ESL-TR-06-08-01

STATEWIDE AIR EMISSIONS CALCULATIONS FROM WIND AND OTHER RENEWABLES

SUMMARY REPORT

A Report to the
Texas Commission on Environmental Quality
For the Period September 2005 – August 2006

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August 2006

ENERGY SYSTEMS LABORATORY

Texas Engineering Experiment Station
Texas A&M University System

ENERGY SYSTEMS LABORATORY
Texas Engineering Experiment Station
Texas A&M University System

3581 TAMU
College Station, Texas 77843-3581

August 31, 2006

Chairman Kathleen Hartnett White
Texas Council on Environmental Quality
P. O. Box 13087
Austin, TX 78711-3087

Dear Chairman White:

The Energy Systems Laboratory (ESL) at the Texas Engineering Experiment Station of the Texas A&M University System is pleased to provide its first annual report, "Statewide Emissions Calculations From Wind and Other Renewables," as required by the 79th Legislature. This work has been performed through a contract with the Texas Environmental Research Consortium (TERC).

In this work the ESL is required to obtain input from public/private stakeholders, and develop and use a methodology to annually report the energy savings from Wind and Other Renewables. This report summarizes the work performed by the Laboratory on this project from September 2005 to August 2006.

Please contact me at (979) 862-8480 should you or any of the TCEQ staff have any questions concerning this report or any of the work presently being done to quantify emissions reductions from energy efficiency and renewable energy measures as a result of the TERP implementation.

Sincerely,

W. Dan Turner, P.E.
Director

Enclosure

cc: Commissioner Larry R. Soward
Executive Director Glenn Shankle

Disclaimer

SUMMARY REPORT

Statewide Air Emissions Calculations From Wind and Other Renewables

1. EXECUTIVE SUMMARY

The 79th Legislature, through Senate Bill 20, House Bill 2481 and House Bill 2129, amended Senate Bill 5 to enhance its effectiveness by adding 5,880 MW of generating capacity from renewable energy technologies by 2015, and 500 MW from non-wind renewables. The capacity of installed wind turbines totals was 2005 MW as of March 2006[1] and the planned capacity for new projects[2] rises to 3,700 MW by 2009 to 7,000 MW by 2015.

This legislation also requires PUC to establish a target of 10,000 megawatts of installed renewable capacity by 2025, and requires TCEQ to develop methodology for computing emissions reductions from renewable energy initiatives and the associated credits. In this Legislation the Laboratory is to assist TCEQ in quantifying emissions reductions credits from energy efficiency and renewable energy programs, through a contract with the Texas Environmental Research Consortium (TERC) to develop and annually calculate creditable emissions reductions from wind and other renewable energy resources for the state's SIP.

The Energy Systems Laboratory, in fulfillment of its responsibilities under this Legislation, submits its first annual report, "Statewide Air Emissions Calculations from Wind and Other Renewables," to the Texas Commission on Environmental Quality.

The report is organized in several deliverables:

- A Summary Report, which details the key areas of work;
- Supporting Documentation, including the Quality Assurance Project Plan;
- Supporting data files, including weather data, and wind production data, which have been assembled as part of the first year's effort.

This executive summary provides summaries of the key areas of accomplishment this year, including:

- development of stakeholder's meetings;
- reporting of NOx emissions reductions from renewable energy generation in the 2005 report to the TCEQ;
- results of preliminary literature search of previous methods;
- proposed weather normalization procedure for a single wind turbine;
- proposed weather normalization procedure for a wind farm containing multiple wind turbines;
- testing of the models;
- weather data collection efforts, and
- proposed modifications to the Laboratory's Quality Assurance Project Plan.

1.1 Development of Stakeholder's meetings.

Legislation passed during the regular session of the 79th Legislature directed the Energy Systems Laboratory to work with the TCEQ to develop a methodology for computing emissions reductions attributable to renewable energy and for the Laboratory to quantify the emissions reductions attributable to renewables for inclusion in the State Implementation Plan annually. HB 2921 directed the Texas Environmental Research Consortium (TERC) to engage the Texas Engineering Experiment Station for the development of this methodology.

[1] Wind project information obtained from Public Utility Commission of Texas (www.puc.state.tx.us) and Electric Reliability Council of Texas (ERCOT). Since the publication of this 2006 Annual report, installed capacity has risen to 2,538 as of September 25, 2006.

[2] Testimony presented by Mr. Gregg Cooke to the Texas State Legislature, May, 2005.

To initiate this effort, the TERC and Texas A&M held a Stakeholder's meeting at the Texas State Capitol on Tuesday, August 30, 2005. At this meeting the draft scope of work, schedule and deliverables were discussed.

On May 30, 2006, a second Stakeholder's meeting was held at the Texas State Capitol. At this meeting the draft scope of work was reviewed and the preliminary analysis of a single wind turbine was presented.

1.2 Reporting of NOx emissions reductions from renewable energy generation in the 2005 report to the TCEQ.

Using data available from the TCEQ and the U.S. Environmental Protection Agency (US EPA) with procedures developed by the Laboratory, the following results were determined for energy-code compliant new residential single-and multi-family construction in both non-attainment and affected counties built in 2004[3].

Total cumulative NOx reductions were determined to be 5,738.58 tons/year, and 15.43 tons/peak-OSD in 2009, and 6,034.93 tons/year and 17.13 tons/peak-OSD in 2013, which contain the following contributions from the Laboratory, the Public Utilities Commission (PUC), the State Energy Conservation Office (SECO), and green power provided by wind turbines[4]renewable energy sources Wind/ERCOT programs:

- from energy efficiency savings from code-compliant new construction: 900.52 tons/year, and 4.47 tons/peak-OSD in 2009; and 1,167.49 tons/year with 5.75 tons/peak-OSD in 2013 (2007 eGRID),
- from the PUC SB7 and SB5 programs: 1,483.22 tons/year, and 3.98 tons/peak-day-OSD in 2009, and 1,981.05 tons/year, and 5.31 tons/peak-OSD in 2013 (2007 eGRID),
- from the SECO program, 447.10 tons/year, and 1.29 tons/OSD in 2009, and 699.86 tons/year, and 1.76 tons/peak-OSD in 2013, and
- from the Wind-ERCOT program: 2,880.74 tons/year and 5.69 tons/peak-OSD in 2009 and 2,186.33 tons/year and 4.32 tons/peak-OSD in 2013.

1.3 Results of preliminary literature search of previous methods.

In order to develop an analysis that calculated the 1999 base-year electricity savings from wind-generated electricity produced in non-base years, weather data files needed to be assembled, cleaned and analyzed. Results from a preliminary search of the literature on weather data synthesis, and data filling techniques is included. These results show that there are previous studies regarding the filling-in of missing data using a variety of techniques. However, there appear to be no previous attempts to synthesize on-site wind data from published NOAA records. All previous literature showed only measured weather data, or data triangulated from nearby sites. Additional references will be searched to look for previous papers in this area.

A preliminary search was also performed on the literature regarding the synthesis of solar radiation data. This search located a number of procedures that have been proposed for synthesizing solar radiation data in locations where only non-solar weather data are collected. Based on the results of this search, a procedure has been chosen for use[5]. In addition, results from a recent ASHRAE project has shown new procedures

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[3] The values shown are those presented in the Laboratory's 2005 Annual Report to the Texas Commission on Environmental Quality (TCEQ). Report ESL-TR-06-06-07, available at (eslsb5.tamu.edu). These values include data collected in 2004 through 2005. Data collected in 2005 through 2006 will be presented in the Laboratory's 2006 Annual Report to the TCEQ.
NOx reductions

[4] The green power provided by wind turbine installations is currently monitored by the Electric Reliability Council of Texas (ERCOT).

[5] The procedure chosen for use in the current compilation of solar data is the procedure developed by Kasten and Czeplak (1980) for the synthesis of Global Horizontal Solar Radiation.

have been developed that may improve the proposed model. The results from the ASHRAE project will be further investigated to determine if these will prove useful for Texas[6].

Finally, a review of ASHRAE's Inverse Model Toolkit (IMT) analysis method, which uses linear, and change-point linear algorithms is presented. This includes a analysis of the accuracy of IMT and its algorithms versus other well-accepted statistical analysis tools, such as SAS. Also, included is a review of the history of the IMT, and the linear and change-point linear models, and a review of the published comparisons of the IMT and other analysis software, which was part of the accuracy testing that was performed as part of ASHRAE's Research Project 1050-RP.

1.4 Weather data collection efforts.

An analysis is presented regarding the expansion of the weather data collection efforts for wind and other renewables. In 2005, in cooperation with the TCEQ, the 9 weather stations, which had been assembled for calculating emissions from the non-attainment and affected counties were expanded to include all counties in ERCOT. To accomplish this, 8 additional weather stations were added to the original 9 stations for a total of 17 weather stations. Assignment of weather stations was then performed, and data collection efforts initiated, including the synthesis of solar radiation for sites where no solar data have been collected since 2003, when the USDOE ceased funding the NREL solar radiation network in Texas.

1.5 Proposed weather normalization procedures

In order to develop procedures for calculating creditable NOx emissions reductions in the base year for a specific wind generation site, a method for calculating the base-year electricity produced by a wind turbine at a specific site needed to first be developed. Such a procedure requires the development of weather-normalized electricity production for a given site, then recalculating the base-year electricity savings using the recorded NOAA wind data at the wind generation site, and NOx emissions reductions calculated using eGRID.

1.5.1 Proposed weather normalization procedure for a single wind turbine

To investigate the proposed weather normalization procedures for the wind power generation of a single wind turbine, an actual wind electricity generator with a 44-ft rotor diameter, installed in the Southern Great Plains at the USDA Conservation and Production Research Laboratory in 1982 in Randall County, Texas was analyzed. This analysis includes a description of the on-site and NOAA wind data, measured electricity production data (including curtailment and maintenance), modeling of the power production using the IMT, analysis of the ability of the model to forecast wind power for other years, and an analysis of the capacity factors generated using the model.

1.5.2 Proposed weather normalization procedure for a wind farm containing multiple wind turbines, and testing of the models.

To investigate the proposed weather normalization procedures for the wind power generation of a wind farm with multiple wind turbines, the Indian Mesa Wind Farm located in Pecos County, TX was used. This wind farm project was completed in 2001. One hundred and twenty-five Vestas V-47 wind turbines produce up to 82.5 Megawatts of electricity. Electricity produced by the project is purchased by the Lower Colorado River Authority for Austin Energy, Austin, Texas, and TXU Energy Trading Company, Dallas, Texas. The project is connected to the transmission lines of American Electric Power subsidiary West Texas Utilities. This analysis includes a description of the on-site and NOAA wind data, measured electricity production data (including curtailment and maintenance), modeling of the power production using the IMT, analysis of the ability of the model to forecast wind power for other years, and an analysis of the capacity factors generated using the model.

[6] ASHRAE Research Project 1309 – Development of Solar Radiation Model for Troical Climate, Moncef Krarti, University of Colorado, and Joe Huang, LBNL, in preparation.

1.6 Proposed modifications to the Laboratory's Quality Assurance Project Plan.

Modifications to the Laboratory's Quality Assurance Project Plan (QAPP) have been outlined for the 2006/2007 effort. These modifications include expansion of the QAPP to include the new weather sites, expansion of the dataset to include ERCOT electric power from wind generators, and other renewables data.

1.7 Technical Assistance

The Laboratory provided technical assistance to the TCEQ, the PUC, SECO and ERCOT, as well as Stakeholders participating in the Energy Code and Renewables programs. In 2005 the Laboratory worked closely with the TCEQ to develop an integrated emissions calculation procedure, that provided the TCEQ with a creditable NOx emissions reduction from energy efficiency and renewable energy (EE/RE) programs reported to the TCEQ in 2005 by the Laboratory, PUC, SECO, and Wind-ERCOT.

The Laboratory has also enhanced the previously developed emissions calculator by: expanding the capabilities to include all counties in ERCOT; including the collection and assembly of weather from 1999 to the present from 17 NOAA weather stations; and enhancing the underlying computer platform for the calculator.

1.8 Technology Transfer

To accelerate the transfer of technology developed as part of the Senate Bill 5 program, the Laboratory: delivered an invited presentation to the US EPA's Air Innovations conference in Chicago, August, 2005; delivered six papers at International Conference on Enhanced Building Operation at Carnegie Mellon University in Pittsburg, PA, in October 2005; hosted the Emissions Reduction and Leadership Summit in Dallas, in November 2005, developed an article for the *ibpsaNEWS* newsletter[7]; and published technical reports.

The Laboratory has and will continue to provide leading edge technical assistance to counties and communities working toward obtaining full SIP credit for the energy efficiency and renewable energy projects that are lowering the emissions and improving the air quality for all Texans. The Laboratory will continue to provide superior technology to the State of Texas through efforts with the TCEQ and US EPA. The efforts taken by the Laboratory have produced significant success in bringing EE/RE closer to US EPA acceptance in the SIP.

[7] *ibpsaNEWS* is the electronic newsletter for the International Building Performance Simulation Association, co-sponsored by the US DOE.

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2 INTRODUCTION

Texas is now the largest producer of wind energy in the United States. Wind developers are attracted to Texas by the many windy sites suitable for wind development here. The capacity of installed wind turbines totals was 2005 MW as of March 2006[8] and the planned capacity for new projects[9] rises to 3,700 MW by 2009 to 7,000 MW by 2015 (Figure 1). This summary report presents the results of the 2005/2006 emissions reporting to the TCEQ and presents the results of the development of a preliminary methodology to calculate the electricity savings from green power purchases from Texas wind energy providers. In the proposed method, the ASHRAE Inverse Model Toolkit (IMT) is used for weather normalization of the daily electric generation data. The EPA's Emissions and Generations Resource Integrated Database (eGRID) is used for calculating annual and Ozone Season Day's NOx emissions reductions for the electric utility provider associated with the user.

2.1 Statement of Work for Calculations of Emissions from Wind and Other Renewables.

This summary report covers Laboratory's work from September 2005 through August 2006. This work is intended to cover the basic work outline included below:

Task 1: Obtain input from public/private stakeholders.

a. Establish list of stakeholders for wind/other renewables.
b. Hold stakeholder's meeting & obtain input, including concerns, goals, objectives, etc.
c. Develop response to stakeholder input, circulate response to stakeholders.
d. Setup and maintain list server for ongoing comments to/from stakeholders.

Legislation passed during the regular session of the 79th Legislature directed the Energy Systems Laboratory to work with the TCEQ to develop a methodology for computing emissions reductions attributable to renewable energy and for the Laboratory to quantify the emissions reductions attributable to renewables for inclusion in the State Implementation Plan annually. HB 2921 directed the Texas Environmental Research Consortium (TERC) to engage the Texas Engineering Experiment Station for the development of this methodology.

To initiate this effort, the TERC and Texas A&M held a Stakeholder's meeting at the Texas State Capitol on Tuesday, August 30, 2005. At this meeting the draft scope of work, schedule and deliverables were discussed. Figure 2 shows the invitation letter that was sent to Stakeholders, and Figure **3** and Figure 4 contain the slides that were used at the meeting.

[8] Wind project information obtained from Public Utility Commission of Texas (www.puc.state.tx.us) and Electric Reliability Council of Texas (ERCOT).
[9] Testimony presented by Mr. Gregg Cooke to the Texas State Legislature, May, 2005.

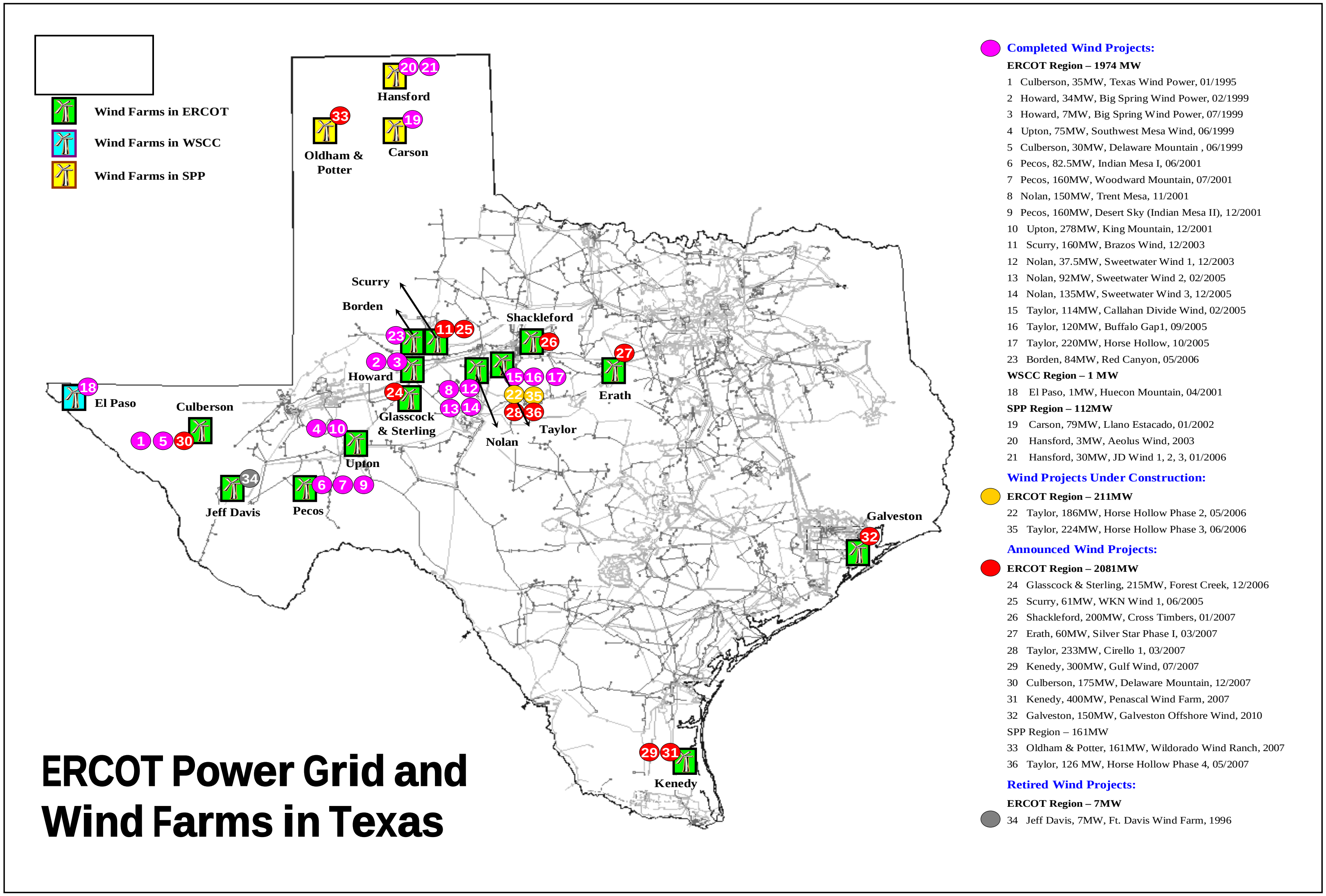


Figure 1: Completed and Announced Wind Projects in Texas

Texas Environmental Research Consortium — environmental improvement through research and science

Energy Systems Laboratory

MEMORANDUM

To: Texas Renewable Energy Stakeholders

From: Bruce LaBoon, Texas Environmental Research Consortium
Dan Turner, Energy Systems Laboratory (ESL), Texas Engineering Experiment Station

Subject: Stakeholders Meeting Regarding Renewables Study

Date: August 17, 2005

Legislation passed during the regular session of the 79th Legislature directs the Energy Systems Laboratory of the Texas A&M University System to work with TCEQ to develop a methodology for computing emissions credits from renewable energy and for the ESL to quantify the emissions reductions attributable to renewables for inclusion in the State Implementation Plan annually. HB 2921 directs the Texas Environmental Research Consortium (TERC) to engage the Texas Engineering Experiment Station for the development of this important and timely methodology.

TERC and ESL are in the process of developing the scope of work and the related deliverables for this study. Both TERC and Texas A&M are committed to obtaining input from all of the relevant stakeholders prior to finalizing the study plan. Accordingly, our respective organizations are inviting you to attend a renewable energy stakeholder's input meeting on Tuesday, August 30, 2005.

The meeting will be held in Austin at the Capitol Extension, Room E1.016 from 9:30 a.m. to 11:30 a.m. The draft scope of work, deliverables and the schedule to complete the study will be discussed at the meeting. Please feel free to invite other persons that you believe could positively contribute to this important study. Additionally, contact Mr. David Hitchcock of the Houston Advanced Research Center if you have questions regarding the upcoming meeting. Mr. Hitchcock's telephone number and email address are 281-364-4007 and dhitchcock@harc.edu. We look forward to seeing you on Tuesday, August 30th and setting in place a process to obtain your input on this important matter.

Attachment

TERC-Texas A&M System Renewable Energy Stakeholders Meeting
Tuesday, August 30, 2005
9:30 a.m. – 11:30 a.m.
Capitol Extension, Room E1.016

AGENDA

I. Introductions	Mr. Bruce LaBoon, Chairman, TERC Board of Directors
II. Opening Remarks	The Honorable Ken Armbrister, Chairman, Senate Natural Resources Committee
	The Honorable Dennis Bonnen, Chairman, House Environmental Regulations Committee
	Dr. Dan Turner, Director, Energy Systems Lab, Texas A&M University System
III. Presentation of Draft Study Plan	Dr. Jeff Haberl, Associate Director, Energy Systems Lab, Texas A&M University System
	David Hitchcock, The Houston Advanced Research Center
IV. Open Discussion of Study Plan	All Stakeholders
V. Establish an Ongoing Communication Process	(TERC, Texas A&M System, Stakeholders)
VI. Adjournment	

Figure 2: Letter of Invitation to the Wind/Renewables Stakeholder's Meeting, August 30, 2005.

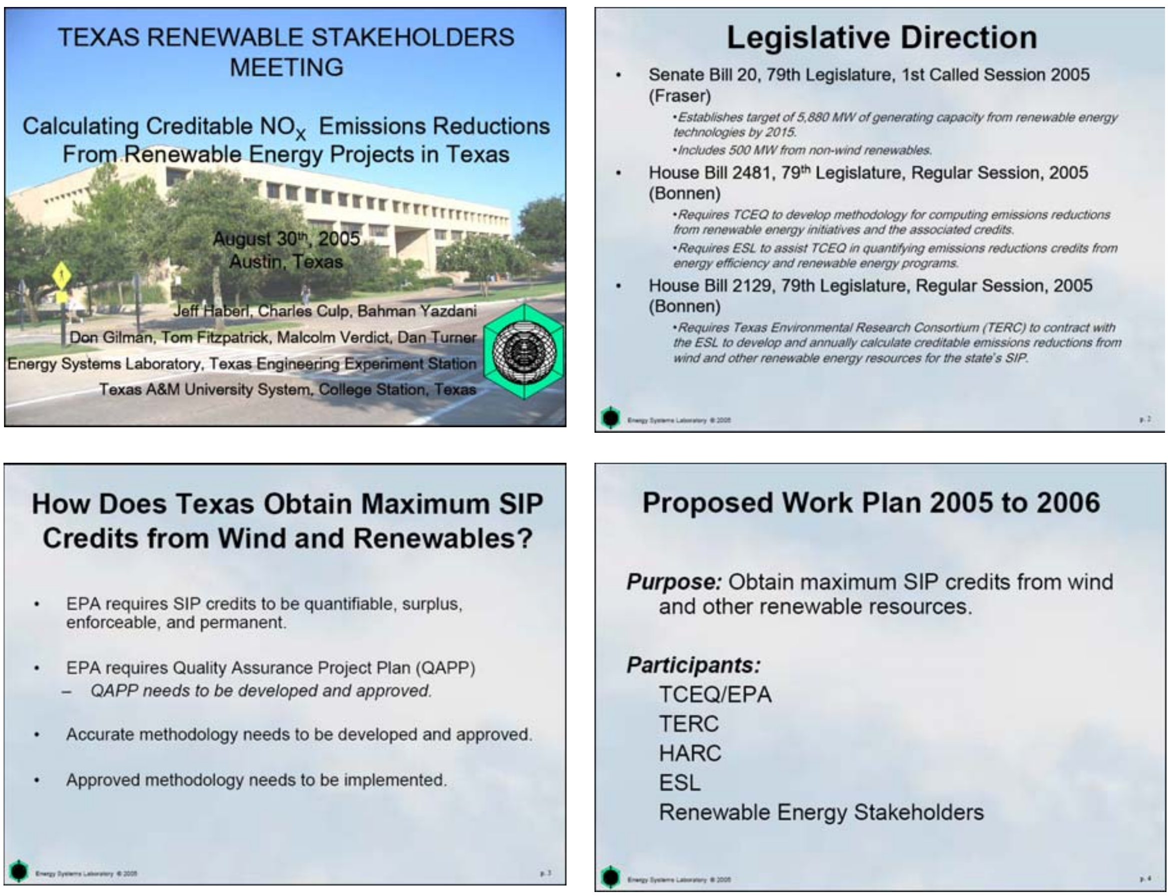


Figure 3: Slides Presented at Wind/Renewables Stakeholder's Meeting, August 30, 2005 (Part 1).

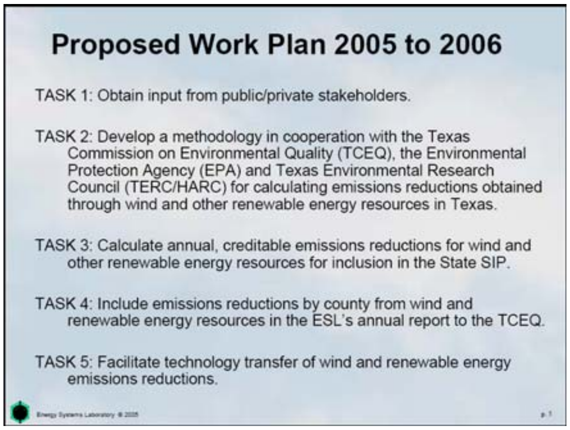


Figure 4: Slides Presented at Wind/Renewables Stakeholder's Meeting, August 30, 2005 (Part 2).

