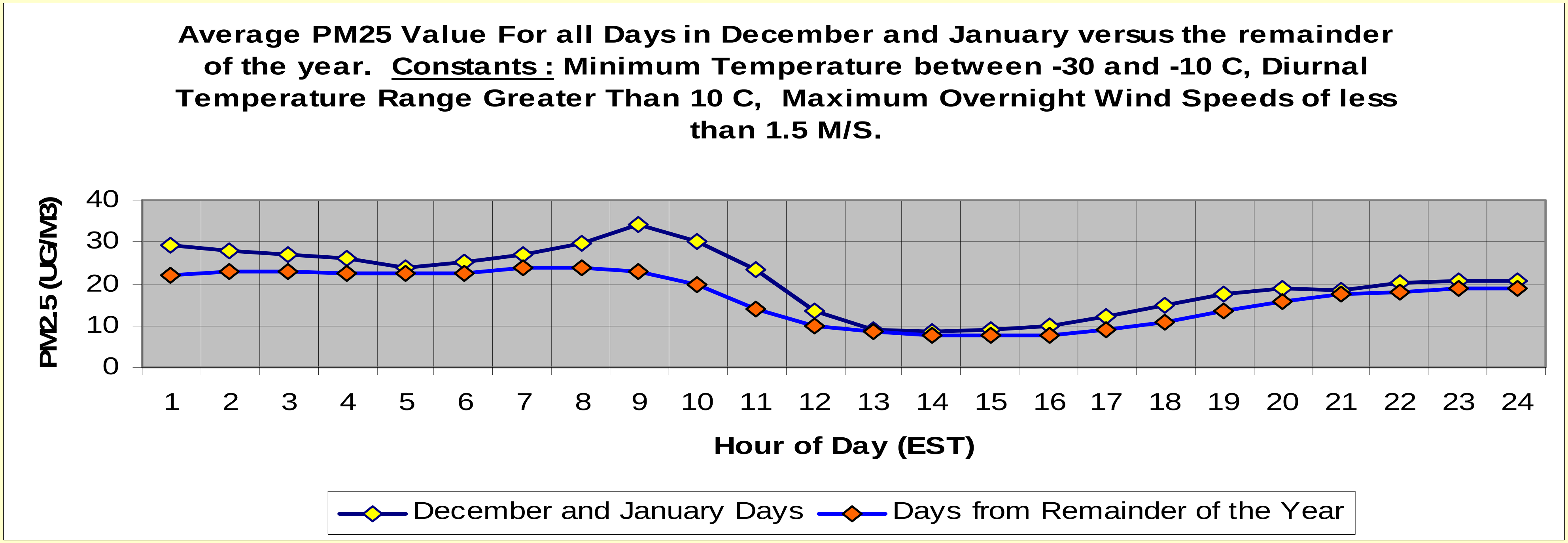
- Forecasting PM25 levels for Local emissions events in the wintertime for a northern appalachian mountain valley setting.
- **Approach :** An evaluation of surface meteorology at the measurement site is utilized to develop forecasters' 'rules of thumb'.
- Subsets of days in the 2006 – 2009 time series are selected based on these criteria :
- Minimum Daily Temperature.
- Minimum Diurnal Temperature Range.
- Maximum overnight wind speed.
- Midwinter days (December and January), versus the remainder of the year.