Renewable Energy Stakeholder's Meeting		
Austin, Texas - August 30, 2005		
Attendee Name	**Organization**	**E-Mail Address**
Donald McArthur	Texas Genco	dmcarthur@txgenco.com
Rusty Hodapp	DFW Airport Board	rhodapp@dfwairport.com
Amy Fitzgerald	Texas Electric Co-ops	amyf@texas-ec.org
Irvin Bilsky	Environmental Consultant/EPEC	irvinbilsky@msn.com
Tracy Hester	Bracewell & Giuliani	tracy.hester@bracewellgiuliani.com
Don Lewis	TXDOT	dlewis1@dot.state.tx.us
Jon W. Fainter, Jr.	AECT	john@aect.net
Soll Sussman	GLO	soll.sussman@glo.state.tx.us
Walt Baum	AECT	walt@aect.net
Chad Adams	Ellis County	chad.adams@co.ellis.tx.us
Diane Mazuca	TCEQ	dmazuca@tceq.state.tx.us
Travis Brown	Public Citizen	tbrown@citizen.org
Mary Miksa	TAB	mmiksa@txbiz.org
Sarah Bagwell	Senator Shapiro	sarah.bagwell@senate.state.tx.us
Scott Anderson	Environmental Defense	sanderson@environmentaldefense.org
Jess Totten	PUC	jesstotten@puc.state.tx.us
Tom Smith	Public Citizen	smitty@citizen.org
Dan Titerle	SAWS	dtiterle@saws.org
Pam Groce	SECO	pam.groce@cpa.state.tx.us
Shelly Botkin	Office of the Lt. Governor	shelly.botkin@ltgov.state.tx.us
Mary-Jo Rowan	SECO	mary-jo.rowan@cpa.state.tx.us
Ned Ross	FPL Energy	ned_ross@fpl.com
Russel E. Smith	TREIA	R1346@aol.com
Jeff Trucksess	Good Company	jtrucksess@goodcompanyasssociates.com
Mari Villarreal	Solar	mariv@onr.com
Dan Turner	ESL	danturner@tees.tamus.edu
Robert King	Good Company	rking@goodcompanyassociates.com
Dan Hinkle	Solar	kdan@airmail.net
Bahman Yazdani	ESL	bahmanyazdani@tees.tamus.edu
Mike Sloan	Wind Coalition	Sloan@veia.com
Joni Brown	City of Victoria	jbrown@victoriatx.org
Nelson H. Nease	Cardinal Glass	nnease@bbrsaustin.com
Tom Fitzpatrick	ESL	tfitzpatrick@mail.utexas.edu
Cathy Reiley	TEES	c-reiley@tamu.edu
Malcolm Verdict	ESL	malcolmverdict@esl.tamu.edu
Dub Taylor	SECO	dub.taylor@cpa.state.tx.us
Michael Hoke	Environmental Reg. Committee	michael.hoke_hc@house.state.tx.us
Gregg Cooke	Gunter Slavich	cooke@gsfpc.com
John Hall	TERC	jhallpa@aol.com
Jeff Haberl	ESL	jeffhaberl@tees.tamus.edu
Jim Lester	TERC	none given
Rebecca Brister	ESL	rebeccabrister@tees.tamus.edu

Table 1: Attendees of the August 2005 Wind and Renewable Stakeholders Meeting.

On May 30, 2006, a second Stakeholder's meeting was held at the Texas State Capitol. At this meeting the draft scope of work was reviewed and the preliminary analysis of a single wind turbine was presented. Figure 5 through Figure 8 show the slides that were presented at the Wind/Renewables Stakeholder's meeting, which were used to gather input from the participants.

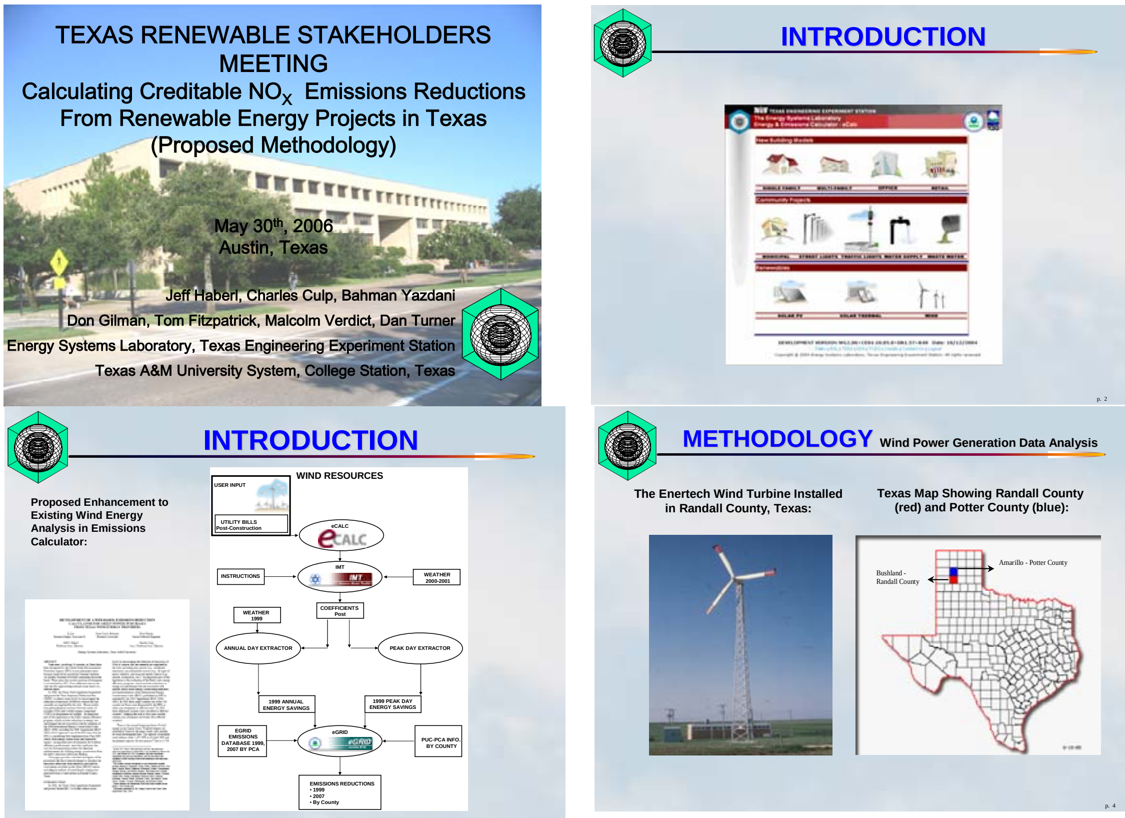
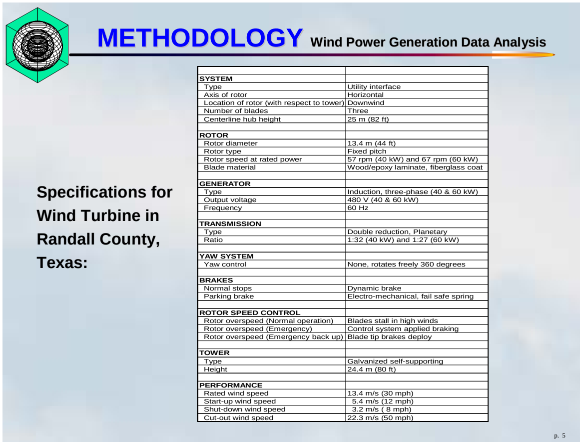
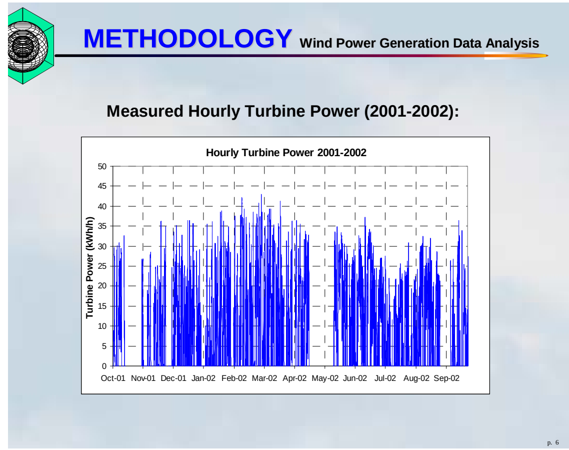
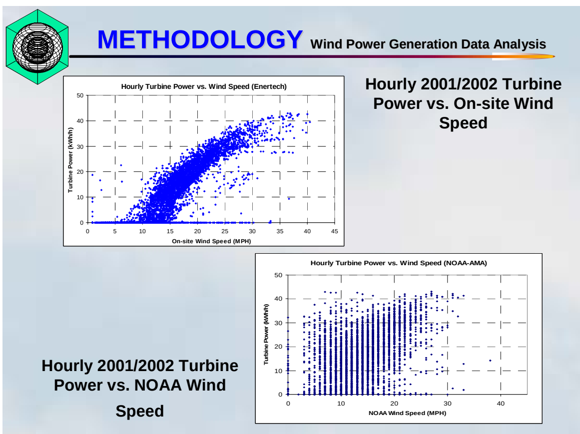


Figure 5: Slides Presented at Wind/Renewables Stakeholder's Meeting, May 30, 2006.



SYSTEM	
Type	Utility interface
Axis of rotor	Horizontal
Location of rotor (with respect to tower)	Downwind
Number of blades	Three
Centerline hub height	25 m (82 ft)
ROTOR	
Rotor diameter	13.4 m (44 ft)
Rotor type	Fixed pitch
Rotor speed at rated power	57 rpm (40 kW) and 67 rpm (60 kW)
Blade material	Wood/epoxy laminate, fiberglass coat
GENERATOR	
Type	Induction, three-phase (40 & 60 kW)
Output voltage	480 V (40 & 60 kW)
Frequency	60 Hz
TRANSMISSION	
Type	Double reduction, Planetary
Ratio	1:32 (40 kW) and 1:27 (60 kW)
YAW SYSTEM	
Yaw control	None, rotates freely 360 degrees
BRAKES	
Normal stops	Dynamic brake
Parking brake	Electro-mechanical, fail safe spring
ROTOR SPEED CONTROL	
Rotor overspeed (Normal operation)	Blades stall in high winds
Rotor overspeed (Emergency)	Control system applied braking
Rotor overspeed (Emergency back up)	Blade tip brakes deploy
TOWER	
Type	Galvanized self-supporting
Height	24.4 m (80 ft)
PERFORMANCE	
Rated wind speed	13.4 m/s (30 mph)
Start-up wind speed	5.4 m/s (12 mph)
Shut-down wind speed	3.2 m/s (8 mph)
Cut-out wind speed	22.3 m/s (50 mph)





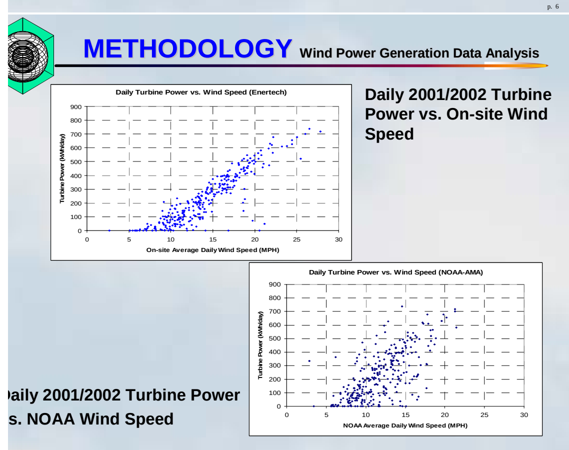
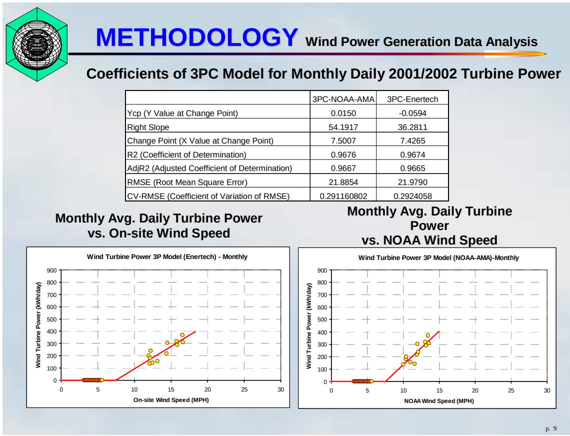
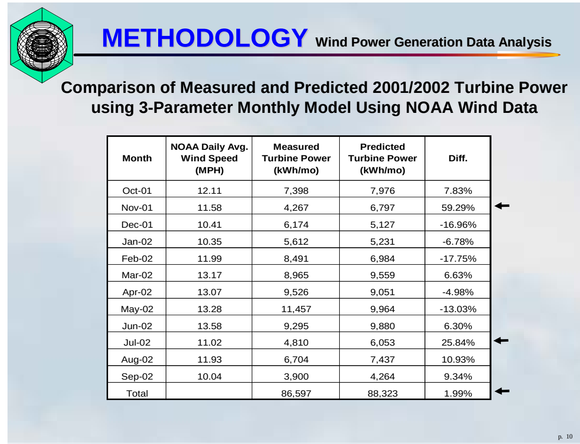
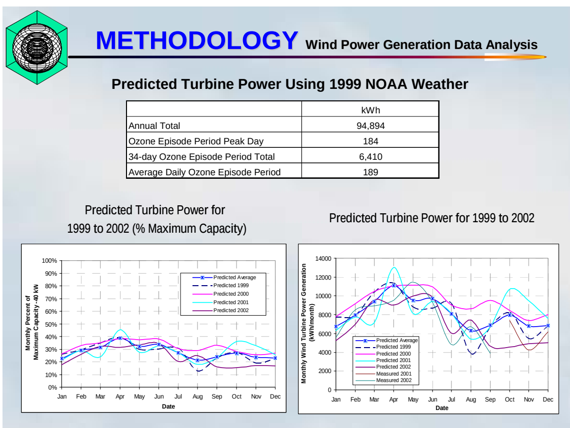


Figure 6: Slides Presented at Wind/Renewables Stakeholder’s Meeting, May 30, 2006 (Cont’d.).







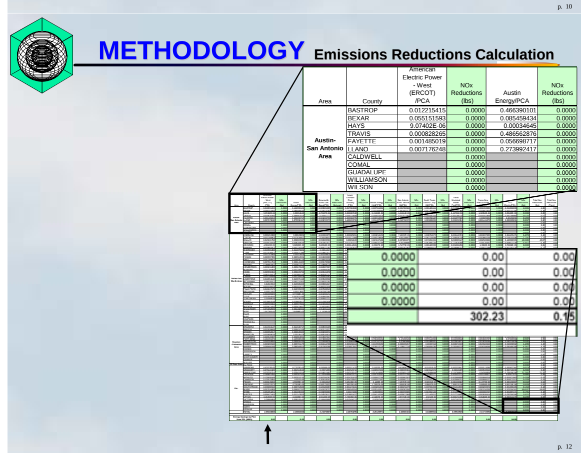
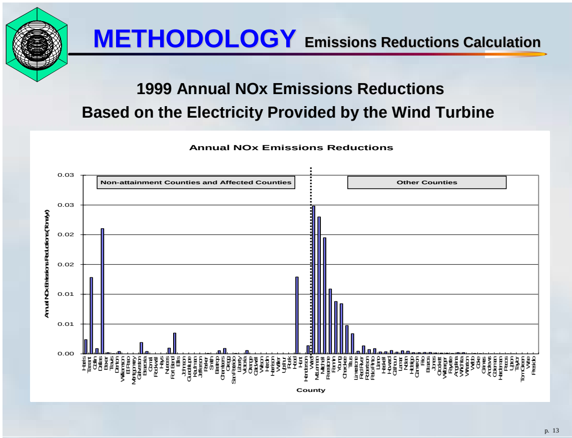
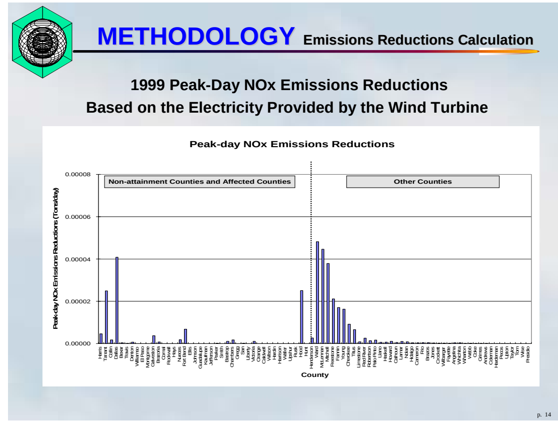


Figure 7: Slides Presented at Wind/Renewables Stakeholder's Meeting, May 30, 2006 (Cont'd.).





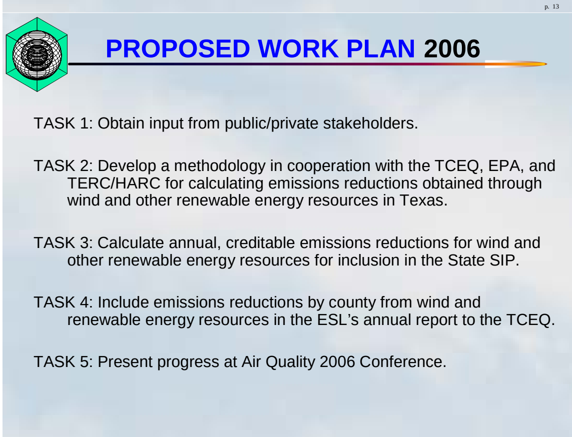


Figure 8: Slides Presented at Wind/Renewables Stakeholder's Meeting, May 30, 2006 (Cont'd.).

Wind & Renewal Energy Stakeholders Meeting - 05/30/2006, Austin,			
ATTENDEE:		AFFILIATION:	EMAIL ADDRESS:
Adams	Chad	Ellis County	chad.adams@co.ellis.tx.us
Alvarez	Ramon	Environmental Defense	
Armstrong	Reed	PPM Energy	reed.armstrong@ppmenergy.com
Baum	Walt	AECT	walt@aect.net
Bertin	Suzanne	Reliant Energy	sbertin@reliant.com
Carter	Teddy	State of Texas, Committee on Natural Resources	teddy.carter_sc@senate.state.tx.us
Chapman	Betsy	TCEQ	bchapman@tceq.state.tx.us
Culp	Charles	TAMU, TEES, ESL	cculp@tamu.edu
Durrwachter	Henry L.	TXU Wholesale	hdurrwachter@txu.com
Freeman	Jeff	Good Company	jfreeman@goodcompanyassociates.com
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Table 2: Attendees of the May 2006 Wind and Renewable Stakeholders Meeting.

Task 2: Develop a methodology in cooperation with the Texas Commission on Environmental Quality (TCEQ) and the Environmental Protection Agency for calculating emissions reductions obtained through wind and other renewable energy resources in Texas.

e. Review existing methodologies for calculating emissions reductions from wind energy and other renewable energy systems with EPA, TCEQ and stakeholders. Develop acceptable methodologies for wind and renewables.
f. Determine how to implement methodologies for Texas, including accounting of current installations, future sites, degradation, discounting/uncertainty, grid constraints, etc.
g. Review methodologies for verifying wind energy production and renewable energy installations with TCEQ, EPA and stakeholders. Develop acceptable methodologies for verifying installations, including documentation, EPA QAPP, etc.

Task 3: Calculate annual, creditable emissions reductions for wind and other renewable energy resources for inclusion in the State SIP.

h. Calculate annual emissions from wind and other renewable energy projects.
i. Verify annual installations of wind and renewable energy systems in Texas.
j. Verify ERCOT historical data for wind production and other renewables.

Task 4: Include emissions reductions by county from wind and renewable energy resources in the ESL's annual report to the TCEQ.

k. Report annual emissions from wind and other renewable energy projects.
l. Report on verification of installations of wind and renewable energy systems in Texas.
m. Develop documentation for all methods developed.

Task 5: Incorporate wind and renewable energy emissions reductions as a component of the ESL annual Energy Leadership & Emissions Reduction Conference to facilitate technical transfer.

Preliminary results of the Laboratory's efforts on Tasks 2, 3, 4 and 5 are presented in the following sections. This work was performed during the period September 2005 through August 2006.

3 REPORTING OF EMISSIONS REDUCTIONS IN 2005 ANNUAL REPORT TO THE TCEQ

3.1 Background.

In January 2005, the Laboratory was asked to propose a method by which the NOx emissions savings from the energy efficiency programs from multiple Texas State Agencies working under SB5 and SB7 could be reported in a combined format to allow the TCEQ to consider the combined savings for SIP planning purposes. This required that the analysis should include the cumulative savings estimates from all projects through 2013 for both the annual and Ozone Season Day (OSD) NOx reductions. The NOx emissions reductions from all these programs were calculated using the emissions factors for 2007 from the U.S.E.P.A. The different programs included in this cumulative analysis are:

- ESL-Single-family
- ESL-Multi-family
- PUC-SB7
- PUC-SB5
- SECO
- Wind-ERCOT

The Laboratory's single-and multi-family programs include the energy savings attained by constructing new residences according to IECC 2000/2001 building code[10]. The baseline for comparison for the code programs is the published data on residential construction characteristics by the National Association of Home Builders[11] (NAHB) for 1999 to 2003. Annual MWh (electric) and MBtu (natural gas) savings are from the Laboratory's Annual Reports to the TCEQ.

The PUC's SB5 and SB7 programs include their incentive and rebates programs managed by the different Utilities for the Texas. These include the Residential Energy Efficiency Programs as well as the Commercial & Industrial Standard Offer Programs (C&I SOP). The energy efficiency measures include high efficiency HVAC equipment, variable speed drives, increased insulation levels, infiltration reduction, duct sealing, Energy Star homes etc. Annual MWh saving according to the utilities (or Power Control Authorities – PCAs) were reported for the different programs completed in the years 2001, 2002, 2003 and 2004. The PUC also reported the savings from the SB5 grant program which was conducted in 2002 and 2003.

The Texas State Energy Conservation Office (SECO) funds energy efficiency programs directed towards school districts, government agencies, city and county governments, private industries and residential energy consumers. For the 2004 reporting year SECO submitted annual energy saving values of 292,773.2 MWh for 149 projects, or 802.12 MWh/OSD, which included projects funded by SECO and by Energy Service projects.

The wind-ERCOT project includes NOx emissions savings from the current installed green power generation capacity in west Texas. For projections through 2013, two annual growth factors were available, 17% annual growth through 2009 to reach a production level of 3,700 MW in 1009, and 22.7% annual growth to reach a production level of 7,000 MW till 2015. In the numbers shown in this report a 17.0% growth factor was assumed for the wind energy portion of savings.

[10] IRC 2001. International Residential Code for One and Two Family Dwellings. International Code Congress, Falls Church, VA, Second printing, January.
[11] NAHB. 2003. "The Builders Practices Survey Reports," National Association of Home Builders. Upper Marlboro, MD: NAHB Research Center.

3.2 Description of Analysis Method.

Annual and Ozone Season Day (OSD) NOx emissions reductions were calculated for 2004 and cumulatively from 2005 up to 2013 using assumed growth factors. The following factors were used to adjust the cumulative savings for future predictions:

Annual Degradation Factor:
This factor was used to account for the decrease in efficiency of the measures installed as the equipment wears down and degrades. An annual degradation factor of 5% was used for all the programs. This value has been taken from a study by Kats et al. 1996.

Transmission and Distribution Loss:
This factor adjusts the reported savings to account for the loss in energy resulting in the transmission and distribution of the power from the electricity producers to the electricity consumers. For this calculation, the energy savings reported at the consumer level are increased by 7% to give credit for the actual power produced that gets lost in the transmission and distribution system on its way to the customer. In the case of Wind-ERCOT, The T&D losses were assumed to cancel out since wind energy is displacing the actual power produced by the conventional power plants, therefore, no net increase or decrease in T&D losses.

Initial Discount Factor:
This factor was used to discount the reported savings for the assumptions and methods employed in the calculation procedures. For the Laboratory's single-family and multi-family code compliance program, the discount factor was assumed to be 20%. For PUC's SB5 and SB7 programs and Wind-ERCOT, the discount factor was taken as 25%. For the savings in the SECO program, the discount factor was 60%.

Growth Factor:
The factors shown in Table 7 were used to account for several different factors. First, in the case of wind energy, the factor accounted for the increased number of wind turbines, which are being installed every year in the western portion of the state. Three different scenarios were studied for wind energy projections:

- No annual growth.
- 17% growth factor, on the basis that the installed wind power generation capacity will grow to 3700 MW till 2009 from current installed level of 2000 MW. For this growth scenario, the 17% growth will achieve 3700 MW by 2009, after that the wind power generation will be fixed at the production level achieved in 2009.
- 22.7% growth factor, on the basis that the installed wind power generation capacity will grow to 7000 MW in 2015.

In the numbers shown in this report a 17.0% growth factor was assumed for the wind energy portion of savings.

Also, included in Table 7 are growth factors for single-family (3.25%) and multi-family residential (1.54%) construction. These values represent the average growth rate for these housing types from the U.S. Census data for Texas[12].

Figure 9 shows the overall information flow that was used to calculate the NOx emissions savings from the annual and OSD MWh numbers from all programs. For the Laboratory's single-family and multi-family code implementation programs, the annual and ozone season savings were calculated from DOE-2 hourly simulation models based on the Chapter 4 of IECC 2000/2001. The base case is taken as the average characteristics of single- and multi-family residences for Texas published by National Association of Home Builders for 1999. The OSD consumption is the average daily consumption between July 15th and September 15th of 1999.

[12] U.S. Census data obtained from the RECenter 2005. Texas Real Estate Research Center, College of Business, Texas A&M University, College Station, Texas. URL: recenter.tamu.edu.

The annual MWh numbers from PUC programs are calculated through deemed savings tables and spreadsheets created for the utilities incentive programs by Frontier Associates in Austin, Texas.

The SECO MWh saving were submitted as annual savings by project (i.e., no break down by project type). A description of the measures completed for the project was also submitted for information purposes.

The electricity production used for the Wind-ERCOT data, are from the actual on-site metered data, measured at 15-minute intervals.

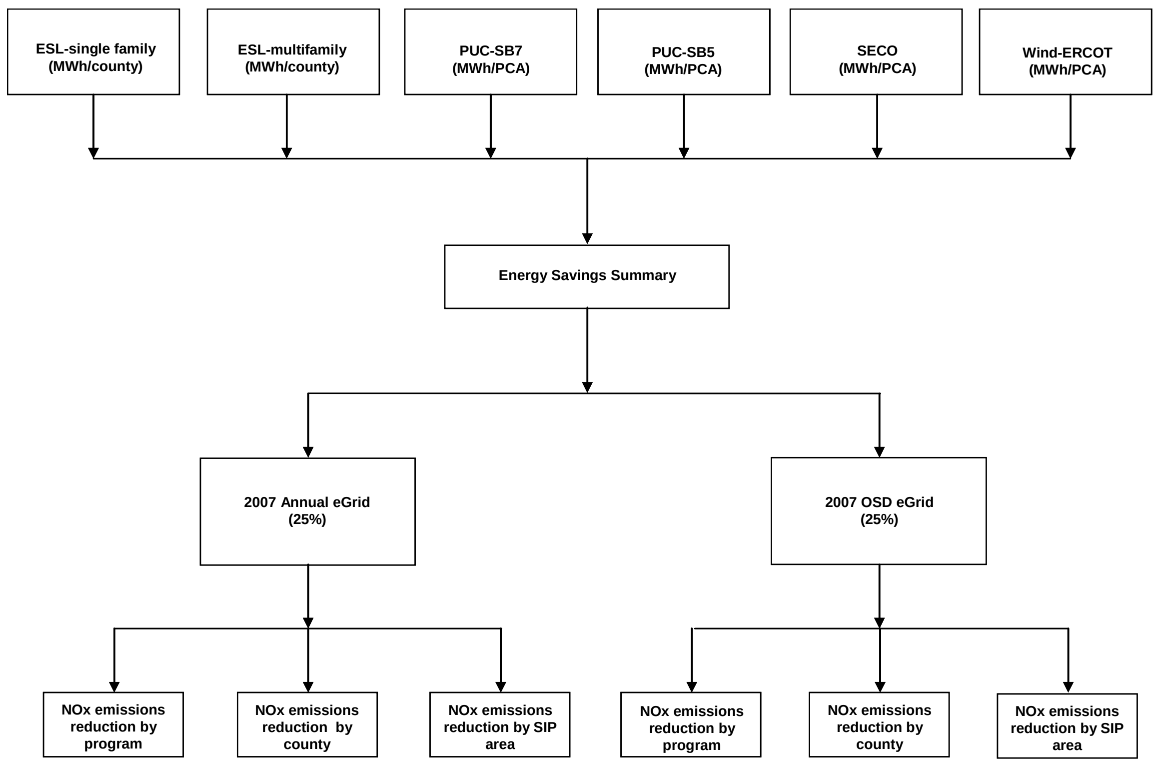

Figure 9: Process flow diagram of the NOx emissions reduction calculations

3.3 Calculation Procedure for the 2005 Annual Report: Wind-ERCOT.

The monthly measured MWh production from 19 wind farms for 2001, 2002, 2003 and 2004 was obtained from the Energy Reliability Council of Texas[13] (ERCOT). To obtain the annual production, the monthly data was summed for the 12 months while for the OSD production, average production for the months of July, August and September was taken. The MWh production for the months of July, August and September was divided by the total number of days in these three months to obtain average MWh savings per day for OSD calculations. The annual and OSD MWh numbers obtained were then input according to the wind farm and PCA as shown in Table 3. Using the reported numbers for 2004, savings up to 2013 were projected incorporating the different adjustment factors mentioned above. As an example, using 100 MWh for the reported year for AEP and 5% for annual degradation factor (a), 0% for the transmission and distribution loss (b), 25% for the discount factor (c) and a 17% growth factor (d), the projected savings for 2005 will be calculated as:

$$MWh2005 = (MWh2004 \times d) + (MWh2004 \times (1 + b) \times (1 - c) \times (1 - a)) \quad (1)$$

[13] The 2004 data represented the most current year for the 2005 annual report. 2005 and 2006 data will be reported in the 2006 report.

The wind power production is not cumulative, and it is being assumed that each year the wind production increases by 22.7% or 17% or by 0% of the production level in 2004. If the growth rate is 17%, then it is assumed that the production grows by 17% until 2009 and then is constant at the same rate achieved in 2009, until 2013. Using a growth factor of 17%, the projected 2005 savings come out to be 102.5 MWh for an actual production of 100MWh for 2004. Table 4 shows the projected annual and OSD MWh savings till 2013 with a growth factor of 17%.

2007 annual and OSD eGRID has been used to calculate the NOx emissions savings for the Wind-ERCOT program. An example of the eGRID spreadsheet[14] is given in Table 5. The total MWh savings for each PCA are used to calculate the NOx emissions reduction for each of the different county through the USA-EPA prescribed emission fractions. The eGRID spreadsheet shown in Table 5 is duplicated for each year for which the analysis is required. NOx emission reduction numbers for each county and SIP area for the different programs is provided in Table 6.

[14] In this table, the units shown in columns 3,5,7, etc., are lbs-NOx/MWh (white colored column), and lbs-NOx in the calculated columns for each county (i.e., blue colored column).

Wind Unit Name	Power Purchaser/User	Wind Turbine Unit in Texas	2001 Generation (MWh)		2002 Generation (MWh)		2003 Generation (MWh)		2004 Generation (MWh)		Total
			annual total	OSD	annual total	OSD	annual total	OSD	annual total	OSD	
BRAZ_WND_WND1	**American Electric Power**	GSITETOT_19_BRAZ_WND_136_U1_W03/W04_2_SU1_BRAZ_WND_WND1	**0**	**0**	**0**	**0**	**5,564**	**0**	**253,529**	**621**	259,094
BRAZ_WND_WND2	**American Electric Power**	GSITETOT_19_BRAZ_WND_136_U1_W03/W04_2_SU1_BRAZ_WND_WND2	**0**	**0**	**0**	**0**	**1,622**	**0**	**215,688**	**376**	217,311
DELAWARE_WIND_NWP	**Reliant Energy HL&P**	GSITETOT_11_DELAWARE_16_U1_W01_130_SU1_DELAWARE_WIND_NWP	**6,772**	**25**	**54,429**	**95**	**55,936**	**115**	**59,810**	**101**	176,947
	LCRA		**782**	**3**	**6,284**	**11**	**6,458**	**13**	**6,905**	**12**	20,428
INDNENR_INDNENR	**City Public Service of San Antonio**	GSITETOT_14/77/139_INDNENR_107_U1_W02/03/04_7_SU1_INDNENR_INDNENR	**0**	**0**	**188,592**	**578**	**197,570**	**577**	**207,154**	**435**	593,316
INDNENR_INDNENR_2	**City Public Service of San Antonio**	GSITETOT_14/77/139_INDNENR_107_U1_W02/03/04_7_SU1_INDNENR_INDNENR_2	**0**	**0**	**173,315**	**535**	**178,667**	**538**	**189,903**	**396**	541,885
INDNNWP_INDDNWP	**City Public Service of San Antonio**	GSITETOT_11_INDNNWP_17_U1_W01_7_SU1_INDNNWP_INDNNWP	**54,404**	**196**	**111,483**	**348**	**112,194**	**347**	**119,588**	**252**	397,669
INDNNWP_INDNNWP	**TXU**	GSITETOT_18/19_INDNNWP_86_U1_W01/02/03/04_7_SU1_INDNNWP_INDNNWP	**17,208**	**77**	**26,532**	**85**	**27,543**	**85**	**29,011**	**61**	100,294
	LCRA		**26,495**	**119**	**40,850**	**131**	**42,408**	**131**	**44,668**	**94**	154,421
KING_NE_KINGNE	**TNMP**	GSITETOT_58_KING_NE_97_U1_W02/03/04_7_SU1_KING_NE_KINGNE	**0**	**0**	**7,299**	**36**	**13,206**	**36**	**13,868**	**27**	34,373
	Reliant Energy HL&P		**0**	**0**	**74,184**	**361**	**134,232**	**366**	**140,959**	**270**	349,375
	Austin Energy		**0**	**0**	**2,642**	**13**	**4,780**	**13**	**5,020**	**10**	12,441
KING_NW_KINGNW	**TNMP**	GSITETOT_58_KING_NW_96_U1_W02/03/04_7_SU1_KING_NW_KINGNW	**0**	**0**	**9,965**	**43**	**14,451**	**43**	**15,032**	**28**	39,447
	Reliant Energy HL&P		**0**	**0**	**101,283**	**436**	**146,879**	**433**	**152,792**	**282**	400,954
	Austin Energy		**0**	**0**	**3,607**	**16**	**5,230**	**15**	**5,441**	**10**	14,278
KING_SE_KINGSE	**TNMP**	GSITETOT_58_KING_SE_97/98_U1_W02/03/04_7_SU1_KING_SE_KINGSE	**0**	**0**	**3,876**	**20**	**6,362**	**18**	**6,943**	**13**	17,181
	Reliant Energy HL&P		**0**	**0**	**39,397**	**206**	**64,662**	**184**	**70,571**	**134**	174,631
	Austin Energy		**0**	**0**	**1,403**	**7**	**2,303**	**7**	**2,513**	**5**	6,219
KING_SW_KINGSW	**TNMP**	GSITETOT_5_KING_SW_94_U1_W01/02/03/04_7_SU1_KING_SW_KINGSW	**5,950**	**21**	**13,116**	**41**	**13,993**	**41**	**14,447**	**27**	47,506
	Reliant Energy HL&P		**60,481**	**213**	**133,310**	**421**	**142,227**	**419**	**146,842**	**272**	482,859
	Austin Energy		**2,154**	**8**	**4,747**	**15**	**5,065**	**15**	**5,229**	**10**	17,195
KUNITZ_WIND_LGE	**LCRA**	GSITETOT_11_KUNITZ_67_U1_W01_148_SU1_KUNITZ_WIND_LGE	**21,672**	**57**	**57,530**	**73**	**56,424**	**91**	**46,793**	**70**	182,419
KUNITZ_WIND_LGE	**LCRA**	GSITETOT_5_KUNITZ_87_U1_W02_148_SU1_KUNITZ_WIND_LGE	**8,847**	**24**	**23,090**	**30**	**22,867**	**37**	**19,135**	**29**	73,940
SGMTN_SIGNALMT	**TXU**	GSITETOT_18/19_SGMTN_52_U1_W01/02/03/04_2_SU1_SGMTN_SIGNALMT	**43,590**	**120**	**100,309**	**198**	**97,917**	**209**	**93,726**	**192**	335,542
SW_MESA_SW_MESA	**American Electric Power**	GSITETOT_20_SW_MESA_18_U1_W01/02/03/04_7_SU1_SW_MESA_SW_MESA	**85,248**	**334**	**190,976**	**569**	**170,032**	**506**	**169,077**	**338**	615,332
SWEETWND_WND1	**TXU**	GSITETOT_19_SWEETWND_135_U1_W04_2_SU1_SWEETWND_WND1	**0**	**0**	**0**	**0**	**0**	**0**	**129,456**	**288**	129,456
TRENT_TRENT	**TXU**	GSITETOT_19_TRENT_70_U1_W02/03/04_98_SU1_TRENT_TRENT	**0**	**0**	**431,798**	**947**	**462,302**	**937**	**509,928**	**1,084**	1,404,028
WOODWRD1_WOODWD1	**TXU**	GSITETOT_18/19_WOODWRD1_93_U1_W01/02/03/04_7_SU1_WOODWRD1_WOODWRD1	**68,285**	**312**	**164,618**	**530**	**167,781**	**524**	**171,937**	**339**	572,621
WOODWRD2_WOODWRD2	**TXU**	GSITETOT_18/19_WOODWRD2_93_U1_W01/02/03/04_7_SU1_WOODWRD2_WOODWRD2	**31,238**	**150**	**159,116**	**502**	**159,550**	**490**	**161,159**	**315**	511,062

Table 3: Annual and OSD MWh production according to wind farms and PCAs from 2001 to 2004

Utility	Cumulative Energy Savings 2005 Electric		Cumulative Energy Savings 2006 Electric		Cumulative Energy Savings 2007 Electric		Cumulative Energy Savings 2008 Electric		Cumulative Energy Savings 2009 Electric		Cumulative Energy Savings 2010 Electric		Cumulative Energy Savings 2011 Electric		Cumulative Energy Savings 2012 Electric		Cumulative Energy Savings 2013 Electric	
	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day	MWh	MWh/ average day
American Electric Power	563,295	1,178	642,444	1,344	716,167	1,498	784,465	1,641	847,337	1,772	796,273	1,666	745,209	1,559	694,146	1,452	643,082	1,345
Austin Energy	16,064	30	18,321	34	20,423	38	22,371	42	24,164	45	22,708	43	21,252	40	19,795	37	18,339	34
City Public Service of San Antonio	455,939	956	520,003	1,091	579,676	1,216	634,957	1,332	685,846	1,439	644,515	1,352	603,183	1,265	561,851	1,179	520,520	1,092
LCRA	103,695	180	118,265	205	131,836	229	144,409	250	155,982	270	146,582	254	137,182	238	127,782	222	118,382	205
Reliant Energy HL&P	503,884	934	574,685	1,065	640,632	1,188	701,726	1,301	757,967	1,405	712,289	1,321	666,611	1,236	620,934	1,151	575,256	1,066
TNMP	44,381	83	50,617	95	56,426	106	61,807	116	66,760	125	62,737	118	58,714	110	54,691	103	50,667	95
TXU	966,529	2,011	1,102,336	2,294	1,228,834	2,557	1,346,022	2,801	1,453,901	3,026	1,366,284	2,843	1,278,666	2,661	1,191,049	2,479	1,103,431	2,296
Totals	**2,653,787**	**5,373**	**3,026,671**	**6,128**	**3,373,994**	**6,832**	**3,695,756**	**7,483**	**3,991,958**	**8,083**	**3,751,388**	**7,596**	**3,510,818**	**7,109**	**3,270,248**	**6,622**	**3,029,678**	**6,134**

Table 4: Projected annual and OSD MWh savings for Wind-ERCOT

Area	County	American Electric Power - West (ERCOT) /PCA	NOx Reductions (lbs)	Austin Energy/PCA	NOx Reductions (lbs)	Brownsville Public Utils Board/PCA	NOx Reductions (lbs)	Lower Colorado River Auhotrity /PCA	NOx Reductions (lbs)	Reliant Energy HL&P/PCA	NOx Reductions (lbs)	San Antonio Public Service Bd/PCA	NOx Reductions (lbs)	South Texas Electric Coop INC/PCA	NOx Reductions (lbs)	Texas Municipal Power Pool/PCA	NOx Reductions (lbs)	Texas-New Mexico Power Co/PCA	NOx Reductions (lbs)	TXU Electric/PCA	NOx Reductions (lbs)	Total Nox Reductions (lbs)	Total Nox Reductions (Tons)
Houston-Galveston Area	Brazoria	0.008831132	5636.867568	0.010890729	198.2403293	0.006522185	0	0.003944232	463.4506863	0.065444292	37366.95039	0.014877434	7686.352554	0.006262315	0	0.004817148	0	0.121274957	6098.948293	0.00816387	8941.211489	66392.02131	33.19601066
	Chambers	0.021762222	13890.71762	0.026955801	490.6675084	0.016072371	0	0.009076193	1066.460611	0.164940225	94176.4829	0.037472294	19359.87524	0.015055623	0	0.009553214	0	0.011518588	579.2727181	0.015818592	17324.79541	146888.272	73.444136
	Fort Bend	0.070431234	44955.90428	0.087239726	1587.995822	0.052016606	0	0.029374182	3451.492031	0.533812376	304792.6729	0.121275295	62656.28042	0.048726002	0	0.030918012	0	0.037278747	1874.757632	0.051195276	56069.95015	475389.0533	237.6945266
	Galveston	0.033856739	21610.58734	0.041710519	759.2427448	0.025004711	0	0.015351589	1803.825078	0.249587379	142507.7569	0.056747051	29318.08309	0.024143087	0	0.019297151	0	0.567751219	28552.35266	0.032836887	35963.52512	260515.3729	130.2576865
	Harris	0.068267332	43574.6969	0.084559408	1539.206868	0.050418468	0	0.028471701	3345.449758	0.517411736	295428.3437	0.117549281	60731.2537	0.047228963	0	0.029968099	0	0.03613341	1817.158322	0.049622373	54347.27923	460783.3885	230.3916942
	Liberty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Montgomery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Waller	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaumont/ Port Arthur Area	Hardin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Jefferson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Orange	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dallas/ Fort Worth Area	Collin	0.002039135	1301.569768	0.003716345	67.64738967	0.001505992	0	0.005950953	699.2421389	0.002481478	1416.858064	0.000717051	370.460713	0.019166247	0	0.07668094	0	0.00086441	43.47140525	0.004000199	4381.087339	8280.336818	4.140168409
	Dallas	0.004539471	2897.521732	0.004683963	85.26061893	0.003352602	0	0.00774211	909.7046795	0.002085611	1190.82854	0.00068106	351.8664458	0.007502816	0	0.026717045	0	0.007524933	378.430791	0.040370454	44214.41802	50028.03082	25.01401541
	Denton	0.00047388	302.4754211	0.000872802	15.88731679	0.000349982	0	0.001396994	164.1479964	0.000585443	334.2725917	0.000168971	87.29778012	0.00454374	0	0.018187155	0	0.000186605	9.384437551	0.000849405	930.2834404	1843.748984	0.921874492
	Tarrant	0.012162492	7763.258034	0.012266309	223.2795641	0.008982543	0	0.020308652	2386.284365	0.005316504	3035.582708	0.001752506	905.4235883	0.017326428	0	0.060216761	0	0.020603444	1036.152438	0.110647237	121182.7639	136532.7446	68.26637229
	Ellis	0.003279814	2093.488577	0.003307809	60.21095974	0.002422289	0	0.005476558	643.5003239	0.001433682	818.5941645	0.000472592	244.1621715	0.004672353	0	0.016238427	0	0.005556053	279.4153284	0.029837824	32678.89987	36818.2714	18.4091357
	Johnson	0.000286058	182.5896975	0.000526868	9.590400291	0.000211267	0	0.000843297	99.08816029	0.000353404	201.7841026	0.000101999	52.69742319	0.002742835	0	0.010978701	0	0.000112645	5.664928436	0.000512745	561.5668585	1112.981571	0.556490785
	Kaufman	0.006325453	4037.504715	0.006379446	116.122933	0.004671629	0	0.010562096	1241.055538	0.002765	1578.74174	0.000911441	470.8914725	0.009011105	0	0.031317452	0	0.010715411	538.8807554	0.057545265	63024.56758	71007.76473	35.50388236
	Parker	0.000217489	138.8224485	0.000400576	7.291555153	0.000160626	0	0.000641157	75.33645769	0.00268692	153.4159022	7.75498E-05	40.06570695	0.00208537	0	0.008347076	0	8.56434E-05	4.307029621	0.000389838	426.9577491	846.1968492	0.423098425
	Rockwall	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Henderson	0.000819895	523.3348348	0.000826893	15.05166687	0.000605529	0	0.001369042	160.8636127	0.000358395	204.6339524	0.00011814	61.03619151	0.001168005	0	0.004059317	0	0.001388914	69.84885245	0.007458924	8169.142575	9203.911686	4.601955843
	Hood	0.01252711	7995.99162	0.012634039	229.9732297	0.009251829	0	0.020917482	2457.822437	0.005475887	3126.586001	0.001805044	932.5671507	0.017845854	0	0.062021991	0	0.021221112	1067.215101	0.113964315	124815.6844	140625.8399	70.31291996
	Hunt	0.006187558	3949.487563	0.006240374	113.5914661	0.004569788	0	0.010331844	1214.000666	0.002704724	1544.325347	0.000891572	460.626091	0.008814664	0	0.030634735	0	0.010481817	527.1332151	0.056290785	61650.63905	69459.8034	34.7299017
El Paso Area	El Paso	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
San Antonio Area	Bexar	0.033413751	21327.8302	0.051775843	942.4585146	0.024677545	0	0.090663423	10653.03143	0.001141841	651.9609965	1.143571754	590820.684	0.046873844	0	0.004669544	0	0.000519582	26.12992681	0.002503865	2742.276361	627164.3715	313.5821857
	Comal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Guadalupe	0.002000467	1276.888192	0.076378745	1390.296971	0.001477434	0	0.133848731	15727.34276	0.001237133	706.3699155	0.003554796	1836.567891	0.001061766	0	0.001855699	0	0.000401718	20.20251653	0.001835165	2009.904183	22967.57242	11.48378621
	Wilson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austin Area	Bastrop	0.004502334	2873.817156	0.171901148	3129.059623	0.003325174	0	0.301245466	35396.60535	0.002784342	1589.785224	0.008000571	4133.455336	0.002389654	0	0.004176513	0	0.000904124	45.46861578	0.004130298	4523.573135	51691.76445	25.84588222
	Caldwell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hays	0.002458599	1569.311542	0.093870431	1708.692348	0.001815785	0	0.164501762	19329.10075	0.001520452	868.1374518	0.004368889	2257.164884	0.001304924	0	0.002280677	0	0.000493717	24.82914524	0.00225544	2470.197354	28227.43348	14.11371674
	Travis	0.000510007	325.5349258	0.299602906	5453.572383	0.000376663	0	0.033939476	3987.918097	0.000334709	191.1098165	0.000906121	468.1429327	0.000271138	0	0.000471744	0	0.000103327	5.19633436	0.000467336	511.8342008	10943.30869	5.471654345
	Williamson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
North East Texas Area	Gregg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Harrison	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rusk	0.000685965	437.8479279	0.00069182	12.59297244	0.000506616	0	0.001145408	134.5864919	0.000299851	171.2069331	9.88414E-05	51.06591077	0.000977211	0	0.003396227	0	0.001162035	58.43902082	0.006240507	6834.710611	7700.449868	3.850224934
	Smith	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upshur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corpus Christi Area	Nueces	0.22756873	145255.9825	0.004556851	82.94685381	0.168069652	0	0.007612767	894.5067845	0.001680888	959.7422735	0.001626796	840.4760888	0.046792036	0	0.007246366	0	0.001609426	80.93843941	0.008283395	9072.116855	157186.7098	78.59335488
	San Patricio	0.050313351	32114.76054	0.001007478	18.3387858	0.037158653	0	0.001683113	197.7672155	0.000371629	212.1901816	0.00035967	185.8215261	0.010345288	0	0.001602105	0	0.000355829	17.89474386	0.001831382	2005.761522	34752.53452	17.37626726
Victoria Area	Victoria	0.021836736	13938.2792	0.002215582	40.32950779	0.016127403	0	0.003612695	424.4948489	0.001199621	684.9517622	0.000555389	286.9388704	0.52545648	0	0.032412721	0	0.000476855	23.98117573	0.002254849	2469.549722	17868.52509	8.934262543
Other ERCOT counties	Andrews	2.47421E-05	15.79274761	2.49533E-05	0.454216231	1.82731E-05	0	4.13138E-05	4.854403465	1.08153E-05	6.175267053	3.56511E-06	1.841897583	3.5247E-05	0	0.000122499	0	4.19135E-05	2.10783847	0.000225089	246.5213441	277.7477145	0.138873857
	Angelina	0.00031082	198.3948006	0.000313473	5.706045631	0.000229554	0	0.000519	60.9829544	0.000135867	77.57617013	4.47864E-05	23.1386528	0.000442787	0	0.001538876	0	0.000526534	26.4795084	0.002827658	3096.899545	3489.177677	1.744588839
	Bosque	0.000595392	380.0355906	0.001096604	19.9611122	0.000439723	0	0.001755208	206.2385119	0.000735562	419.9861309	0.000212298	109.6825101	0.005708837	0	0.02285067	0	0.000234455	11.79077709	0.001067208	1168.824942	2316.519575	1.158259788
	Brazos	0.001939725	1238.116899	0.003572622	65.03125218	0.001432574	0	0.005718288	671.9038772	0.002396384	1368.271653	0.000691644	357.3343461	0.018598805	0	0.074445136	0	0.000763829	38.41314007	0.003476855	3807.911546	7546.982713	3.773491357
	Calhoun	0.082699809	52786.87435	0.001655986	30.14337224	0.061077496	0	0.002766524	325.0690019	0.000610844	348.7759605	0.000591187	305.4339308	0.0170045	0	0.002633372	0	0.000584875	29.41350269	0.003010234	3296.860373	57122.57049	28.56128525
	Cameron	0.048371747	30875.44422	0.000968599	17.63108765	0.297964476	0	0.001618161	190.1353312	0.000357288	204.0017115	0.00034579	178.6506288	0.009946061	0	0.001540279	0	0.000342098	17.2041814	0.001760709	1928.358703	33411.42587	16.70571293
	Cherokee	0.003503899	2236.521148	0.003533808	64.32472873	0.002587786	0	0.00585073	687.4659356	0.001531635	874.5226417	0.00050488	260.8439646	0.00499158	0	0.017347879	0	0.005935657	298.5057086	0.031876422	34911.6071	39333.79122	19.66689561
	Coke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Coleman	0.001298787	829.0091711	2.6007E-05	0.473396698	0.000959212	0	4.34478E-05	5.105155157	9.59321E-06	5.477469039	9.2845E-06	4.796789598	0.000267053	0	4.13567E-05	0	9.18536E-06	0.461934217	4.72752E-05	51.77664938	897.1005652	0.448550283
	Crockett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ector	0.003535748	2256.850036	0.003565928	64.90940918	0.002611307	0	0.005903911	693.7146661	0.001545556	882.4716266	0.00050947	263.2149092	0.005036951	0	0.017505563	0	0.00598961	301.2189801	0.032166163	35228.9366	39691.31623	19.84565811
	Fannin	0.007056315	4504.010391	0.007116546	129.5401328	0.005211403	0	0.011782473	1384.4509	0.003084477	1761.154402	0.001016752	525.2997173	0.010052276	0	0.034935966	0	0.011953503	601.1446903	0.064194222	70306.61938	79212.21962	39.60610981
	Fayette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Freestone	0.003677178	2347.124038	0.003708565	67.50578555	0.00271576	0	0.006140067	721.4632527	0.001607379	917.7704916	0.000529848	273.7435055	0.005238429	0	0.018205785	0	0.006229194	313.2677393	0.033452809	36638.09406	41278.96888	20.63948444
	Frio	0.008588335	5481.891067	0.000871383	15.86149663	0.006342868	0	0.001420864	166.9527843	0.000471808	269.3898503	0.000218433	112.8523549	0.206660746	0	0.012747844	0	0.000187546	9.431737673	0.000886827	971.2678565	7027.647148	3.513823574
	Grimes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hardeman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Haskell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hidalgo	0.188527456	120336.1324	0.003775086	68.71664366	0.139235931	0	0.006306735	741.0468406	0.001392518	795.0906488	0.001347706	696.285552	0.03876448	0	0.006003193	0	0.001333316	67.05278915	0.006862311	7515.721121	130220.046	65.11002302
	Howard	0.000555113	354.3258825	0.000559851	10.19078952	0.000409976	0	0.000926915	108.9133338	0.000242653	138.5482123	7.99868E-05	41.32479052	0.000790802	0	0.002748377	0	0.00094037	47.29143684	0.005050094	5530.949708	6231.544154	3.115772077
	Jack	0.002121449	1354.110022	0.002139557	38.94564551	0.001566784	0	0.003542346	416.2287997	0.000927334	529.4829759	0.000305682	157.9289455	0.00302217	0	0.010503338	0	0.003593766	180.731388	0.019299698	21137.36196	23814.78974	11.90739487
	Jones	0.040718722	25990.55677	0.000815354	14.84162563	0.030072592	0	0.001362147	160.0535067	0.00030076	171.7260495	0.000291082	150.3858301	0.008372468	0	0.001296587	0	0.000287974	14.48226137	0.001482142	1623.267862	28125.3139	14.06265695
	Lamar	0.000950838	606.9150422	0.000958954	17.4555226	0.000702236	0	0.001587687	186.5546488	0.000415633	237.3154157	0.000137007	70.78409515	0.001354543	0	0.004707619	0	0.001610734	81.00419925	0.008650166	9473.811374	10673.8403	5.336920149
	Limestone	0.000719757	459.4171555	0.000891528	16.22818038	0.000531572	0	0.000300183	35.27177746	0.00545518	3114.762901	0.001239347	640.3023271	0.000497945	0	0.00031596	0	0.000380962	19.15868077	0.000523179	572.9947472	4858.135769	2.429067885
	Llano	0.001238174	790.3202435	0.047274044	860.5137451	0.000914447	0	0.082844655	9734.319285	0.000765714	437.2022914	0.002200214	1136.72974	0.000657172	0	0.001148571	0	0.000248641	12.50419409	0.001135861	1244.014921	14215.60442	7.10780221
	McLennan	0.024534317	15660.13203	0.024743738	450.4020654	0.018119687	0	0.040966843	4813.639845	0.010724513	6123.411817	0.003535175	1826.430717	0.034951066	0	0.121469933	0	0.041561501	2090.138432	0.22319886	244451.2437	275415.3986	137.7076993
	Milam	0.002245405	1433.23073	0.002264571	41.22124129	0.001658332	0	0.003749326	440.5490668	0.000981518	560.4206896	0.000323543	167.1567407	0.003198756	0	0.011117048	0	0.00380375	191.291531	0.02042738	22372.41895	25206.28895	12.60314448
	Mitchell	0.014943169	9538.149879	0.015070721	274.3273427	0.011036196	0	0.024951762	2931.853846	0.006532002	3729.599443	0.002153177	1112.428036	0.02128772	0	0.07398395	0	0.025313952	1273.045055	0.135944204	148888.4383	167747.8419	83.87392095
	Nolan	0.000564654	360.4156353	0.000569473	10.36593729	0.000417022	0	0.000942846	110.7852131	0.000246823	140.9294223	8.13615E-05	42.03503431	0.000804394	0	0.002795613	0	0.000956532	48.1042286	0.005136889	5626.009421	6338.644892	3.169322446
	Palo Pinto	0.003206998	2047.011006	0.005906709	107.5178677	0.002368511	0	0.009454195	1110.876229	0.003962005	2262.199261	0.001143513	590.7902073	0.030749889	0	0.123082087	0	0.001262858	63.50944776	0.005748375	6295.719614	12477.62363	6.238811817
	Pecos	4.09677E-05	26.1494646	4.13174E-05	0.752086435	3.02565E-05	0	6.84069E-05	8.037869957	1.79079E-05	10.22494193	5.90308E-06	3.049794554	5.83617E-05	0	0.000202832	0	6.93999E-05	3.490136664	0.0003727	408.1874363	459.8917305	0.229945865
	Presidio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Red River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Robertson	0.000737708	470.8751569	0.000835096	15.20098285	0.00054483	0	0.000735917	86.47089713	0.003149678	1798.382284	0.000730875	377.6031025	0.00076086	0	0.001866305	0	0.191632518	9637.247891	0.003397737	3721.260649	16107.04096	8.053520482
	Taylor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Titus	0.005696437	3636.007492	0.005745061	104.5754455	0.004207073	0	0.009511781	1117.642591	0.002490043	1421.748629	0.000820806	424.0651201	0.008115023	0	0.028203184	0	0.00964985	485.2934181	0.051822854	56757.28353	63946.61623	31.97330811
	Tom Green	0.001482448	946.2391789	2.96846E-05	0.540339623	0.001094854	0	4.95918E-05	5.827074045	1.09498E-05	6.252036753	1.05974E-05	5.475102579	0.000304817	0	4.72049E-05	0	1.04843E-05	0.527256235	5.39604E-05	59.09837419	1023.959362	0.511979681
	Upton	3.11661E-05	19.89318296	3.14322E-05	0.572149116	2.30176E-05	0	5.20405E-05	6.114802737	1.36234E-05	7.778615879	4.49076E-06	2.320128614	4.43986E-05	0	0.000154304	0	5.27959E-05	2.6551185	0.000283531	310.5282452	349.862243	0.174931122
	Ward	0.018559529	11846.45431	0.01871795	340.7166351	0.013707039	0	0.030990277	3641.384657	0.008112796	4632.190724	0.002674262	1381.644037	0.026439509	0	0.091888626	0	0.03144012	1581.131589	0.16884373	184920.5668	208344.0887	104.1720444
	Webb	0.020014327	12775.045	0.000400768	7.295050931	0.014781473	0	0.000669531	78.67052517	0.000147832	84.40788823	0.000143074	73.91860682	0.004115289	0	0.000637307	0	0.000141547	7.118413908	0.000728512	797.8790209	13824.33451	6.912167253
	Wharton	0.00014434	92.13130695	0.000178787	3.254391895	0.000106601	0	6.01986E-05	7.073386174	0.001093979	624.6331323	0.000248538	128.4059368	9.98576E-05	0	6.33625E-05	0	7.6398E-05	3.842073108	0.000104918	114.9081054	974.2483326	0.487124166
	Wichita	0.000207633	132.5312397	0.000209406	3.811739518	0.000153346	0	0.000346701	40.73769335	9.07612E-05	51.82225527	2.99181E-05	15.45702978	0.00029579	0	0.001027996	0	0.000351734	17.68878048	0.001888925	2068.783732	2330.832471	1.165416235
	Wilbarger	0.028616818	18265.9719	0.000573025	10.4305852	0.021134796	0	0.000957307	112.4844258	0.000211372	120.687803	0.00020457	105.6900539	0.005884109	0	0.000911232	0	0.000202386	10.17802664	0.001041639	1140.820699	19766.26349	9.883131745
	Wise	0.002844488	1815.622181	0.002882008	52.460237	0.002100781	0	0.00476997	560.475697	0.001256075	717.1856279	0.000413241	213.4990654	0.004181914	0	0.014614274	0	0.004797945	241.2898489	0.025761411	28214.34215	31814.8748	15.9074374
	Young	0.006235856	3980.315908	0.006289085	114.4781221	0.004605458	0	0.010412491	1223.476738	0.002725836	1556.37982	0.000898531	464.2215803	0.008883468	0	0.030873859	0	0.010563634	531.2478361	0.056730171	62131.86278	70001.98279	35.00099139
	Total	**1.121837219**	**716063.0879**	**1.172570094**	**21343.90474**	**1.090766584**	**0**	**1.189130767**	**139723.9038**	**1.629360006**	**930321.2407**	**1.542362643**	**796854.022**	**1.359385821**	**0**	**1.231642808**	**0**	**1.221806085**	**61444.9376**	**1.528786947**	**1674353.847**	**4340104.944**	**2170.052472**
Energy Savings by PCA (MWh)		638,295		18,203		0		117,501		570,973		516,645		0		0		50,290		1,095,217			