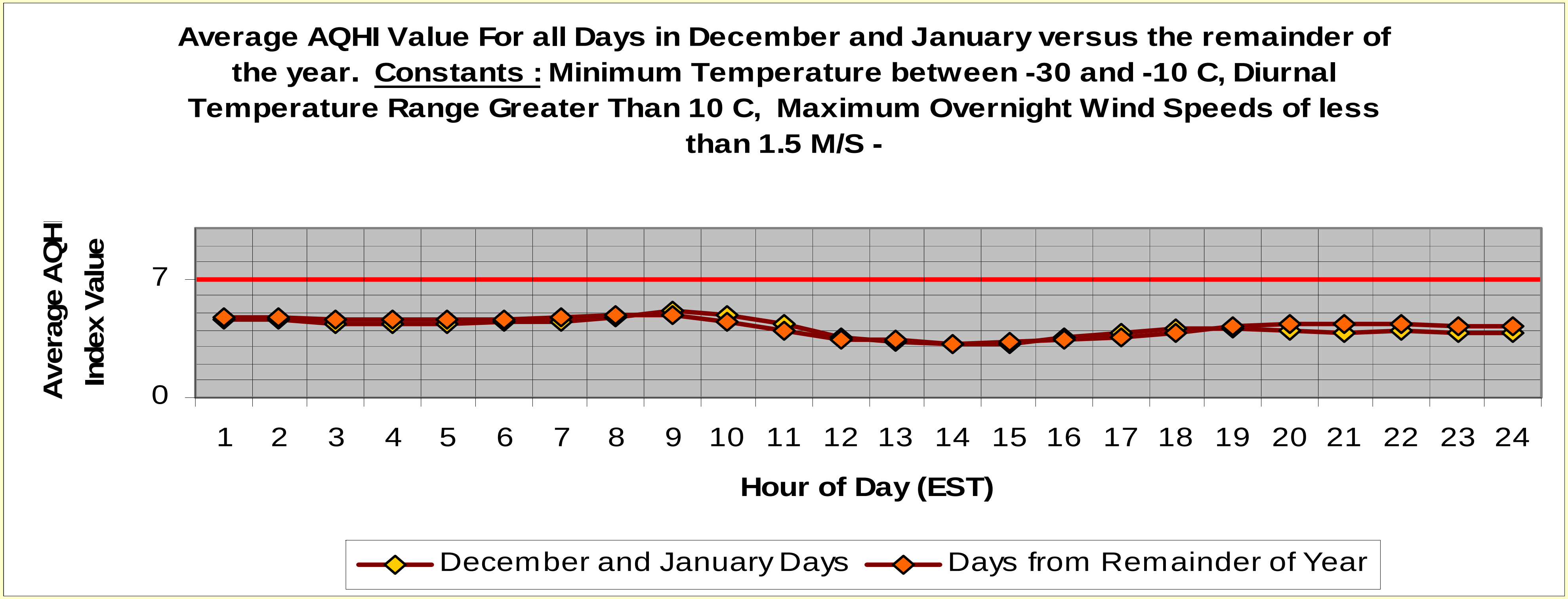

Average PM2.5 Diurnal Profile for all days included with minimum temperature of -30 to -10 C versus -10 to 0 C. Constants : Diurnal Temperature Range greater than 10 C; Maximum wind speed less than 1.5 M/S overnight. . Midwinter Days only
PM2.5 (UG/M3)
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
Meteorological Criteria : Minimum Temperature between -30 and -20 C.
Minimum Temperature between -10 and 0 C.


Average AQHI Diurnal Profile for all days included with minimum temperature of -30 to -10 C versus -10 to 0 C. Constants : Diurnal Temperature Range greater than 10 C; Maximum wind speed less than 1.5 M/S overnight. Midwinter Days only.
AQHI Index Scale
7
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
AQHI Value for -30 C to -10 C Minimum Temperature"
AQHI Value for -10 C to 0 C Minimum Temperature