Table 5: Example of NOx emissions reduction calculations according to Counties and PCA

Program	Area	County	FIP Code	2004		Cumulative 2005		Cumulative 2006		Cumulative 2007		Cumulative 2008		Cumulative 2009		Cumulative 2010		Cumulative 2011		Cumulative 2012		Cumulative 2013	
				Total NOx emissions reduction (Tons) (2007 25% annual and ozone season eGrid)																			
				Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day	Annual	Ozone Season Day
Wind-ERCOT	Houston-Galveston Area	Brazoria	039	33.196	0.069	29.295	0.061	33.412	0.070	37.246	0.078	40.798	0.085	44.068	0.092	41.412	0.086	38.756	0.081	36.101	0.075	33.445	0.070
		Chambers	071	73.444	0.143	64.814	0.126	73.922	0.144	82.404	0.160	90.263	0.176	97.497	0.190	91.622	0.178	85.746	0.167	79.870	0.155	73.995	0.144
		Fort Bend	157	237.695	0.364	209.765	0.321	239.240	0.366	266.693	0.408	292.127	0.447	315.539	0.483	296.524	0.454	277.508	0.425	258.493	0.395	239.477	0.366
		Galveston	167	130.258	0.212	114.952	0.187	131.104	0.214	146.149	0.238	160.087	0.261	172.917	0.282	162.496	0.265	152.076	0.248	141.655	0.231	131.235	0.214
		Harris	201	230.392	0.505	203.321	0.446	231.889	0.508	258.499	0.567	283.151	0.621	305.845	0.670	287.414	0.630	268.982	0.590	250.551	0.549	232.120	0.509
		Liberty	291	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Montgomery	339	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Waller	473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Beaumont/ Port Arthur Area	Hardin	199	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Jefferson	245	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Orange	361	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dallas/ Fort Worth Area	Collin	085	4.140	0.008	3.654	0.007	4.167	0.008	4.645	0.009	5.088	0.010	5.496	0.010	5.165	0.010	4.834	0.009	4.502	0.008	4.171	0.008
		Dallas	113	25.014	0.057	22.075	0.050	25.177	0.057	28.066	0.063	30.742	0.070	33.206	0.075	31.205	0.071	29.204	0.066	27.203	0.062	25.202	0.057
		Denton	121	0.922	0.002	0.814	0.002	0.928	0.003	1.034	0.003	1.133	0.003	1.224	0.003	1.150	0.003	1.076	0.003	1.003	0.003	0.929	0.003
		Tarrant	439	68.266	0.181	60.245	0.160	68.710	0.182	76.595	0.203	83.899	0.222	90.624	0.240	85.162	0.226	79.701	0.211	74.240	0.197	68.778	0.182
		Ellis	139	18.409	0.041	16.246	0.036	18.529	0.041	20.655	0.046	22.625	0.050	24.438	0.054	22.965	0.051	21.493	0.047	20.020	0.044	18.547	0.041
		Johnson	251	0.556	0.001	0.491	0.001	0.560	0.001	0.624	0.001	0.684	0.002	0.739	0.002	0.694	0.002	0.650	0.002	0.605	0.001	0.561	0.001
		Kaufman	257	35.504	0.075	31.332	0.067	35.735	0.076	39.835	0.085	43.634	0.093	47.131	0.100	44.291	0.094	41.451	0.088	38.610	0.082	35.770	0.076
		Parker	367	0.423	0.002	0.373	0.002	0.426	0.002	0.475	0.002	0.520	0.002	0.562	0.002	0.528	0.002	0.494	0.002	0.460	0.002	0.426	0.002
		Rockwall	397	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Henderson	213	4.602	0.011	4.061	0.010	4.632	0.011	5.163	0.012	5.656	0.014	6.109	0.015	5.741	0.014	5.373	0.013	5.005	0.012	4.636	0.011
		Hood	221	70.313	0.143	62.051	0.126	70.770	0.144	78.891	0.161	86.415	0.176	93.340	0.190	87.715	0.179	82.090	0.167	76.465	0.156	70.840	0.144
		Hunt	231	34.730	0.074	30.649	0.065	34.956	0.074	38.967	0.083	42.683	0.091	46.104	0.098	43.326	0.092	40.547	0.086	37.769	0.080	34.990	0.074
	El Paso Area	El Paso	141	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	San Antonio Area	Bexar	029	313.582	0.611	276.736	0.539	315.620	0.615	351.839	0.685	385.393	0.751	416.280	0.811	391.194	0.762	366.107	0.713	341.021	0.664	315.934	0.615
		Comal	091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Guadalupe	187	11.484	0.021	10.134	0.019	11.558	0.021	12.885	0.024	14.114	0.026	15.245	0.028	14.326	0.026	13.407	0.025	12.489	0.023	11.570	0.021
		Wilson	493	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Austin Area	Bastrop	021	25.846	0.047	22.809	0.041	26.014	0.047	28.999	0.053	31.765	0.058	34.310	0.062	32.243	0.058	30.175	0.055	28.107	0.051	26.040	0.047
		Caldwell	055	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Hays	209	14.114	0.026	12.455	0.023	14.205	0.026	15.836	0.029	17.346	0.032	18.736	0.034	17.607	0.032	16.478	0.030	15.349	0.028	14.220	0.026
		Travis	453	5.472	0.010	4.829	0.008	5.507	0.010	6.139	0.011	6.725	0.012	7.264	0.013	6.826	0.012	6.388	0.011	5.950	0.010	5.513	0.010
		Williamson	491	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	North East Texas Area	Gregg	183	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Harrison	203	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Rusk	401	3.850	0.000	3.398	0.000	3.875	0.000	4.320	0.000	4.732	0.000	5.111	0.000	4.803	0.000	4.495	0.000	4.187	0.000	3.879	0.000
		Smith	423	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Upshur	459	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Corpus Christi Area	Nueces	355	78.593	0.161	69.359	0.142	79.104	0.162	88.182	0.181	96.591	0.198	104.333	0.214	98.045	0.201	91.758	0.188	85.470	0.175	79.183	0.162
		San Patricio	409	17.376	0.040	15.335	0.035	17.489	0.040	19.496	0.045	21.355	0.049	23.067	0.053	21.677	0.050	20.287	0.047	18.897	0.043	17.507	0.040
	Victoria Area	Victoria	469	8.934	0.017	7.884	0.015	8.992	0.018	10.024	0.020	10.980	0.021	11.860	0.023	11.145	0.022	10.431	0.020	9.716	0.019	9.001	0.018
	Other ERCOT counties	Andrews	003	0.139	0.000	0.123	0.000	0.140	0.000	0.156	0.000	0.171	0.000	0.184	0.000	0.173	0.000	0.162	0.000	0.151	0.000	0.140	0.000
		Angelina	005	1.745	0.004	1.540	0.003	1.756	0.004	1.957	0.004	2.144	0.005	2.316	0.005	2.176	0.005	2.037	0.004	1.897	0.004	1.758	0.004
		Bosque	035	1.158	0.004	1.022	0.003	1.166	0.004	1.300	0.004	1.424	0.005	1.538	0.005	1.445	0.005	1.352	0.004	1.260	0.004	1.167	0.004
		Brazos	041	3.773	0.007	3.330	0.007	3.798	0.008	4.234	0.008	4.638	0.009	5.009	0.010	4.707	0.009	4.406	0.009	4.104	0.008	3.802	0.008
		Calhoun	057	28.561	0.064	25.205	0.056	28.747	0.064	32.046	0.072	35.102	0.078	37.915	0.085	35.630	0.080	33.345	0.075	31.060	0.069	28.775	0.064
		Cameron	061	16.706	0.039	14.743	0.035	16.814	0.040	18.744	0.044	20.531	0.048	22.177	0.052	20.840	0.049	19.504	0.046	18.167	0.043	16.831	0.040
		Cherokee	073	19.667	0.041	17.356	0.036	19.795	0.041	22.066	0.046	24.171	0.050	26.108	0.054	24.534	0.051	22.961	0.048	21.388	0.044	19.814	0.041
		Coke	081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Coleman	083	0.449	0.001	0.396	0.001	0.451	0.001	0.503	0.001	0.551	0.001	0.595	0.001	0.560	0.001	0.524	0.001	0.488	0.001	0.452	0.001
		Crockett	105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Ector	135	19.846	0.042	17.514	0.037	19.975	0.042	22.267	0.047	24.390	0.052	26.345	0.056	24.757	0.053	23.170	0.049	21.582	0.046	19.995	0.042
		Fannin	147	39.606	0.089	34.952	0.078	39.864	0.089	44.438	0.099	48.676	0.109	52.577	0.118	49.409	0.111	46.240	0.103	43.072	0.096	39.903	0.089
		Fayette	149	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Freestone	161	20.639	0.044	18.214	0.039	20.774	0.044	23.158	0.049	25.366	0.054	27.399	0.058	25.748	0.055	24.097	0.051	22.445	0.048	20.794	0.044
		Frio	163	3.514	0.013	3.101	0.011	3.537	0.013	3.943	0.014	4.318	0.015	4.665	0.017	4.383	0.016	4.102	0.015	3.821	0.014	3.540	0.013
		Grimes	185	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.003	0.000	0.003	0.000	0.003	0.000	0.003	0.000	0.002	0.000	0.002
		Hardeman	197	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Haskell	207	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Hidalgo	215	65.110	0.173	57.460	0.153	65.533	0.174	73.053	0.194	80.020	0.212	86.434	0.229	81.225	0.216	76.016	0.202	70.807	0.188	65.598	0.174
		Howard	227	3.116	0.007	2.750	0.006	3.136	0.007	3.496	0.008	3.829	0.008	4.136	0.009	3.887	0.008	3.638	0.008	3.388	0.007	3.139	0.007
		Jack	237	11.907	0.025	10.508	0.022	11.985	0.025	13.360	0.028	14.634	0.031	15.807	0.034	14.854	0.032	13.902	0.030	12.949	0.027	11.997	0.025
		Jones	253	14.063	0.031	12.410	0.027	14.154	0.031	15.778	0.034	17.283	0.038	18.668	0.041	17.543	0.038	16.418	0.036	15.293	0.033	14.168	0.031
		Lamar	277	5.337	0.013	4.710	0.011	5.372	0.013	5.988	0.014	6.559	0.015	7.085	0.017	6.658	0.016	6.231	0.015	5.804	0.014	5.377	0.013
		Limestone	293	2.429	0.000	2.144	0.000	2.445	0.000	2.725	0.000	2.985	0.000	3.225	0.000	3.030	0.000	2.836	0.000	2.642	0.000	2.447	0.000
		Llano	299	7.108	0.013	6.273	0.012	7.154	0.013	7.975	0.015	8.735	0.016	9.436	0.017	8.867	0.016	8.298	0.015	7.730	0.014	7.161	0.013
		McLennan	309	137.708	0.267	121.527	0.236	138.603	0.269	154.508	0.300	169.243	0.329	182.807	0.355	171.790	0.334	160.774	0.312	149.757	0.291	138.741	0.269
		Milam	331	12.603	0.019	11.122	0.017	12.685	0.019	14.141	0.022	15.489	0.024	16.731	0.025	15.722	0.024	14.714	0.022	13.706	0.021	12.698	0.019
		Mitchell	335	83.874	0.197	74.019	0.174	84.419	0.198	94.107	0.221	103.081	0.242	111.343	0.261	104.633	0.246	97.923	0.230	91.213	0.214	84.503	0.198
		Nolan	353	3.169	0.007	2.797	0.006	3.190	0.007	3.556	0.008	3.895	0.009	4.207	0.009	3.954	0.009	3.700	0.008	3.447	0.008	3.193	0.007
		Palo Pinto	363	6.239	0.012	5.506	0.011	6.279	0.012	7.000	0.013	7.667	0.015	8.282	0.016	7.783	0.015	7.284	0.014	6.785	0.013	6.286	0.012
		Pecos	371	0.230	0.000	0.203	0.000	0.231	0.000	0.258	0.001	0.283	0.001	0.305	0.001	0.287	0.001	0.268	0.001	0.250	0.001	0.232	0.000
		Presidio	377	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Red River	387	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Robertson	395	8.054	0.008	7.107	0.007	8.106	0.008	9.036	0.008	9.898	0.009	10.691	0.010	10.047	0.009	9.402	0.009	8.758	0.008	8.114	0.008
		Taylor	441	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Titus	449	31.973	0.000	28.216	0.000	32.181	0.000	35.874	0.000	39.295	0.000	42.445	0.000	39.887	0.000	37.329	0.000	34.771	0.000	32.213	0.000
		Tom Green	451	0.512	0.000	0.452	0.000	0.515	0.000	0.574	0.000	0.629	0.000	0.680	0.000	0.639	0.000	0.598	0.000	0.557	0.000	0.516	0.000
		Upton	461	0.175	0.000	0.154	0.000	0.176	0.000	0.196	0.000	0.215	0.000	0.232	0.000	0.218	0.000	0.204	0.000	0.190	0.000	0.176	0.000
		Ward	475	104.172	0.230	91.932	0.203	104.849	0.231	116.881	0.258	128.027	0.283	138.288	0.305	129.955	0.287	121.621	0.269	113.287	0.250	104.953	0.232
		Webb	479	6.912	0.010	6.100	0.009	6.957	0.010	7.755	0.011	8.495	0.013	9.176	0.014	8.623	0.013	8.070	0.012	7.517	0.011	6.964	0.010
		Wharton	481	0.487	0.001	0.430	0.001	0.490	0.001	0.547	0.001	0.599	0.001	0.647	0.001	0.608	0.001	0.569	0.001	0.530	0.001	0.491	0.001
		Wichita	485	1.165	0.003	1.028	0.002	1.173	0.003	1.308	0.003	1.432	0.003	1.547	0.003	1.454	0.003	1.361	0.003	1.267	0.003	1.174	0.003
		Wilbarger	487	9.883	0.000	8.722	0.000	9.947	0.000	11.089	0.000	12.146	0.000	13.120	0.000	12.329	0.000	11.539	0.000	10.748	0.000	9.957	0.000
		Wise	497	15.907	0.034	14.038	0.030	16.011	0.034	17.848	0.038	19.550	0.042	21.117	0.045	19.845	0.042	18.572	0.039	17.299	0.037	16.027	0.034
		Young	503	35.001	0.064	30.888	0.056	35.228	0.064	39.271	0.072	43.016	0.078	46.464	0.085	43.664	0.080	40.864	0.075	38.064	0.069	35.263	0.064

Table 6: NOx emissions reduction values according to SIP areas and Counties (Wind-ERCOT)

The final reported MWh savings and NOx emissions reduction for all the different programs in the integrated format used the adjustment factors[15] shown in Table 7. The projected NOx emissions reduction for the Ozone Season Day (OSD) across all programs amounts to 17.13 tons in 2013. If the savings are projected through 2013, then around 32% of this reduction comes from the ESL-Single-family program. The other large contributors are PUC-SB7 and Wind-ERCOT. If the projections are only considered through 2010, then Wind-ERCOT is the largest contributor to the NOx reductions with 34% of the 15.99 tons reduced. The cumulative OSD NOx savings and the percentage divisions of the NOx savings among the programs is shown in Figure 10, Figure 11, Figure 12, and Figure 13. A summary of the projected annual and OSD energy savings and NOx emissions reduction is given in Table 8 and Table 9.

	ESL-Single Family	ESL-Multifamily	PUC (SB7)	PUC (SB5 Grant Program)	SECO	Wind-ERCOT
Annual degradation factor	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
T&D loss	7.00%	7.00%	7.00%	7.00%	7.00%	0.00%
Initial discount factor	20.00%	20.00%	25.00%	25.00%	60.00%	25.00%
Growth factor	3.25%	1.54%				17.00%

Table 7: Final adjustments factors used for the calculation of the annual and OSD NOx savings for the different programs

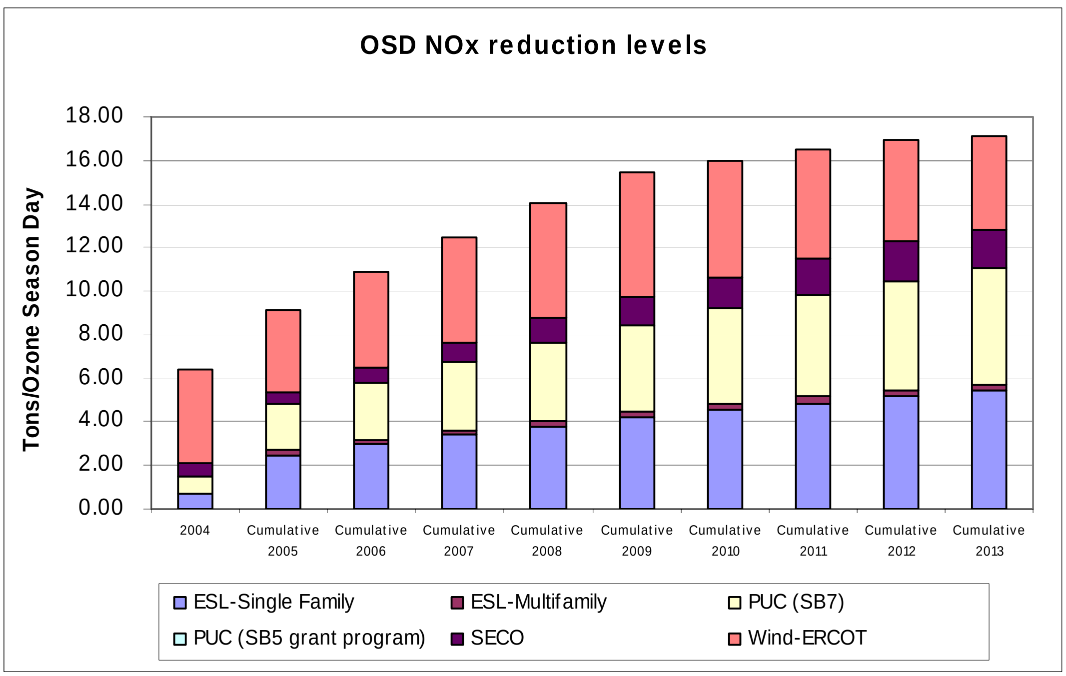

Figure 10: Cumulative OSD NOx emissions reduction projections until 2013

[15] In this table the growth factors for the PUC (SB7 and SB5 grant programs) and SECO are 0%.

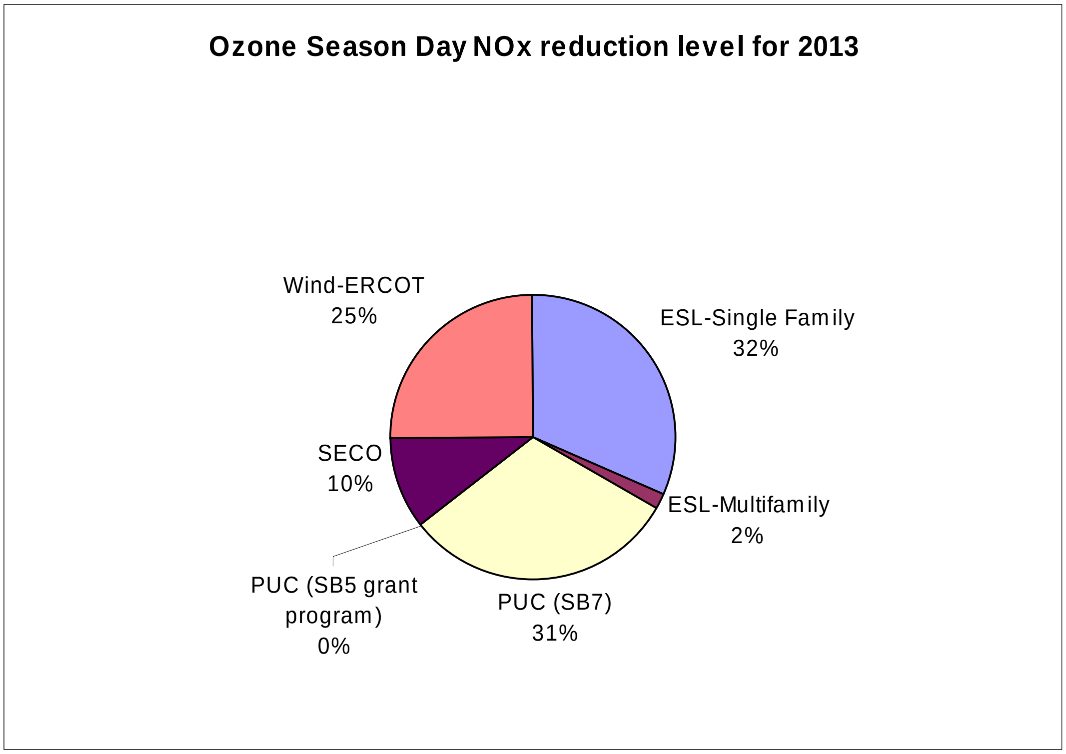

Figure 11: Percentage division of the NOx emissions reductions for the different program (2013 projection)

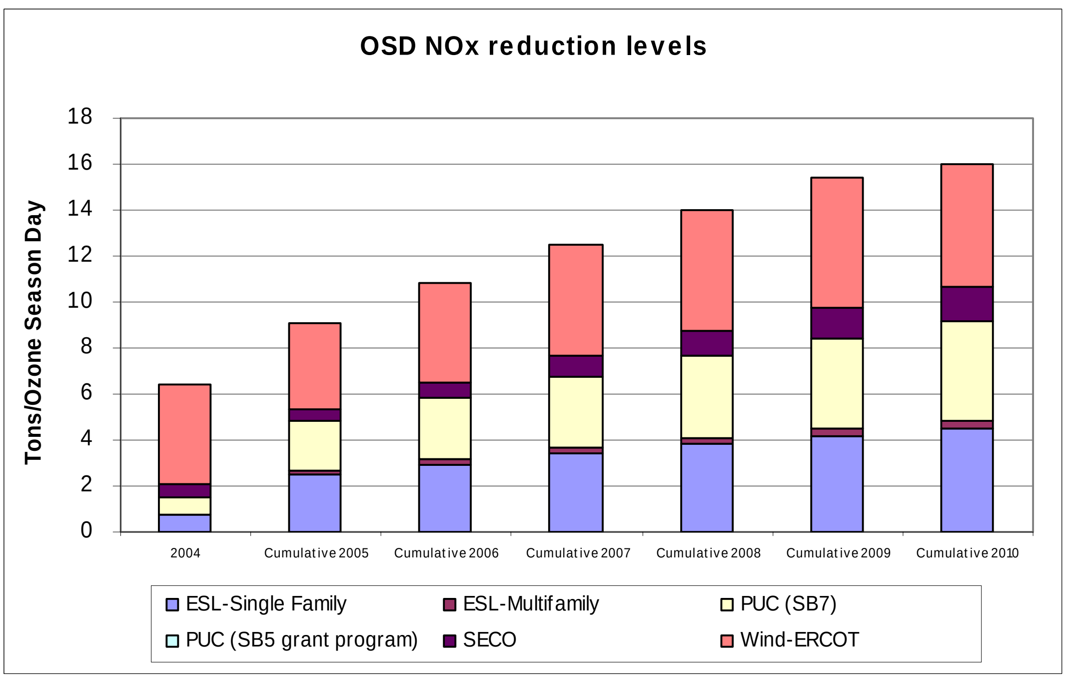

Figure 12: Cumulative OSD NOx emissions reduction projections until 2010

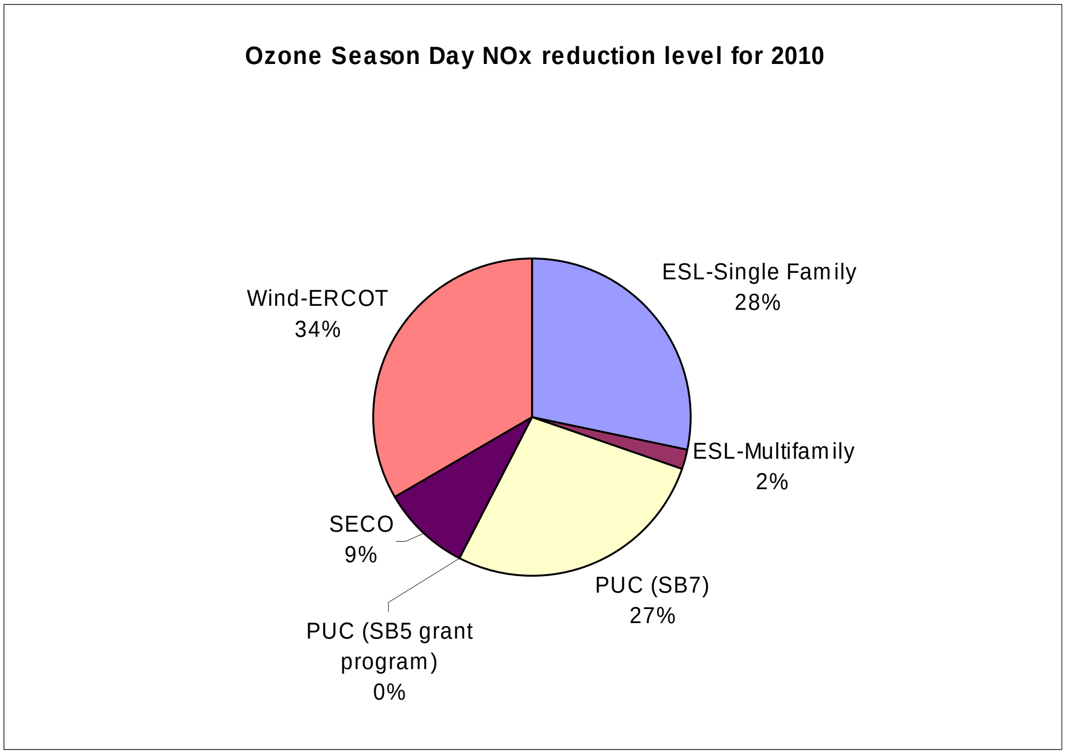

Figure 13: Percentage division of the NOx emissions reductions for the different program (2010 projection)

Program	2004	Cumulative 2005	Cumulative 2006	Cumulative 2007	Cumulative 2008	Cumulative 2009	Cumulative 2010	Cumulative 2011	Cumulative 2012	Cumulative 2013
	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual
ESL-Single Family	207,518.87	678,700.34	819,522.41	951,462.66	1,074,521.11	1,188,697.75	1,293,992.58	1,390,405.60	1,477,936.82	1,556,586.23
ESL-Multifamily	10,991.56	65,176.90	70,922.14	76,196.95	81,001.32	85,335.25	89,198.74	92,591.80	95,514.41	97,966.59
PUC (SB7)	402,922.00	1,101,231.47	1,365,144.19	1,612,889.66	1,844,467.89	2,059,878.87	2,259,122.61	2,442,199.10	2,609,108.34	2,759,850.34
PUC (SB5 grant program)	0.00	14,439.10	13,633.15	12,827.20	12,021.25	11,215.30	10,409.35	9,603.40	8,797.45	7,991.50
SECO	292,773.20	244,348.51	357,124.75	463,635.63	563,881.18	657,861.37	745,576.22	827,025.73	902,209.88	971,128.69
Wind-ERCOT	3,007,124.51	2,653,787.38	3,026,670.82	3,373,993.70	3,695,756.03	3,991,957.79	3,751,387.83	3,510,817.87	3,270,247.91	3,029,677.95
	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD
ESL-Single Family	1,023.59	3,537.01	4,221.07	4,861.32	5,457.77	6,010.40	6,519.23	6,984.24	7,405.45	7,782.85
ESL-Multifamily	45.90	310.03	331.81	351.63	369.48	385.37	399.29	411.25	421.25	429.28
PUC (SB7)	1,103.90	3,017.07	3,740.12	4,418.88	5,053.34	5,643.50	6,189.38	6,690.96	7,148.24	7,561.23
PUC (SB5 grant program)	0.00	39.56	37.35	35.14	32.93	30.73	28.52	26.31	24.10	21.89
SECO	802.12	669.45	978.42	1,270.23	1,544.88	1,802.36	2,042.67	2,265.82	2,471.81	2,660.63
Wind-ERCOT	6,088.76	5,373.33	6,128.34	6,831.59	7,483.09	8,082.83	7,595.73	7,108.63	6,621.53	6,134.43

Table 8: Annual and OSD MWh savings for the different programs

Program	2004	Cumulative 2005	Cumulative 2006	Cumulative 2007	Cumulative 2008	Cumulative 2009	Cumulative 2010	Cumulative 2011	Cumulative 2012	Cumulative 2013
	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual
ESL-Single Family	145.80	480.25	578.99	671.49	757.75	837.77	911.55	979.09	1,040.39	1,095.45
ESL-Multifamily	8.08	47.91	52.14	56.02	59.56	62.75	65.59	68.09	70.24	72.04
PUC (SB7)	288.31	794.13	982.60	1,159.50	1,324.83	1,478.59	1,620.78	1,751.40	1,870.46	1,977.95
PUC (SB5 grant program)	0.00	5.95	5.62	5.29	4.96	4.63	4.29	3.96	3.63	3.30
SECO	210.99	176.09	257.37	334.13	406.37	474.10	537.32	596.01	650.20	699.86
Wind-ERCOT	2,170.05	1,915.07	2,184.16	2,434.80	2,666.99	2,880.74	2,707.14	2,533.54	2,359.93	2,186.33
	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD	OSD
ESL-Single Family	0.71	2.47	2.94	3.39	3.80	4.19	4.54	4.86	5.16	5.42
ESL-Multifamily	0.03	0.22	0.24	0.25	0.27	0.28	0.29	0.29	0.30	0.31
PUC (SB7)	0.77	2.13	2.64	3.11	3.56	3.97	4.35	4.70	5.02	5.31
PUC (SB5 grant program)	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
SECO	0.57	0.48	0.70	0.91	1.10	1.29	1.46	1.62	1.76	1.76
Wind-ERCOT	4.28	3.78	4.31	4.81	5.26	5.69	5.34	5.00	4.66	4.32

Table 9: Annual and OSD NOx emissions reduction values for the different programs

In summary, this section has presented the methods for reporting the partially weather normalized emissions savings factors reported to the TCEQ in the Laboratory's 2005 report. These emissions values are expected to increase as the Laboratory develops and implements measures for weather normalizing the emissions factors, and improves the factors contributing to the discount, degradation and transmission and distribution losses.

4 LITERATURE REVIEW OF WEATHER ANALYSIS METHODS AND REGRESSION PROCEDURES

4.1 Weather Analysis Methods

Since 1990, the Laboratory has been collecting hourly weather data in Texas for use in evaluating the performance of energy conservation retrofits to buildings. These procedures generally require the use of some combination of energy and weather data for the analysis of energy savings. Unfortunately, short gaps are common in such weather data sources. This is even true in feeds of hourly weather data from the National Weather Service where 100-200 hours of missing data scattered through a year are common in an annual file. In a major previous effort – the Texas LoanSTAR program (Verdict et al. 1990, Haberl et al. 2002). Much of what was learned in the past 16 years has been applied to the current effort, which includes models for forecasting wind speeds, and solar radiation, as well as methods for filling-in missing weather data, and regression methods for weather-normalizing energy use, or electricity production against one or more weather variables, such as wind speed or solar radiation data.

To date, procedures have been developed for predicting weather variables, including stochastic procedures by Hansen and Driscoll (1977), and Hittle and Pedersen (1981), the Fourier transform method used by Phillips (1984), the Auto Regressive Moving Average (ARMA) models by Hokoi et al. (1990), and the step-wise regression methods by McCutchan (1979) and Bradshaw and Salazar (1985).

Data-filling techniques for missing measured weather data have been developed for various reasons, and vary greatly. Generally, these techniques fall into three categories: techniques for filling data in one weather station when records are available for that station, techniques for interpolating between weather stations, and combined techniques. These include correlative and additive techniques by Kemp et al. (1983), linear and polynomial, and cubic spline techniques (Colliver et al. 1995), modeling procedures by Atkinson and Lee (1992), linear regression methods (Makhuvha et al. 1997a, 1997b; Bennis et al. 1997; Chen and Claridge, 2000), and methods using flow approximation by Amritkar and Kumar (1995).

However, few of the previous interpolation techniques were found to be satisfactory except when looking at highly aggregate results with hundreds or thousands of filled gaps. Interestingly, one of the more counter-intuitive results to date is that simple linear interpolation is considerably more accurate for filing gaps in hourly cooling and heating consumption data than techniques that consider linear dependence on temperature (Baltazar and Claridge 2002a, Baltazar and Claridge 2002b). More systematic methods, such as estimating missing data from other available climatic parameters, interpolation from other weather stations, historical records, etc., have been used in other applications (Acock and Pachepsky 1999), notably in the generation of ASHRAE design temperatures (Colliver et al. 1998, Klein and Reindl 1998, Thevenard et al. 2004), but they have not been attempted in the field of emissions reductions weather normalization.

Therefore, in the current effort, procedures developed by Baltazar and Claridge (2002a; 2002b) will be used for temperature, and humidity data. No filling techniques were found to be acceptable for filling-in missing wind energy data, with the exception of substitution from a nearby weather station. Solar data filling techniques are discussed in the next section. Additional literature will be reviewed to search for acceptable techniques to develop more accurate on-site wind data, given only long-term NOAA wind data.

4.2 Analysis Methods for Synthesizing Global Horizontal Solar Radiation.

Previous studies have developed various techniques for synthesizing solar radiation, when it is not available (Chandel et al. 2004; Davies and McKay 1982; Davies and McKay 1989; Moriarty 1991; Olseth and Skartveit 1993; Wong and Chow 2001; Zhang et al. 2003). These studies have developed many different methods from complex empirical expressions using existing meteorological data to manually filling of the data should be performed using data from previous "similar" years or from a nearby station.

Unfortunately, missing solar radiation data often occurs in long or short periods. Short periods can be characterized as gaps with a length of days and hours, similarly, ong periods include gap lengths greater than one day to as long as one week. The worst case is the situation where the no data is available for months or years. Therefore, there is a need for a procedure to synthesis hourly Global Horizontal Solar Radiation that will allow for the filling of voids in the data recoreds for all weather sites in Texas.

There are many procedures to determine hourly Global Horizontal Solar Radiation, and its components. Most of these are based upon data taken from other parts of the world. Also some methodologies are based on records that may not be available for the location where the Solar Radiation is needed. As a preliminary study the synthesis of Global Horizontal Solar Radiation was proposed to be determined from meteorological parameters available from NOAA – this was proposed to limit the scope of the number of locations to those taken account by NOAA.

One of the meteorological parameters that is available in all the NOAA station is the cloud cover. This parameter has been used since the eighties to determine hourly global solar radiation. Kasten and Czeplak (1980) proposed a procedure to synthesis of Global Horizontal Solar Radiation from the total cloud amount through a relationship with the global solar radiation under a cloudless sky, which depend of the elevation angle, and can be obtained via a linear parameterization. Therefore, the method of Kasten and Czeplak will be used as the initial model to fill-in missing Global Horizontal Solar Radiation data.

Additional literature will be reviewed to search for acceptable techniques to develop a more accurate synthesis of Global Horizontal Solar Radiation data, given only NOAA parameters. Recently, ASHRAE completed Research Project 1309, "Development of Solar Radiation Models for Tropical Locations" (Krarti et al. (2006). The results from this effort will be studied to determine if these new models can improve predictions over those of Kasten and Czeplak.

4.3 Regression Methods for Weather-normalizing Wind Energy Production

In the report by Haberl and Cho (2004) the uncertainty of ASHRAE's Inverse Model Toolkit (IMT) analysis method, which uses linear, and change-point linear algorithms was presented. This report reviewed the published literature on the related accuracy of IMT and its algorithms versus other well-accepted statistical analysis tools, such as SAS. This report included a review of the history of the IMT, and the linear and change-point linear models, and included a review of the published comparisons of the IMT and other analysis software, which was part of the accuracy testing that was performed as part of ASHRAE's Research Project 1050-RP. The report also included a detailed description of the basic algorithms and an example of the IMT weather-normalization analysis.

Figure 14 shows the history of the different models contained in the IMT. During the 1980s, Goldberg (1982) and Fels (1986) developed the PRInceton Scorekeeping Method (PRISM) method for use in measuring savings in residential buildings. PRISM uses a Variable-Based Degree Day methods (VBDD) for weather-normalizing the monthly energy use of a residence. The algorithm finds the base-temperature that gives the best statistical fit between energy consumption and the number of variable-base degree-days in each energy use period. Goldberg (1982) developed the mathematical basis of the PRISM model, which includes a detailed uncertainty analysis in her Ph.D. dissertation, "A Geometrical Approach to Nondifferentiable Regression Models as Related to Methods for Assessing Residential Energy Conservation," Department of Statistics, Princeton University.

PRISM was one of the first methods to include an estimate of the standard error for all regression parameters (Goldberg, 1982). The method found widespread use in the utility industry, especially in evaluating residential energy conservation programs. Subsequently, PRISM was found to provide adequate statistical fits with commercial building billing data (Eto, 1988; Haberl and Vajda, 1988; Haberl and Komer, 1990; Kissock and Fels, 1995). However, the physical interpretation of the variable-base degree-day method does not always apply to all commercial buildings that may have varying degrees of heating or cooling energy use (i.e., the energy use is not well described by a three-parameter model), as pointed out by Rabl et al. (1992a;1992b) and Kissock (1993).

To resolve this problem, Schrock and Claridge (1989) and later Ruch and Claridge (1992) developed a four-parameter change-point model of energy consumption, along with accompanying error diagnostics for the model's parameters. Their four-parameter change-point model finds the optimal change-point by searching within an interval known to contain the change-point. Ruch and Claridge (1993) also developed the statistically rigorous methods for estimating Normalized Annual Consumption (NAC) with four-parameter change-point and linear regression models, and investigated how best to incorporate additional variables for the weather normalization using principal component analysis (Ruch et al. 1993).

Kissock (1993) developed the algorithms for the EModel software as part of his Ph.D. dissertation, which was then developed into the EModel software by Kissock et al. (1994). The algorithms of the software use a two-stage grid search to identify the best change point. In this method, the minimum x value is selected as the initial change point in a standard piece-wise linear regression equation. The change-point is then incremented and the regression is repeated across the range of x-values. The change point that results in the lowest RMSE is selected as the best-fit change-point temperature. This method is then repeated with a finer grid centered about the initial best-fit change point. The uncertainty with which the change-point temperature is known can be approximated as the width of the finest grid. The method is easily adaptable to three-parameter heating, three-parameter cooling and four-parameter models. The original EModel software also included one-parameter, two-parameter and multi-variable regression models, which used algorithms from Press et al. (1986).

A five-parameter Variable-Based Degree Day (VBDD) model was first reported in Fels (1986) and Fels et al. (1995). An algorithm for five-parameter change-point model was also developed by Kissock et al. (2002). These models have been used extensively with building energy data that have both heating and cooling related loads and have proven to be extremely robust (Haberl et al., 1998).

CP and VBDD models have been shown to provide good statistical fits between building energy use and ambient temperature. However, other variables also influence building energy use. Combination CP-MVR and VBDD-MVR models attempt to retain this ability to describe energy use as a function of ambient temperature while including the effects of additional independent variables. One approach reported in the literature (Rabl and Rialha, 1992; Ruch et al. 1993; Sonderegger, 1997; Sonderegger, 1998) is to sequentially identify the change-point or base temperature and then use this result in a MVR model. An alternative approach is to use indicator variables to produce separate CP or VBDD models for each operating or occupational mode (Austin, 1997; Kissock et al., 1998).

To develop CP-MVR models for Inverse Model Toolkit, the change-point algorithms developed by Kissock (1994, 1996) were extended to include multiple independent variables. Using this approach, CP-MVR models can be identified in a single step, rather than sequentially, and without breaking up the data according to operational modes. The Inverse Model Toolkit can also produce VBDD-MVR models by first running the VBDD model and then running the MVR model on the VBDD residual file.

From the literature it was found that the algorithms in the IMT almost exactly reproduce the same regression analysis one would get by running any one of the programs that it was compared against (i.e., usually to several significant digits). Four sets of accuracy and precision tests (Haberl et al., 2003) were performed as part of the testing for ASHRAE Research Project 1050-RP. The first set of tests was designed to test the accuracy and precision of IMT's computational and regression engines by comparing IMT results with results from the widely used SAS software (SAS 2001). These tests showed that IMT's 1P and 2p and MVR models were accurate to two significant decimal figures, (i.e., 99.99 % accurate or better). In the second set of tests, IMT's 3P, 4P and 5P change-point model results were compared to model results from EModel (Kissock et al., 1994). These tests also showed agreement to two significant figures (i.e., 99.99 % accurate or better). The third set of accuracy tests was designed to see how closely IMT change-point models could identify known change-points and slopes from synthetic data (Sreshthaputra et al., 2001).

The results of the third set of tests showed that IMT's 3PC, 3PH and 4P models were accurate to three significant figures (i.e., 99.999 % accurate or better). In the fourth set of accuracy tests, IMT's variable-base heating and cooling degree-day models were compared to PRISM HO and CO models (Fels et al., 1995). The results of the fourth set of tests showed agreement within 1% of the values calculated with PRISM.

In summary, in the case of IMT's 1P, 2P, 3P, 4P and MVR models, the program performs to within several significant decimal places to the same results from other widely accepted models. In the case of IMT's variable-based degree-day model, agreement is within 1% of the values reported by the Princeton Scorekeeping method (PRISM), which is considered acceptable since IMT and PRISM use different search algorithms for finding the change-point temperature, and both reports result in units that require conversion prior to comparison. Therefore, it can be concluded that the IMT is accurate, when it is called upon to perform weather normalized regressions for modeling building energy use.