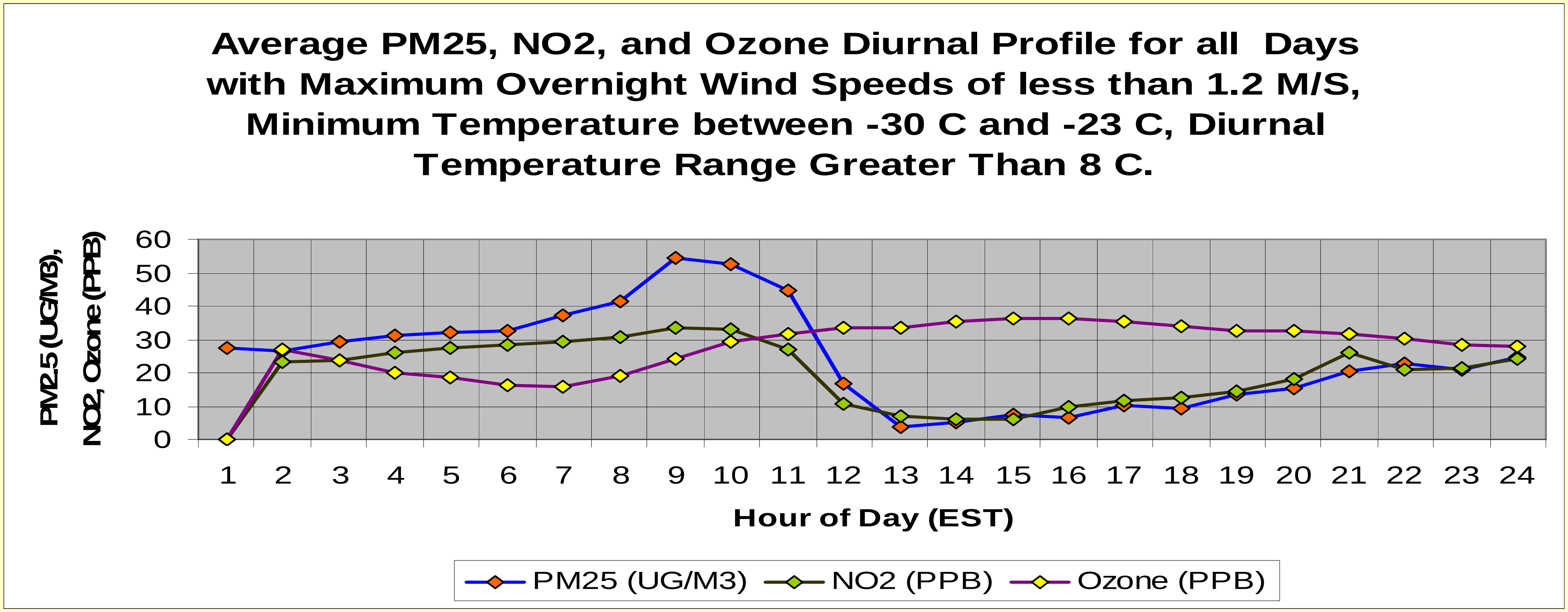

Average PM25 Diurnal Profile for all Days with Maximum Overnight Wind Speeds of less than 0.6 M/S versus less than 3.0 M/S. Constants : Minimum Temperature between -30 C and -10 C, Diurnal Temperature Range Greater Than 6 C.
Average PM25 (UG/M3)
0
5
10
15
20
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
Overnight Winds do not exceed 3 .0 M/S
Overnight Winds do not exceed 0.6 M/S.