Therefore, it is proposed that the ASHRAE IMT will be used as the primary regression toolkit to develop linear and change-point linear models for determining the electrical power production from wind turbines.

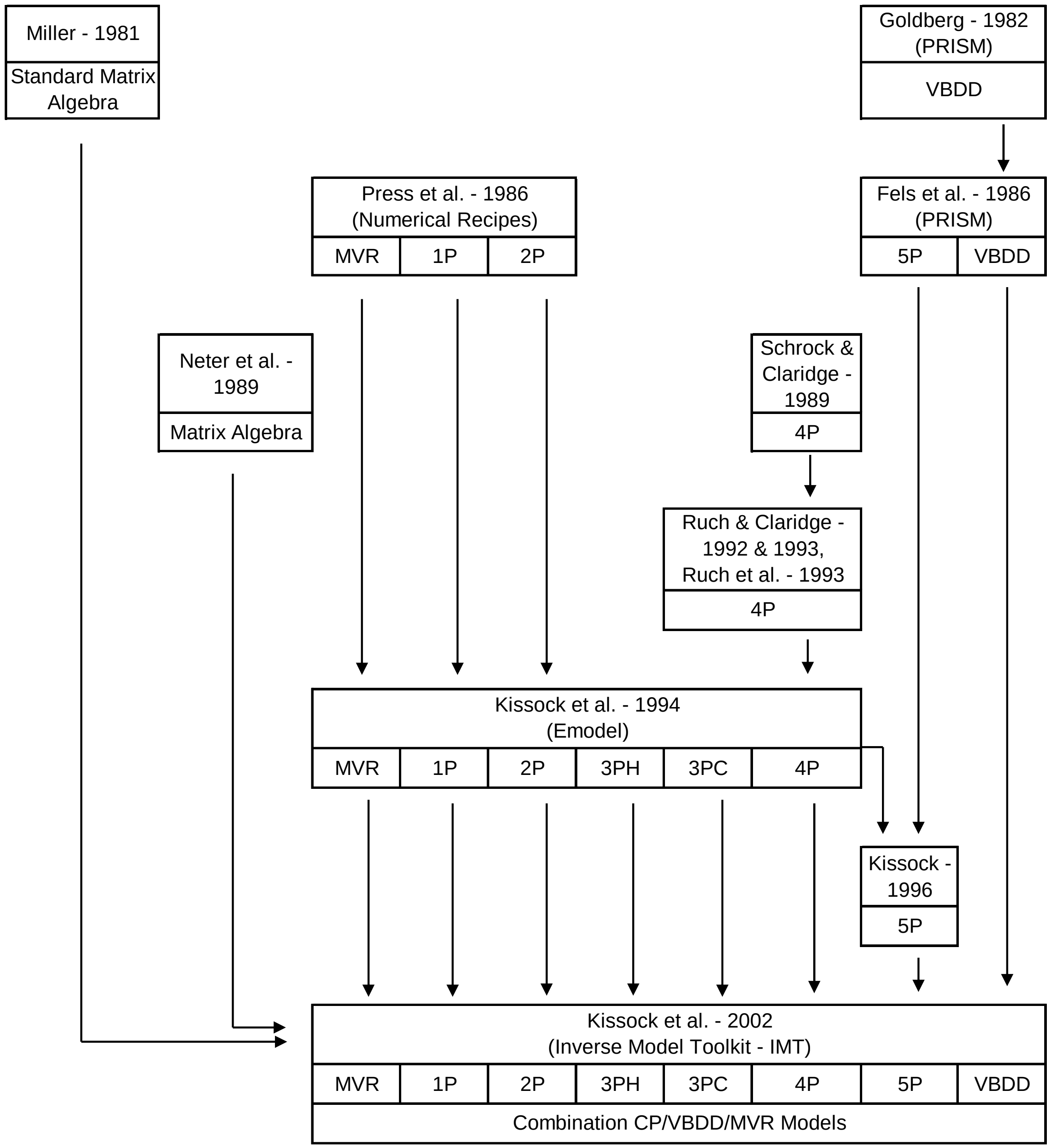

Figure 14. History Diagram of the Inverse Model Toolkit.

5 ANALYSIS OF A SINGLE WIND TURBINE

To investigate the weather normalization procedures for the wind power generation of a single wind turbine, an actual wind electricity generator[16] with a 13.4-m (44-ft) rotor diameter, installed in the Southern Great Plains at the USDA Conservation and Production Research Laboratory in 1982 in Randall County, Texas (Figure 15, and Figure 16) was used for this analysis. The windmill is an Enertech 44 wind with a rated gearbox capacity of 40 kW, and a rated generator capacity of 60 kW. Additional details are provided in Table 10[17].

Figure 15: The Enertech Wind Turbine Installed in Randall, Texas

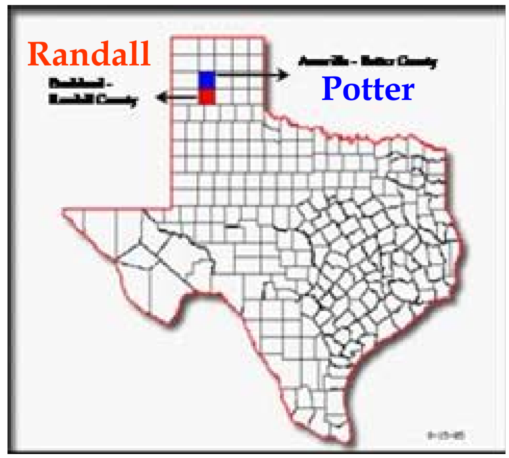

Figure 16: Texas Map Showing Randall (red) and Potter (blue) County

5.1 Wind Speed Data

In Figure 17 and Figure 18, the hourly wind speed data are shown from National Oceanic & Atmospheric Administration (NOAA) – Amarillo, Rick Husband International Airport (AMA)[18]and from on-site measurements[19] for the period October 2001 to September 2002. Figure 19 and Figure 20 show the daily wind speed data from NOAA - AMA and from on-site measurements for the same period (i.e., October 2001 to September 2002), respectively.

The comparison between the hourly and daily wind speed from NOAA and on-site measurements (Figure 21, Figure 22 and Figure 23) shows that the NOAA measurements basically is representative of the site

[16] Data for this site was provided by Alternative Energy Institute, West Texas A&M University. The wind turbine operated for 53.6% of the hours since installation and recorded a capacity factor of 20.4%. Although several component failures occurred during the testing period, the wind turbine had an availability of 90%.
[17] Information obtained from "Performance and Maintenance Experiences with a Wind Turbine During 20 Years of Operation," R. Nolan Clark, USDA-Agricultural Research Service.
[18] NOAA wind measurements were taken at a height of 33 ft.
[19] On-site wind measurements were taken at a height of 33 ft.

though the on-site measuring instrument is more accurate and better maintained. In Figure 23, the number of hours, or frequency, with which winds occur at various speeds throughout the year were plotted for both NOAA and on-site measurements. In this plot it is clear that most of the time the wind speeds fall somewhere in the 8 to 16 MPH range. Though the wind speed distribution from NOAA data differs from the on-site measurements, they follow a very similar trend.

Table 10: Specifications for Wind Turbine in Randall, Texas.

SPECIFICATIONS OF ENERTECH 44 WIND TURBINE INSTALLED AT BUSHLAND, TX, 1982 - 2003	
SYSTEM	
Type	Utility interface
Axis of rotor	Horizontal
Location of rotor (with respect to tower)	Downwind
Number of blades	Three
Centerline hub height	25 m (82 ft)
ROTOR	
Rotor diameter	13.4 m (44 ft)
Rotor type	Fixed pitch
Rotor speed at rated power	57 rpm (40 kW) and 67 rpm (60 kW)
Blade material	Wood/epoxy laminate, fiberglass coat
GENERATOR	
Type	Induction, three-phase (40 & 60 kW)
Output voltage	480 V (40 & 60 kW)
Frequency	60 Hz
TRANSMISSION	
Type	Double reduction, Planetary
Ratio	1:32 (40 kW) and 1:27 (60 kW)
YAW SYSTEM	
Yaw control	None, rotates freely 360 degrees
BRAKES	
Normal stops	Dynamic brake
Parking brake	Electro-mechanical, fail safe spring
ROTOR SPEED CONTROL	
Rotor overspeed (Normal operation)	Blades stall in high winds
Rotor overspeed (Emergency)	Control system applied braking
Rotor overspeed (Emergency back up)	Blade tip brakes deploy
TOWER	
Type	Galvanized self-supporting
Height	24.4 m (80 ft)
PERFORMANCE	
Rated wind speed	13.4 m/s (30 mph)
Start-up wind speed	5.4 m/s (12 mph)
Shut-down wind speed	3.2 m/s (8 mph)
Cut-out wind speed	22.3 m/s (50 mph)

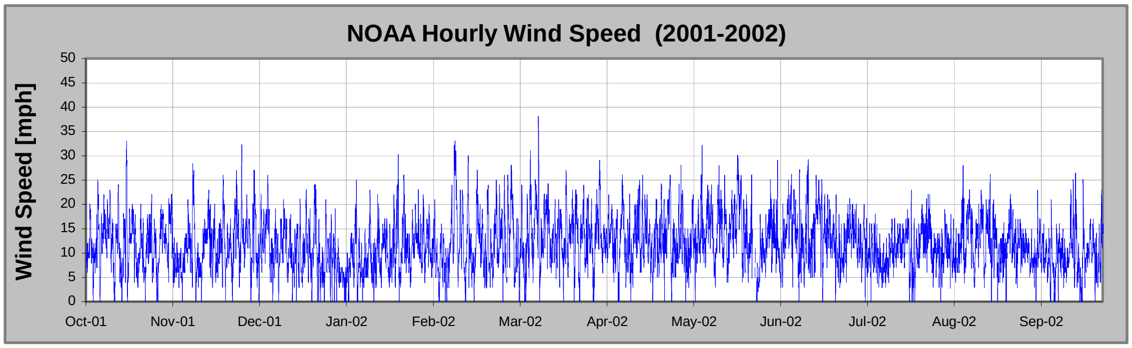

Figure 17: Hourly NOAA-AMA Wind Speed (2001-2002), Randall, Texas.

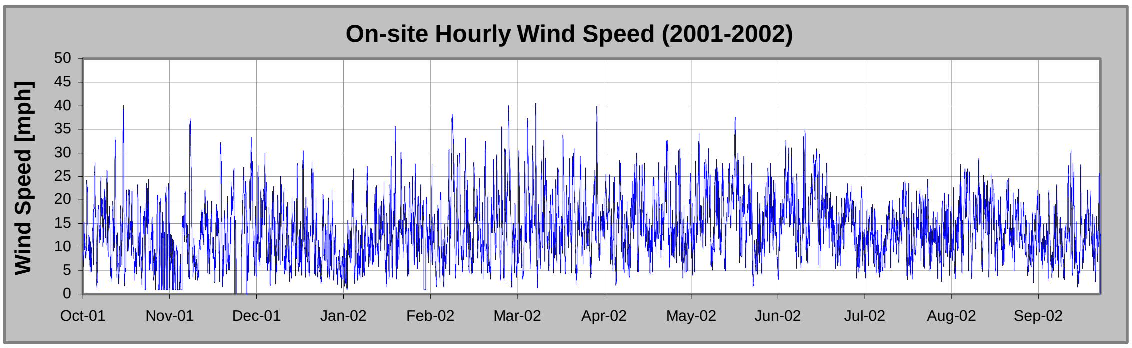

Figure 18: Hourly On-site Wind Speed (2001-2002) , Randall, Texas.

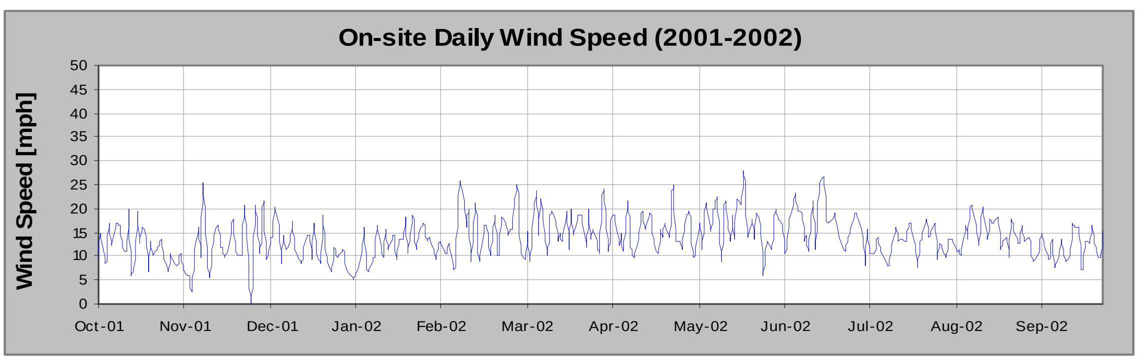

Figure 19: Daily NOAA-AMA Wind Speed (2001-2002) , Amarillo, Texas.

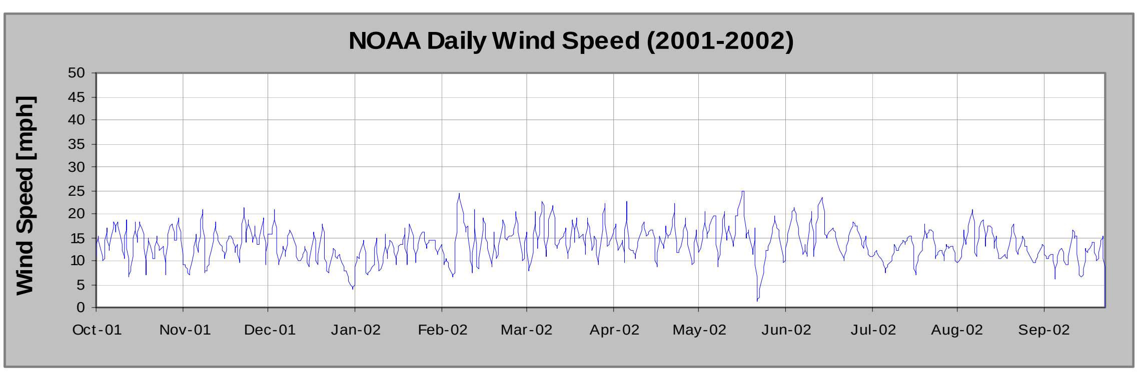

Figure 20: Daily On-site Wind Speed (2001-2002), Randall, Texas.

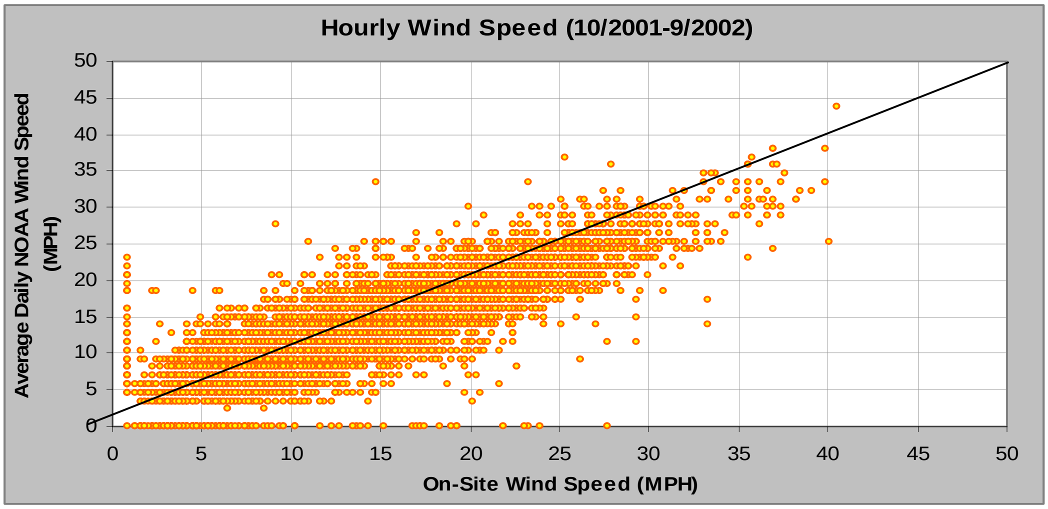

Figure 21: Comparison of NOAA-AMA and On-site Hourly Wind Speed

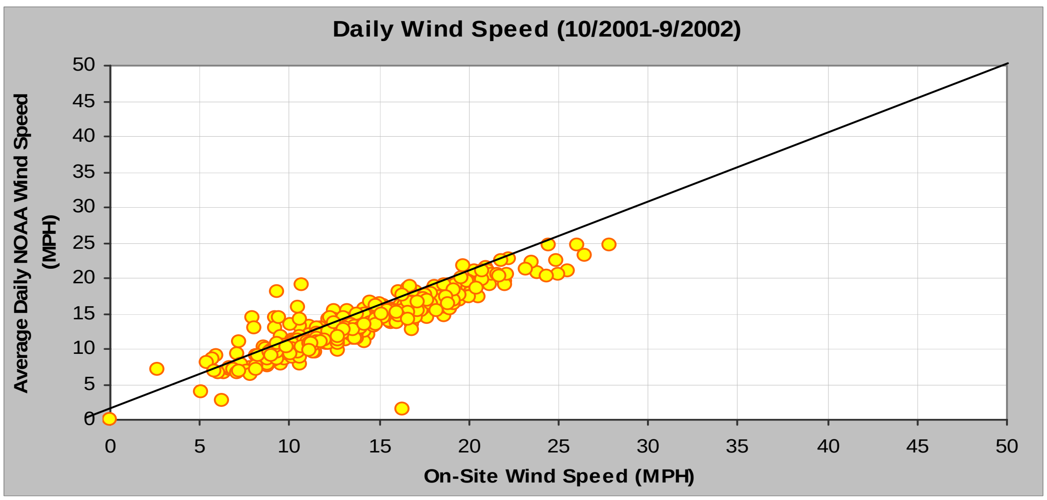

Figure 22: Comparison of NOAA-AMA and On-site Daily Wind Speed

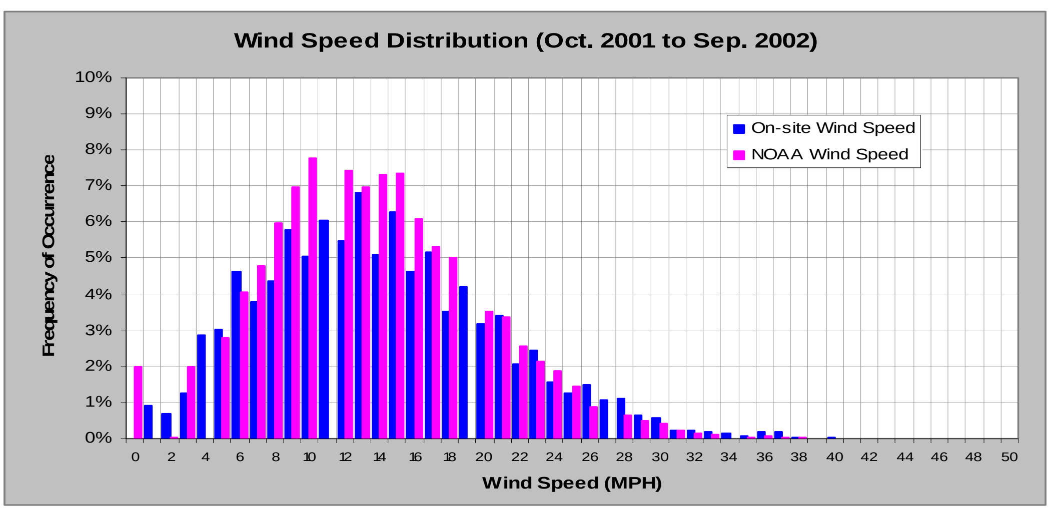

Figure 23: Comparison of NOAA-AMA and On-site Wind Speed Distribution

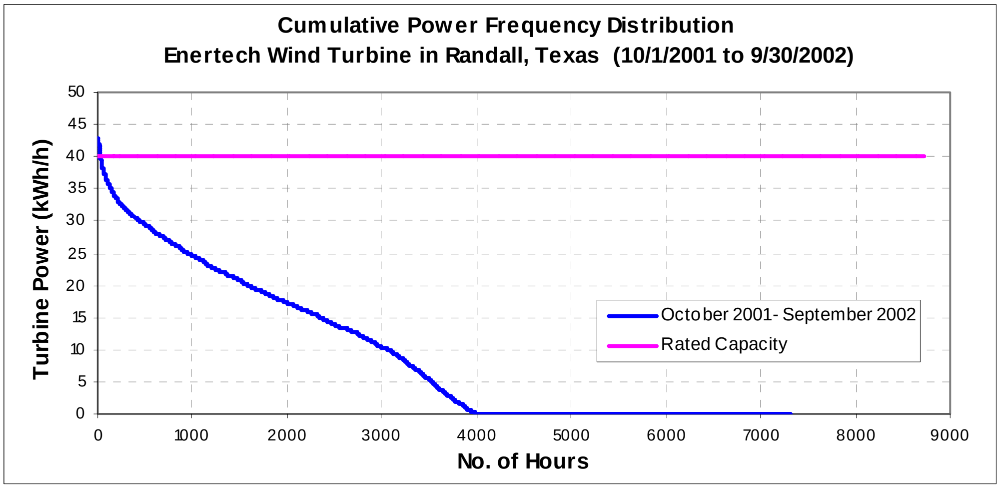

Figure 24: Cumulative Frequency Distribution (10/2001-9/2002), Randall, Texas

5.2 Turbine Power Data

In Figure 25 the measured hourly electricity produced by the wind turbine are shown in time series for the October 2001 to September 2002 period. Figure 26 shows the daily turbine power generation summed from the hourly data. In Figure 27, the hourly turbine power data were plotted against hourly, NOAA wind measurements. In Figure 28 the same hourly electricity data were plotted against the coincident on-site hourly wind data.

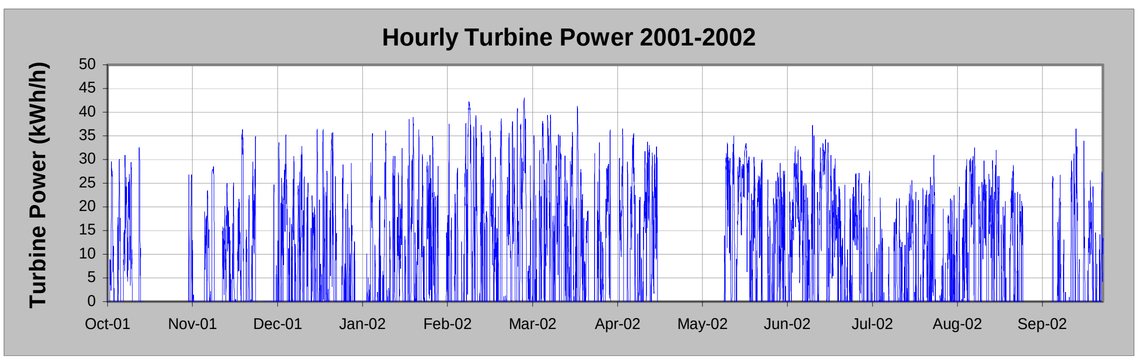

Figure 25: Measured Hourly Turbine Power (2001-2002), Randall, Texas.

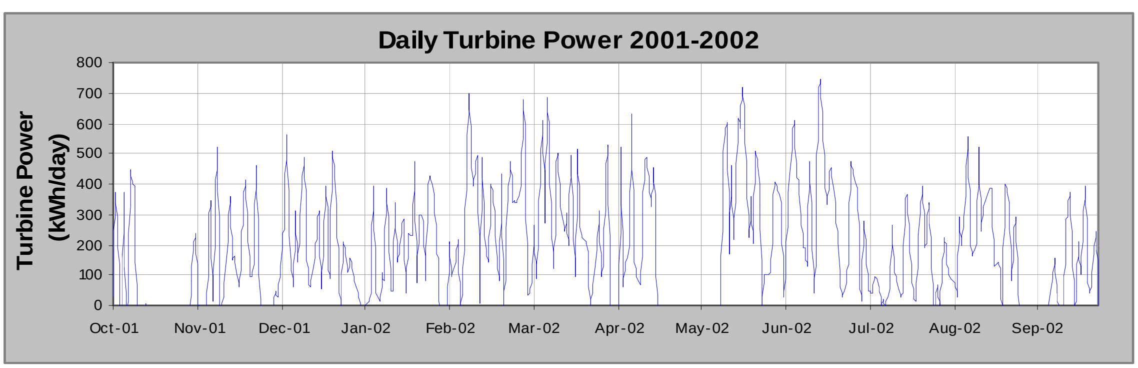

Figure 26: Measured Daily Turbine Power (2001-2002), Randall, Texas.

In Figure 29, the average bins were calculated for the varying hourly power measurements as shown by the superimposed line. These average bins show power measurements that are consistent with the manufacturer's claimed start-up and shut-down speeds of 12 to 8 MPH, respectively.

In Figure 30 the hourly electricity produced by the wind turbine were summed to daily totals and plotted against the daily average wind speed using the NOAA measurements. In Figure 31 the same hourly electricity produced by the wind turbine were summed to daily totals and plotted against the daily average wind speed using on-site measurements.

In Figure 32 the monthly average daily electricity produced by the wind turbine were plotted against the average monthly wind speed per day from NOAA measurements, and in Figure 33 the same monthly average daily electricity produced were plotted against the average monthly average wind speed per day from on-site measurements.

As seen in Figure 27 and Figure 28, the hourly turbine power plotted against NOAA wind speed shows considerably more scatter due to differences in the wind velocity measurements, and physical separation of wind measurements from the wind turbine[20]. As expected, these differences become less pronounced when one compares average daily electricity production against average daily wind measurements, as shown in Figure 30 and Figure 31. Comparisons of the average daily production from monthly data have a similar convergence as shown in Figure 32 and Figure 33 although there is a noticeable shift in the trend.

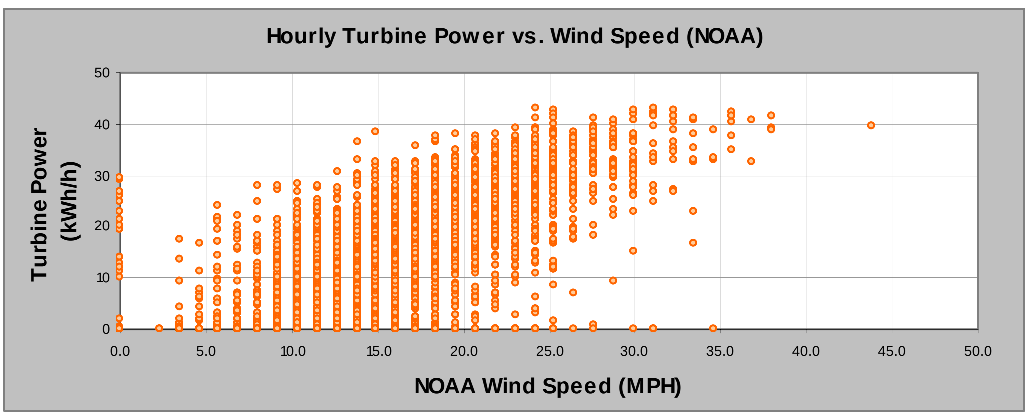

Figure 27: Hourly Turbine Power vs. NOAA-AMA Wind Speed

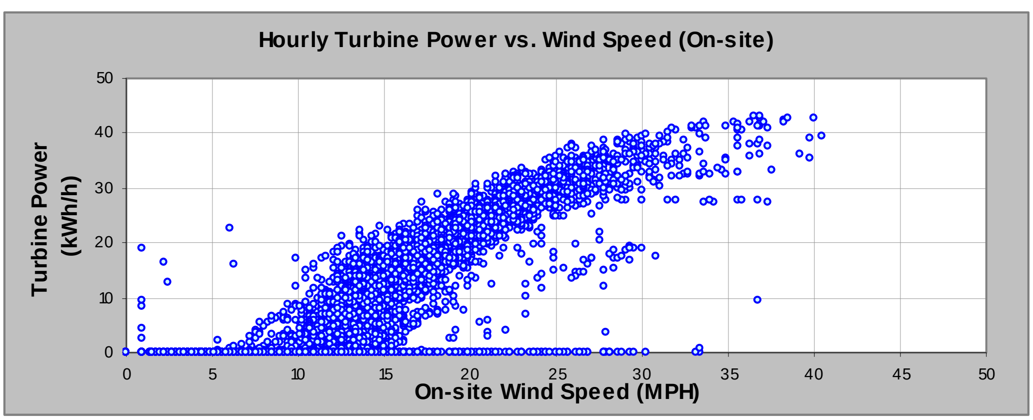

Figure 28: Hourly Turbine Power vs. On-site Wind Speed

[20] The on-site wind measurements were taken with an integrating data logger, and thereby represent the average hourly wind speed. The NWS wind measurements represent an average wind speed taken over a 3 to 5 minute interval at about 15 minutes before the hour, and therefore represent a peak gust measurement, which is required by the FAA for pilots at airports.

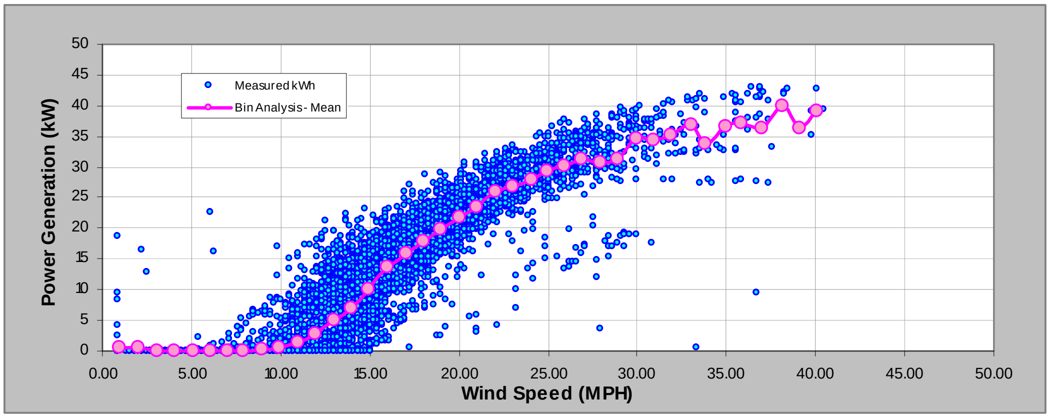

Figure 29: Hourly Turbine Power Bin Analysis

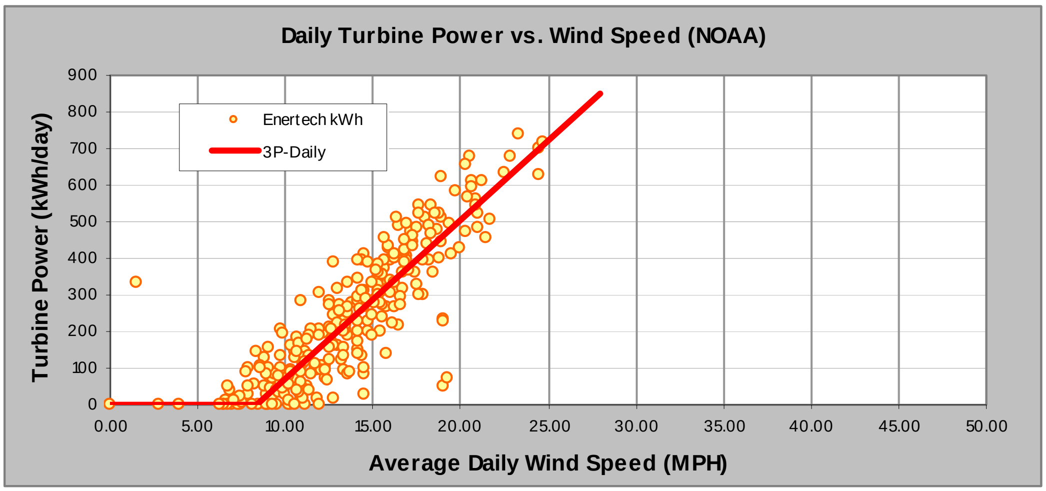

Figure 30: Daily Turbine Power vs. NOAA-AMA Wind Speed

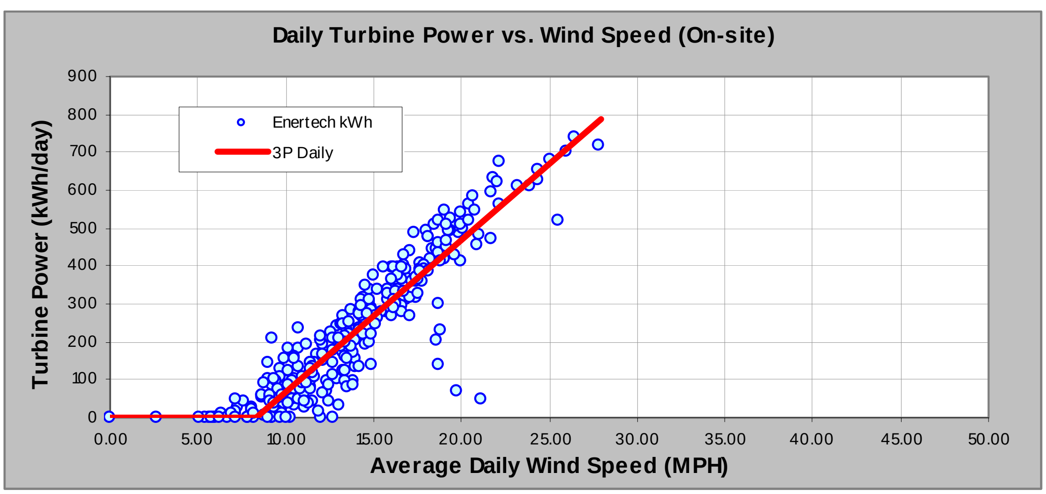

Figure 31: Daily Turbine Power vs. On-site Wind Speed

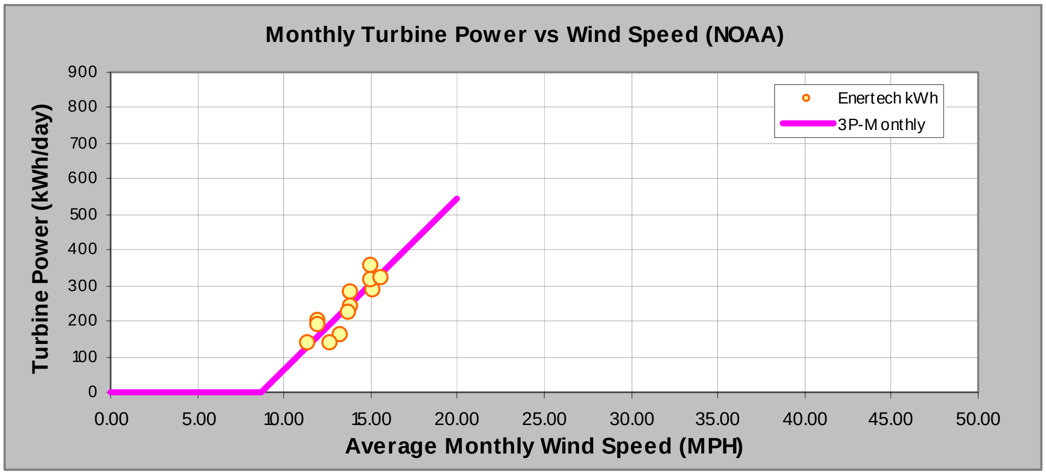

Figure 32: Monthly Daily Turbine Power vs. NOAA-AMA Wind Speed

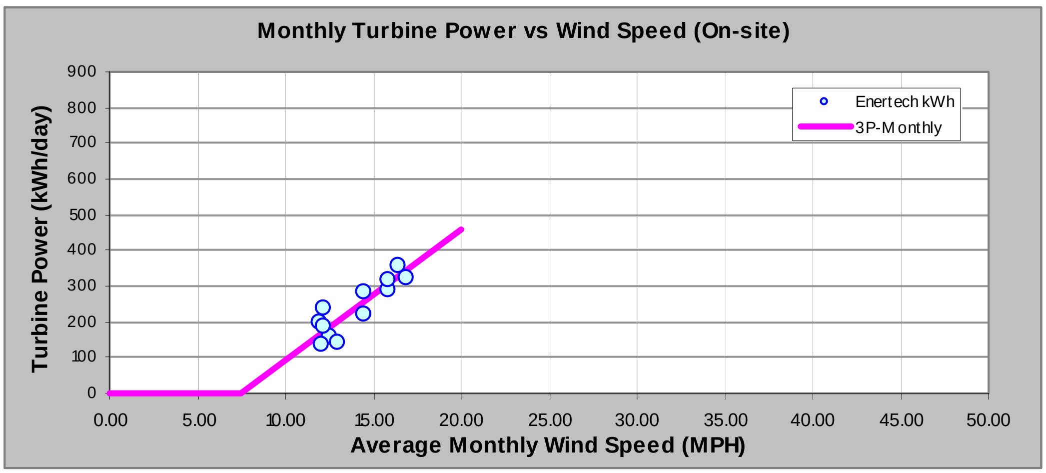

Figure 33: Monthly Daily Turbine Power vs. On-site Wind Speed

5.3 Modeling of Turbine Power vs. Wind Speed

Application of a three-parameter change-point linear regression[21] to the average daily wind power output versus average daily wind speeds using ASHRAE's Inverse Model Toolkit[22] (IMT) is shown in Figure 30 and Figure 31. The three-parameter change-point linear regression to the monthly average daily turbine power versus average monthly wind speeds per day are shown super-imposed on the monthly data in Figure 32 and Figure 33.

In Figure 34 and Figure 35, the monthly daily models developed using NOAA and on-site wind measurements were applied to the average daily wind speed to compare against the corresponding daily models. Good agreement is found in these comparisons although there is a slight shift from the daily model to the monthly model for using on-site or NOAA wind measurements. The summary of the model

[21] These regressions inserted dummy points at zero to force the parameter below the change-point to zero to improve the goodness of fit for the regression.

[22] The ASHRAE Inverse Model Toolkit (IMT) is a public-domain FORTRAN program for calculating linear and change-point linear regressions, which have been shown to be the most effective analysis for performing weather analysis for building energy use. This type of analysis is recognized in the ASHRAE Handbook and in ASHRAE Guideline 14-2002.

coefficients from the daily and monthly daily models using NOAA and on-site wind measurements are listed in Table 11.

5.4 Prediction of Turbine Power

The resultant coefficients (Table 11) from the 3-parameter models were sufficiently robust to allow for their use in projecting the daily average wind production into other weather base years. In Table 12 the predicted electricity production using the 3-parameter, change-point linear daily NOAA model and daily on-site model is shown for the 2001 to 2002 period to compare against the measured monthly electricity in the same period. These two models are moderately described (Table 11) with a root-mean-squared error (RMSE) of 84 kWh/day for the 2001 to 2002 period for the NOAA daily model, and a RMSE of 71 kWh/day for the 2001 to 2002 period for the on-site daily model.

Table 12 shows that, on average, the models performed well, but does contain significant month to month variations (November 2001 and July 2002). Table 13 shows the comparison of the measured and predicted electricity using the 3-paramter, change-point linear monthly daily NOAA model and monthly daily on-site model. The prediction on turbine power using monthly daily models shows a slightly larger difference when compared to the daily models.

In Figure 36 and Figure 37, the daily turbine power output in July 2001 and August 2001 are shown in different color (blue) to help explain the month to month variation in the prediction using the daily or monthly models. In July 2001 there were a large number of measured days when the power output fell below the average predicted by either the average daily or average daily from monthly model. Whereas, in August of 2001, the measured data points were more evenly scattered around the prediction from the model. In Figure 36 and Figure 37 both the predictions from the average daily (red) and average daily from monthly (blue) models are shown to be in good agreement.

Figure 38 shows the predicted electricity production from the wind turbine as a time-series trace for the Ozone Season Period, i.e., July 15 to September 15, using NOAA daily and monthly models. The measured power output for the same period is also presented for comparison. Figure 39 shows the predicted electricity production from the wind turbine as a time-series trace for the Ozone Season Period using on-site daily and monthly models.

In Figure 38 and Figure 39 the on-site and NOAA wind speed are shown in the upper traces of the time series plot, and the predicted average daily, average daily from monthly data and measured electricity produced are shown in the lower trace of the plot. These predictions were previously shown in Figure 30 through Figure 33. As a way of diagnosing the differences in the measured and predicted the 12 MPH start-up speed and 8 MPH shut-down speed were superimposed on top of the wind speed traces, since it was found that a large portion of the differences fell within the region around start-up and shut-down speeds.

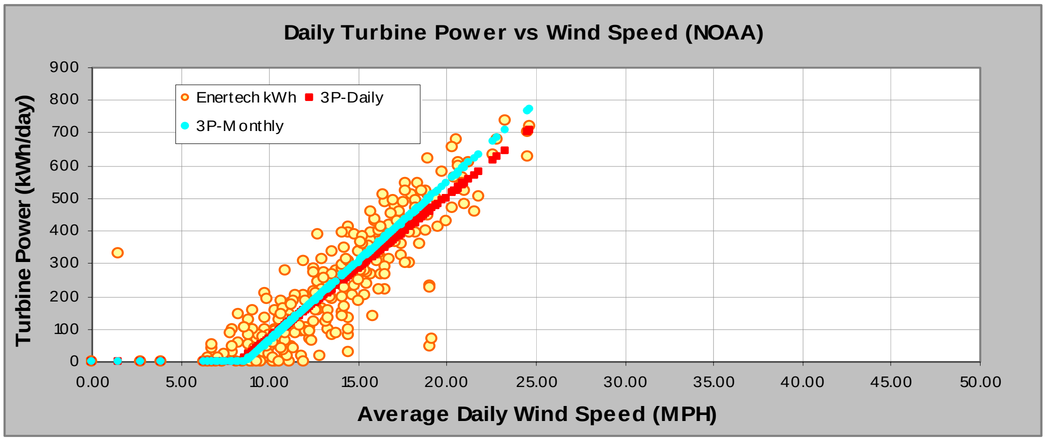

Figure 34: Comparison of Daily and Monthly Daily Models (NOAA-AMA Wind Speed)

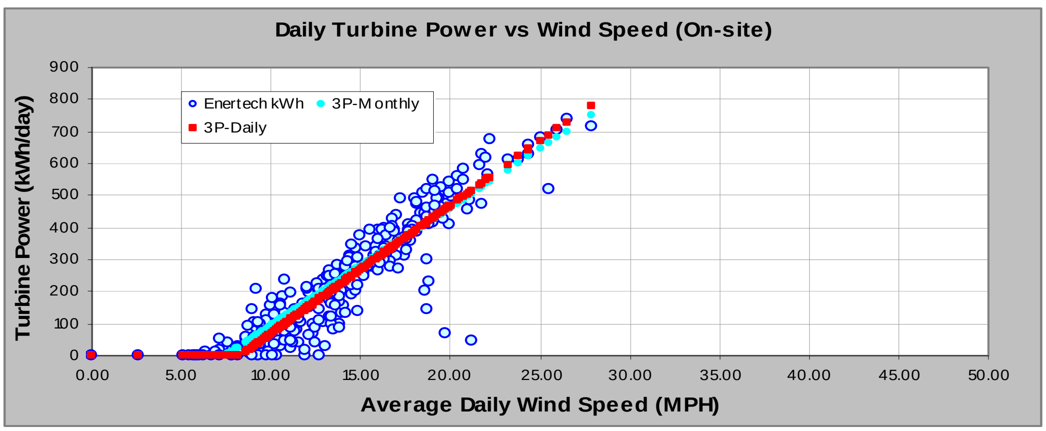

Figure 35: Comparison of Daily and Monthly Daily Models (On-site Wind Speed)

Table 11: Model Coefficients

IMT Coefficients	NOAA Daily Model	On-site Daily Model	NOAA Monthly Model	On-site Monthly Model
Ycp (kWh/day)	0.3033	0.1358	-0.0050	-0.0212
Slope (kWh/mph-day)	43.3974	40.0368	48.3943	36.9140
Change Point (mph)	8.3885	8.3524	8.6961	7.5220
RMSE (kWh/day)	84.2825	70.5564	87.0297	71.8874

Table 12: Predicted Turbine Power Using Daily Models

Month	No. Of Days with Measured Turbine Power	NOAA Daily Avg. Wind Speed (MPH)	On-site Avg. Wind Speed (MPH)	Measured Turbine Power (kWh/mo)	Predicted Turbine Power (kWh/mo) NOAA	Diff. NOAA	Predicted Turbine Power (kWh/mo) On-site	Diff. On-site
Oct-01	10	13.81	12.24	2,386	2,775	-16.29%	1,810	24.15%
Nov-01	24	13.31	12.52	3,841	4,768	-24.16%	4,075	-6.10%
Dec-01	31	11.99	11.95	6,174	5,025	18.61%	4,661	24.51%
Jan-02	29	11.93	12.17	5,431	4,589	15.51%	4,944	8.96%
Feb-02	28	13.79	14.50	7,884	6,572	16.65%	6,801	13.74%
Mar-02	31	15.17	15.88	8,965	9,147	-2.03%	9,346	-4.25%
Apr-02	15	15.05	15.87	4,763	4,380	8.04%	4,467	6.20%
May-02	18	15.02	16.41	6,388	5,630	11.86%	6,154	3.67%
Jun-02	30	15.63	16.87	9,657	9,426	2.39%	10,232	-5.95%
Jul-02	31	12.69	12.94	4,344	5,901	-35.85%	5,753	-32.44%
Aug-02	30	13.74	14.43	6,702	7,006	-4.54%	7,356	-9.76%
Sep-02	18	11.37	12.09	2,470	2,588	-4.79%	2,869	-16.16%
Total	295			69,005	67,808	1.73%	68,469	0.78%

Table 13: Predicted Turbine Power Using Monthly Daily Models

Month	No. Of Days with Measured Turbine Power	NOAA Daily Avg. Wind Speed (MPH)	On-site Avg. Wind Speed (MPH)	Measured Turbine Power (kWh/mo)	Predicted Turbine Power (kWh/mo) NOAA	Diff. NOAA	Predicted Turbine Power (kWh/mo) On-site	Diff. On-site
Oct-01	10	13.81	12.24	2,386	2,961	-24.06%	1,945	18.51%
Nov-01	24	13.31	12.52	3,841	5,017	-30.63%	4,311	-12.25%
Dec-01	31	11.99	11.95	6,174	5,202	15.74%	5,156	16.49%
Jan-02	29	11.93	12.17	5,431	4,767	12.22%	5,325	1.95%
Feb-02	28	13.79	14.50	7,884	6,971	11.58%	7,068	10.36%
Mar-02	31	15.17	15.88	8,965	9,754	-8.80%	9,567	-6.72%
Apr-02	15	15.05	15.87	4,763	4,661	2.14%	4,579	3.87%
May-02	18	15.02	16.41	6,388	6,045	5.37%	6,195	3.02%
Jun-02	30	15.63	16.87	9,657	10,065	-4.22%	10,354	-7.21%
Jul-02	31	12.69	12.94	4,344	6,149	-41.55%	6,205	-42.85%
Aug-02	30	13.74	14.43	6,702	7,366	-9.91%	7,702	-14.92%
Sep-02	18	11.37	12.09	2,470	2,663	-7.82%	3,141	-27.16%
Total	295			69,005	71,621	-3.79%	71,547	-3.68%

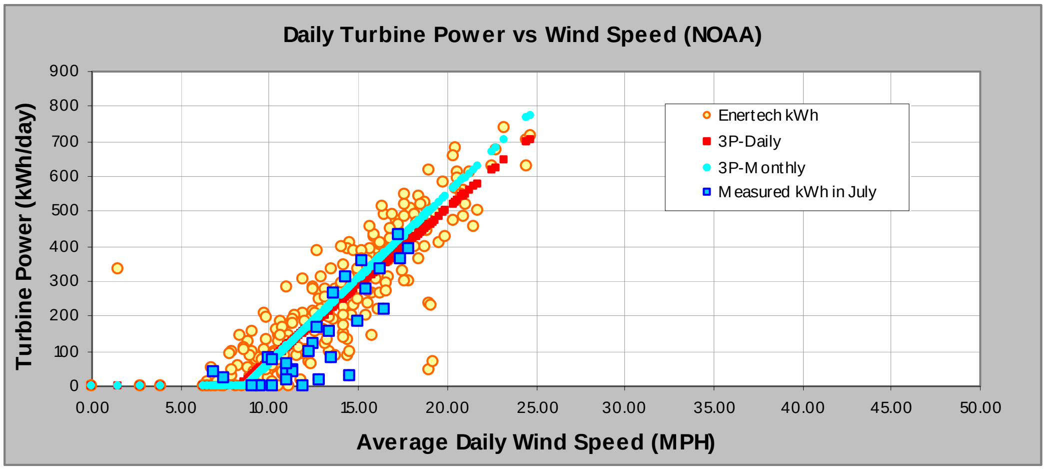

Figure 36: Measured Daily Turbine Power – July 2002 (NOAA-AMA Wind Speed)

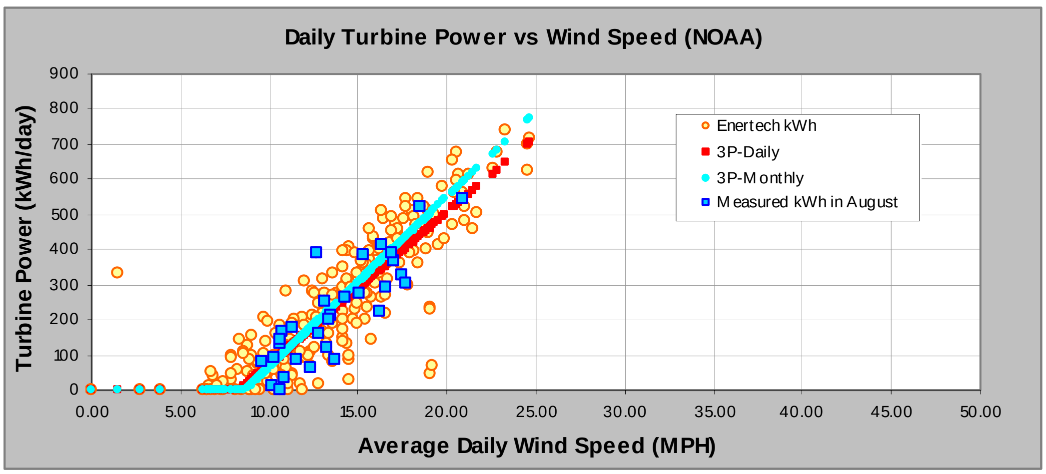

Figure 37: Measured Daily Turbine Power – August 2002 (NOAA-AMA Wind Speed)

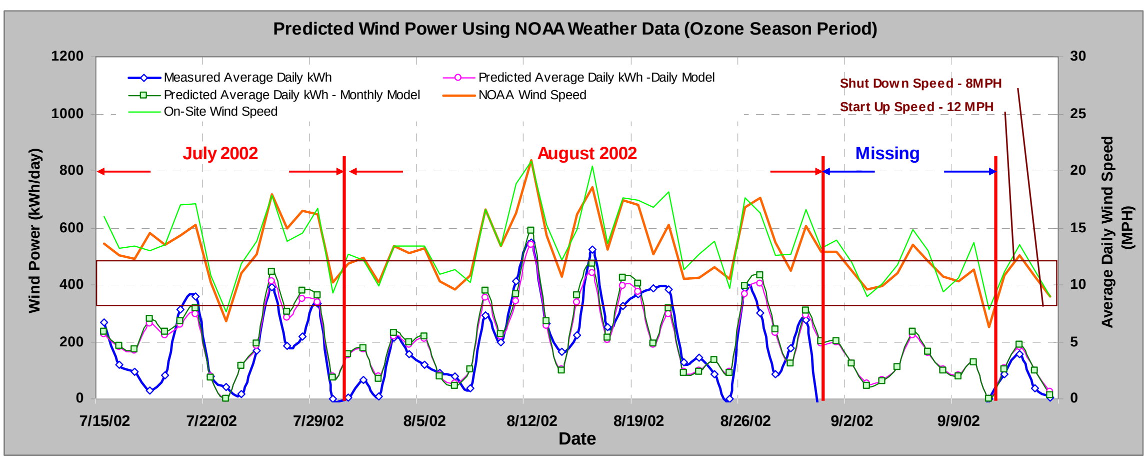

Figure 38: Predicted Turbine Power in OSD Using NOAA-AMA Wind Speed

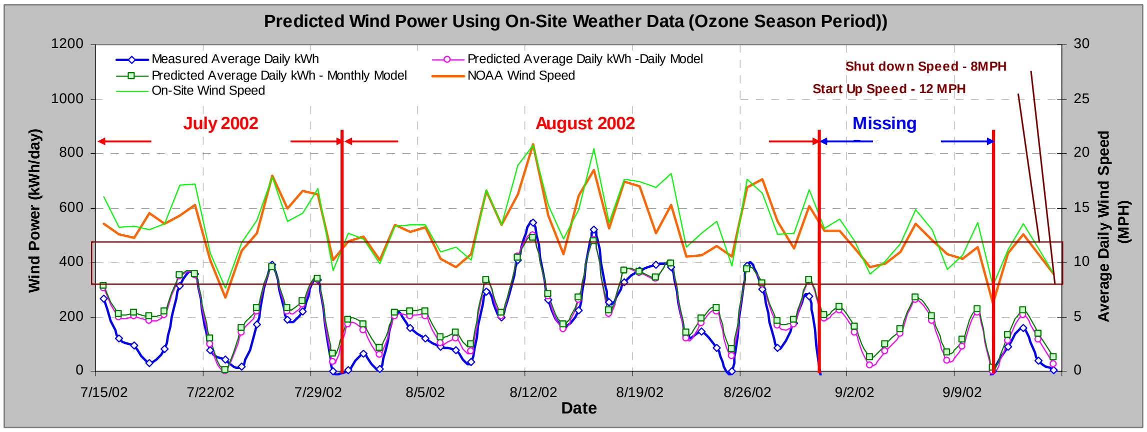

Figure 39: Predicted Turbine Power in OSD Using On-site Wind Speed

5.5 Capacity Factor Analysis

The predicted monthly capacity factors for the period October 2001 to September 2002 using the daily NOAA and on-site models and monthly NOAA and on-site models, as well as the measured monthly capacity factors for the same period are shown in Figure 40 and Figure 41. Figure 42 and Figure 43 show the predicted monthly capacity factors from January to December for the periods 1999 through 2005, as well as the measured monthly capacity factor during 2001 to 2002 and the average monthly capacity factors for these seven years, using daily NOAA model and monthly NOAA model[23].