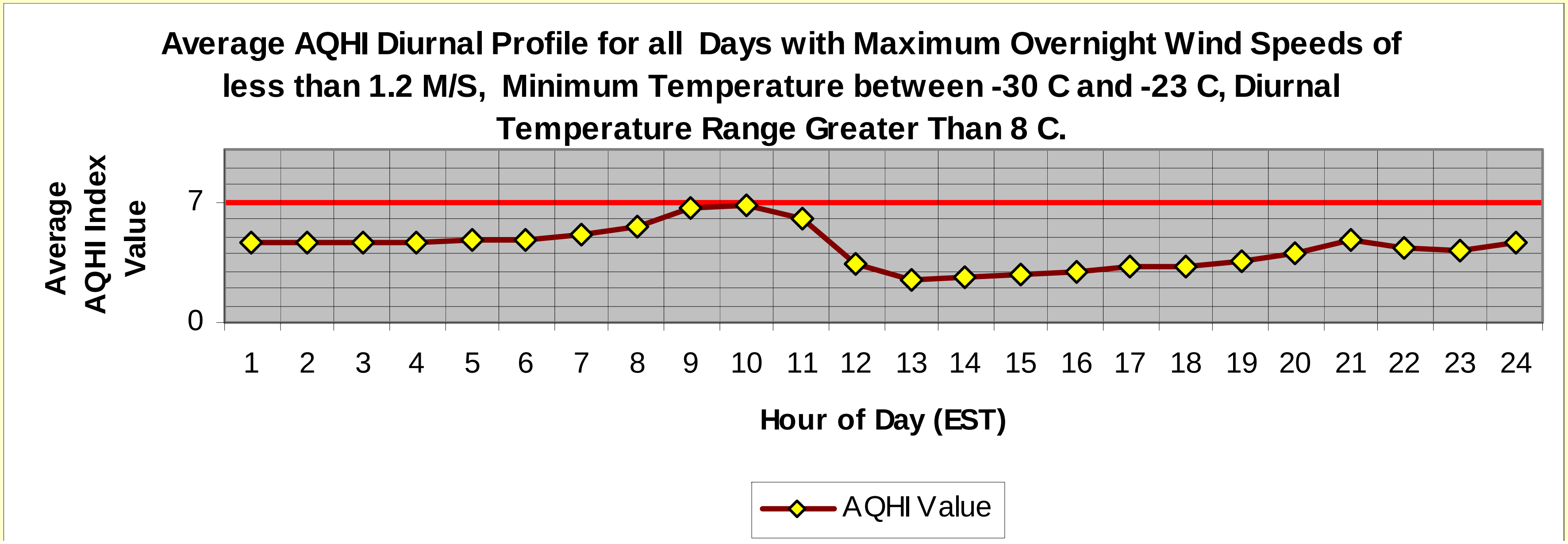

Average AQHI Diurnal Profile for all Days with Maximum Overnight Wind Speeds of less than 0.6 M/S versus less than 3.0 M/S. Constants : Minimum Temperature between -30 C and -10 C, Diurnal Temperature Range Greater Than 6 C.
AQHI Index Value
0
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
Overnight winds do not exceed 3.0 M/S
Overnight Winds do not exceed 0.6 M/S


Average PM25 Value For all Days in December and January versus the remainder of the year. Constants : Minimum Temperature between -30 and -10 C, Diurnal Temperature Range Greater Than 10 C, Maximum Overnight Wind Speeds of less than 1.5 M/S.
PM2.5 (UG/M3)
0
10
20
30
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
December and January Days
Days from Remainder of the Year


Average AQHI Value For all Days in December and January versus the remainder of the year. Constants : Minimum Temperature between -30 and -10 C, Diurnal Temperature Range Greater Than 10 C, Maximum Overnight Wind Speeds of less than 1.5 M/S -
Average AQHI Index Value
0
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (EST)
December and January Days
Days from Remainder of Year

A final rule of thumb for strong diurnal varying conditions most likely to result in an AQHI Exceedance.





Conclusions

- **<u>There is significant variation in AQI versus AQHI exceedances</u>**. It appears that for locations subject to local pollutant buildup and strong diurnal variation that the AQI may be insufficient as an indicator of poor air quality for short term pollutant maximums.

- Because three pollutants are utilized for the AQHI calculations **<u>there is a great range of Possible AQHI values in situations where indicators of local pollutant buildup indicate excessive air pollutant concentrations</u>.** This complexity suggests that further work is necessary to be able to accurately forecast the AQHI quantity using the annual AQHI equation over the entire year. This effort would involve better understanding NO2 and ozone fluctuations during the winter months.

Conclusions (continued)

- Because NO2 may serve as a marker of other hazardous air contaminant emissions from automobiles **The adverse health effects occurring for NO2 events that trigger AQHI exceedances may be inaccurate if the NO2 event is of a regional nature.**

- In northern valleys where residential wood combustion is prevalent, **The likelihood of an AQHI exceedance increases greatly as the minimum temperature drops to -10 F or lower and an extended period of calm is anticipated over the morning hours.**

- The AQHI 3 hour resolution does allow the forecaster to make an accurate statement for days and locations where large fluctuations in air quality occur.