As seen in
Table 14, if the annual capacity factor had been predicted with NOAA daily model, the annual capacity factors for these years would vary from 18.4% to 22.9%, with an average of 20% and the highest electricity production occurring in the spring months. It is interesting to note that the variation across the same month of these years can be larger than 17%; for example, in May and August, due to the significantly different wind conditions. On average, the wind turbine has a 15% to 28% capacity factor, varying from a low of 15% in August to almost 28% in April. The variations from the model-predicted monthly use are well within the variation of the wind turbine's measured output, which can be seen by comparing the measured 2001-2002 production against the modeled production.

It is interesting to note that the variations in the model (i.e., Figure 40 and Figure 41), are well within the year-to-year variations shown in Figure 42 and Figure 43. Furthermore, the average capacity factor over the period 1999 to 2005 helps to show the outlier years, which include the 2001 to 2002 period of measured data used to create the model (i.e., the outlier for August 2001). Figure 42 and Figure 43 also show the importance of weather normalizing the wind speeds back to the base year.

[23] The predictions shown include reductions metered output due to curtailment and/or maintenance.

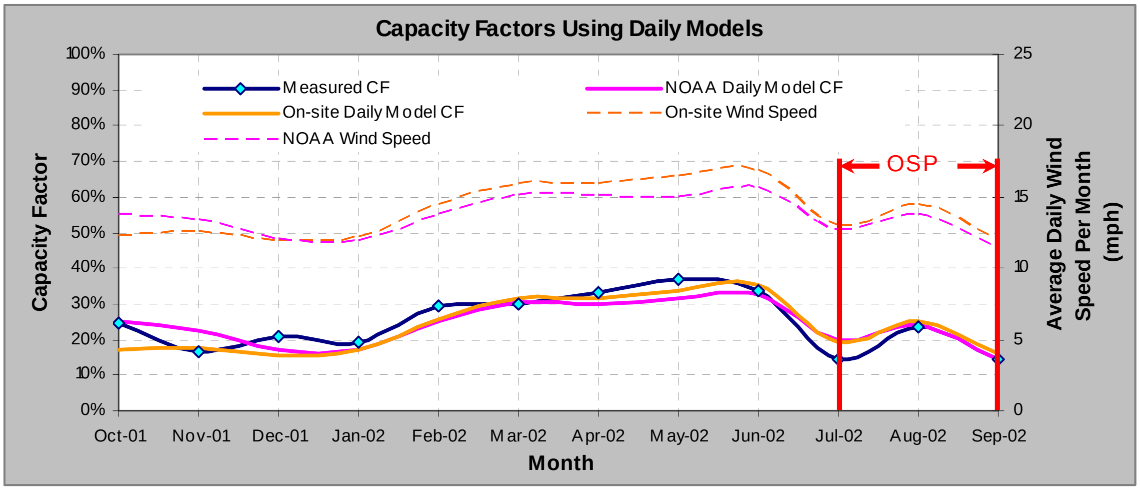

Figure 40: Predicted Capacity Factors Using Daily Models (2001-2002) (NOAA-AMA Wind Speed)

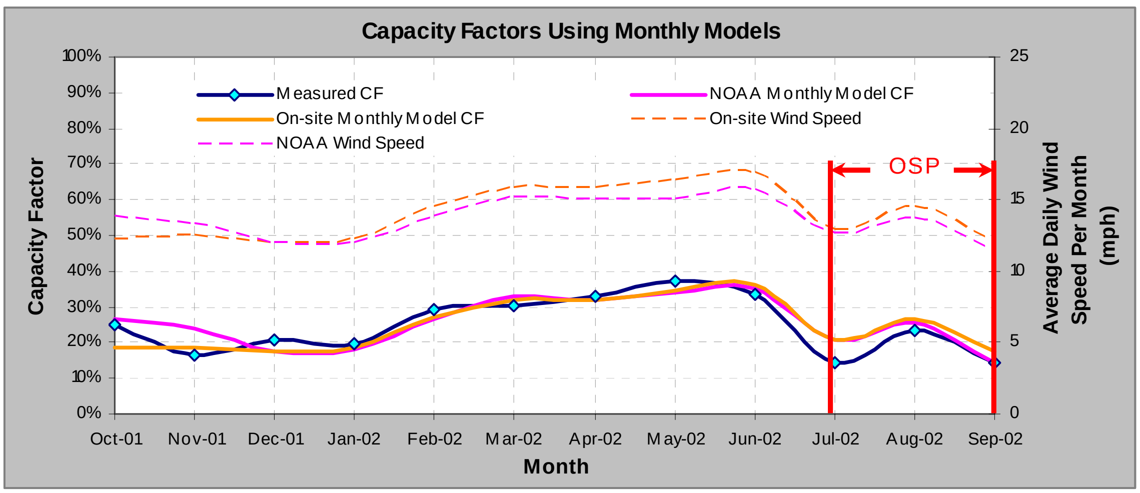

Figure 41: Predicted Capacity Factors Using Monthly Daily Models (2001-2002) (NOAA-AMA Wind Speed)

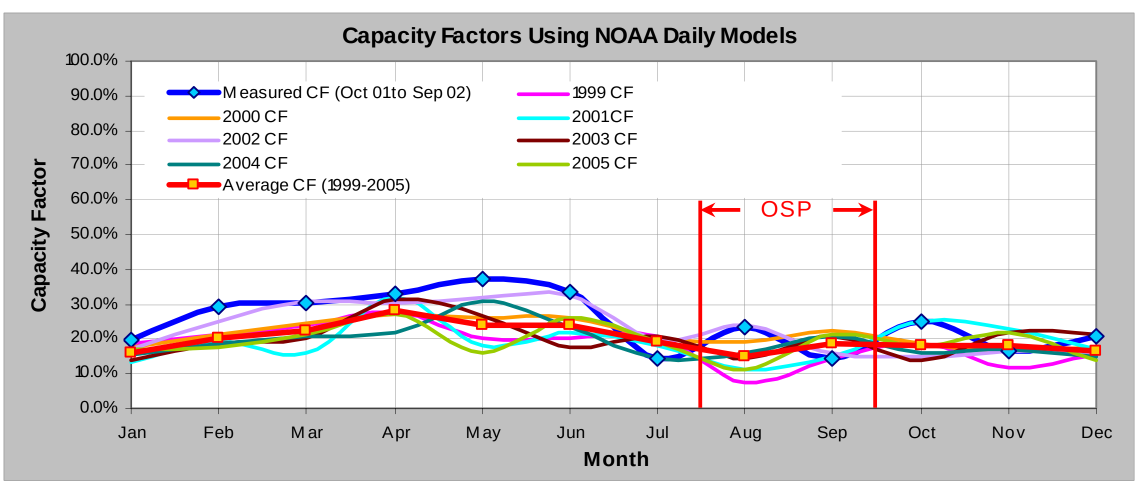

Figure 42: Predicted Capacity Factors Using Daily Models (1999-2005) (NOAA-AMA Wind Speed)

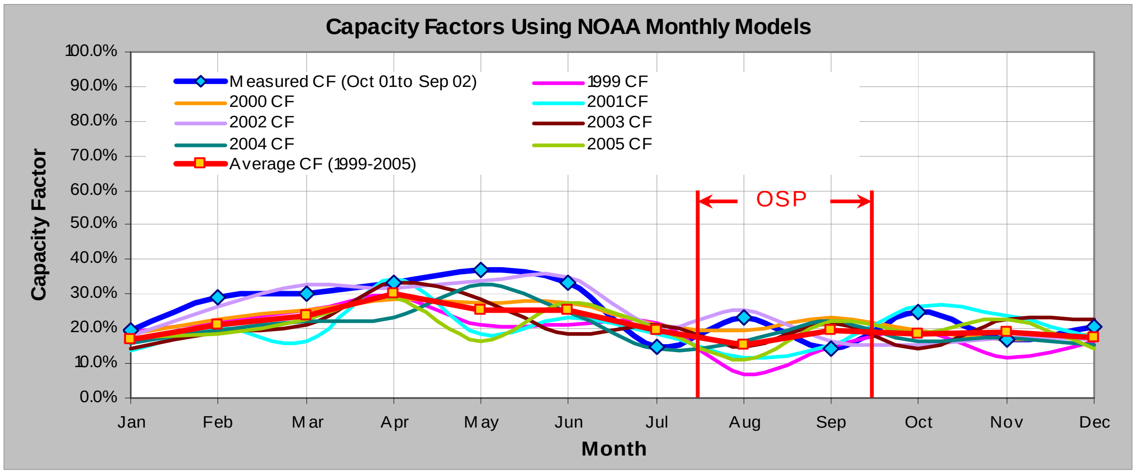

Figure 43: Predicted Capacity Factors Using Monthly Daily Models (1999-2005) (NOAA-AMA Wind Speed)

Table 14: Summary of Capacity Factors (1999-2005)

	NOAA Annual Average Wind Speed (MPH)	Annual Capacity Factor Using NOAA Daily Model	Annual Capacity Factor Using NOAA Monthly Model
1999	12.3	18.4%	19.2%
2000	13.0	21.4%	22.5%
2001	12.5	19.1%	20.0%
2002	13.3	22.9%	24.1%
2003	12.7	20.0%	21.0%
2004	12.1	19.2%	20.1%
2005	12.4	19.2%	20.1%
Measured (Oct. 01-Sep. 02)	13.6	24.7%	24.7%
Average (1999-2005)	12.6	20.0%	21.0%

6 ANALYSIS ON WIND FARM WITH MULTIPLE WIND TURBINES

To investigate the wind power generation of a wind farm with multiple wind turbines, the Indian Mesa Wind Farm located in Pecos County, TX, was used. This project was completed in 2001. One hundred and twenty-five Vestas V-47 wind turbines produce up to 82.5 Megawatts of electricity. Electricity produced by the project is purchased by the Lower Colorado River Authority, Austin, Texas, and TXU Energy Trading Company, Dallas, Texas. The project is connected to the transmission lines of American Electric Power subsidiary West Texas Utilities[24]. The specification of the Vestas V-47 wind turbine is listed in Table 15[25].

Figure 44: The Indian Mesa Wind Farm (82.5 MW) in Pecos, Texas

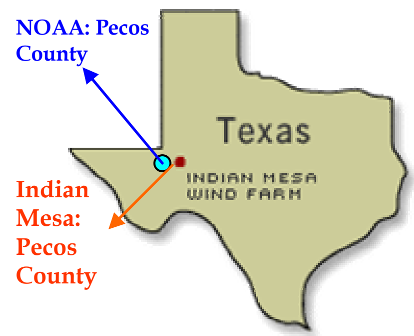

Figure 45: Texas Map Showing Pecos County and Indian Mesa Wind Farm

Table 15: Specifications for Vestas V-47 Wind Turbine

Manufacture	Vestas-American Wind Technology
Nameplate Capacity	660 kW at 33.5 mph or above
Cut-in speed	9 mph
Cut-out speed	56 mph
Rotor diameter	154 ft
Tower height at hub	164 ft
Total height to the top of blade tip	241 ft
Rotor speed	28.5 RPM

[24] Information obtained from Orion Energy, Electric Reliability Council of Texas, and Public Utility Commission of Texas.
[25] Information obtained from Platte River Power Authority, http://www.prpa.org

6.1 Wind Speed Data

In Figure 46 and Figure 47 the hourly wind speed data are shown from National Oceanic & Atmospheric Administration (NOAA) – Fort Stockton Pecos County Airport (FST) [26] and from on-site measurements for the period July 2002 to March 2003. Figure 48 and Figure 49 show the daily wind speed data from NOAA - FST and from on-site measurements for the same period (i.e., July 2002 to March 2003), respectively.

The comparison between the hourly and daily wind speed from NOAA and on-site measurements (Figure 50 and Figure 51) shows that the NOAA measurements are lower than the on-site measurements for speeds greater than about 15 MPH. In Figure 52, the number of times, or frequency, with which winds occur at various speeds throughout the year were plotted for both NOAA and on-site measurements. Figure 52 it is shown that the wind speed distribution from NOAA data differs significantly from that of the on-site measurements; NOAA data are grouped in a tighter pattern in the 5 to 15 MPH range, whereas the on-site measurements have a greater number of hours in the 8 to 20 MPH range, and contains many hours in the 20+ MPH range. The higher on-site wind speeds are due, in part, to the high mesa area where the wind farm is located since the wind in mountainous terrain can change abruptly over short distance, as well as the location of the wind sensor at the height of the turbine. The wind class map[27] in Figure 54 shows the different wind class for the NOAA-FST weather station (Class 2) and the wind farm (Class 3) although these two sites are less than 100 miles away. Figure 53 shows the cumulative frequency distribution.

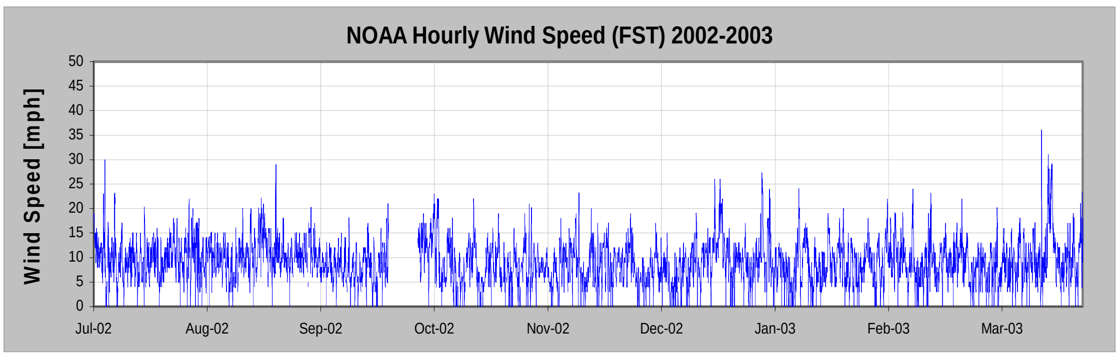

Figure 46: Hourly NOAA-FST Wind Speed (2002-2003), Pecos, Texas

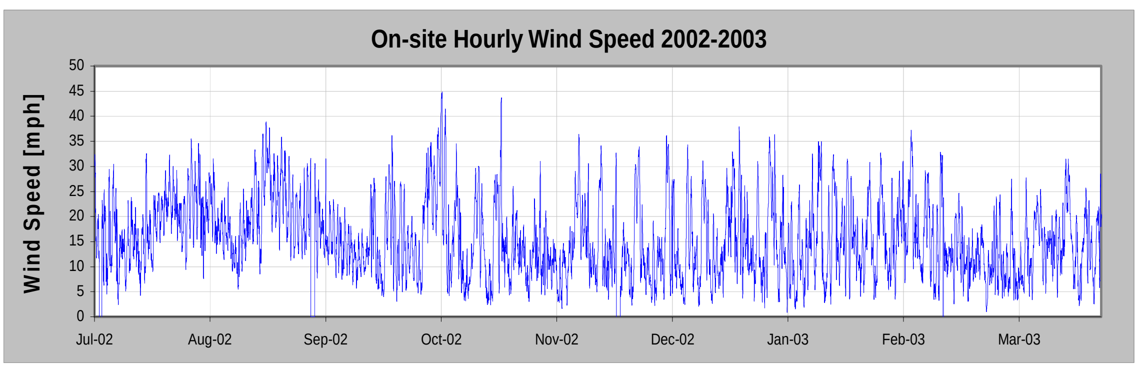

Figure 47: Hourly On-site Wind Speed (2002-2003), Pecos, Texas

[26] NOAA wind measurements were taken at a height of 33 ft.
[27] The wind class map provided by Alternative Energy Institute, West Texas A&M University. http://www.wtamu.edu/research/aei/datasites/index.htm.

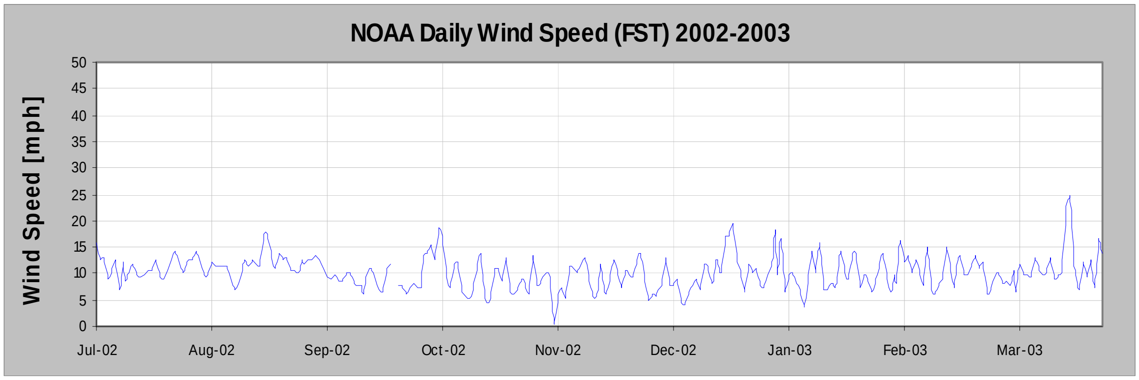

Figure 48: Daily NOAA-FST Wind Speed (2002-2003)

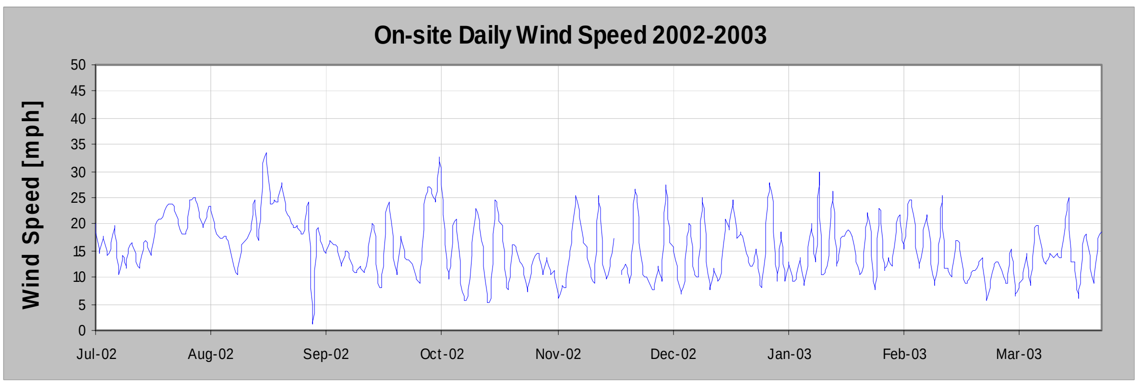

Figure 49: Daily On-site Wind Speed (2002-2003), Pecos, Texas.

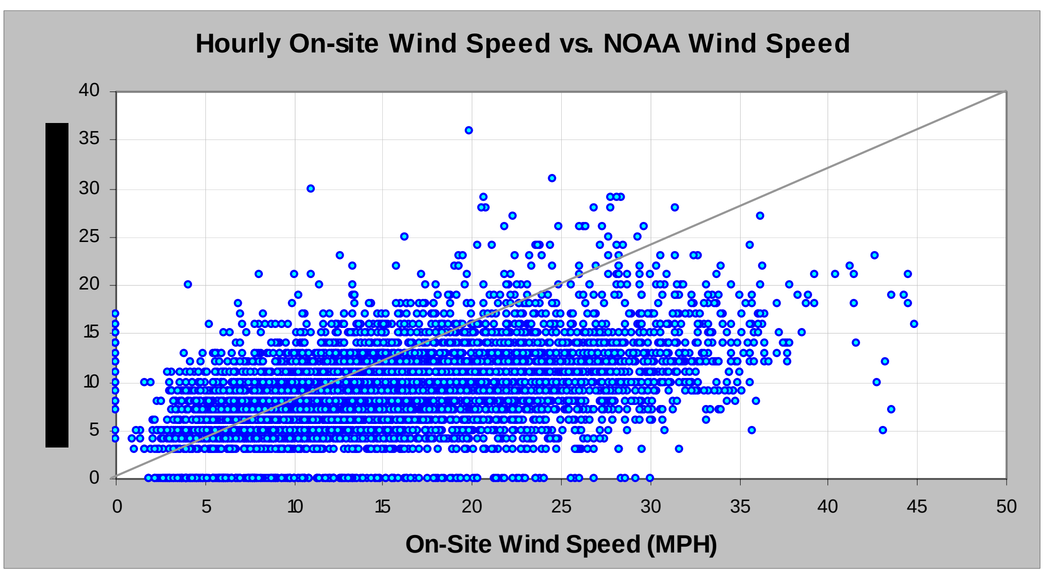

Figure 50: Comparison of NOAA-FST and On-site Hourly Wind Speed

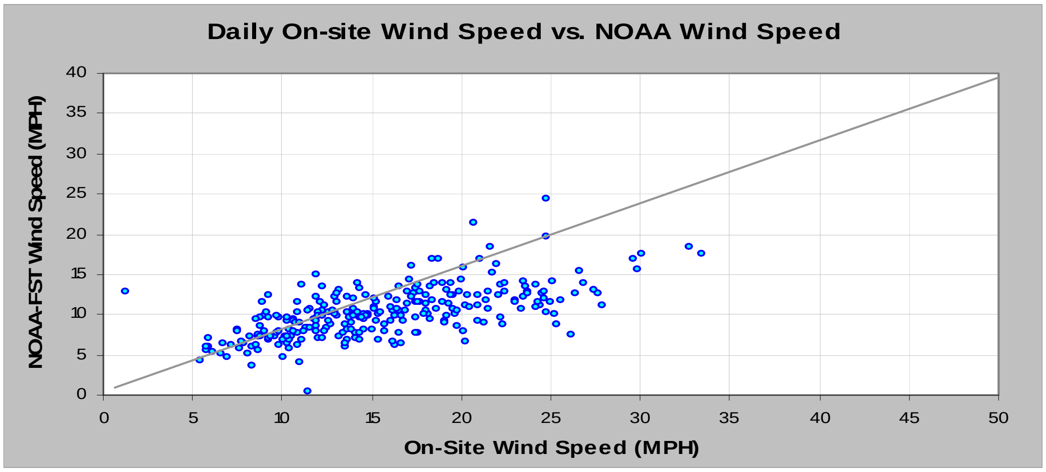

Figure 51: Comparison of NOAA-FST and On-site Daily Wind Speed

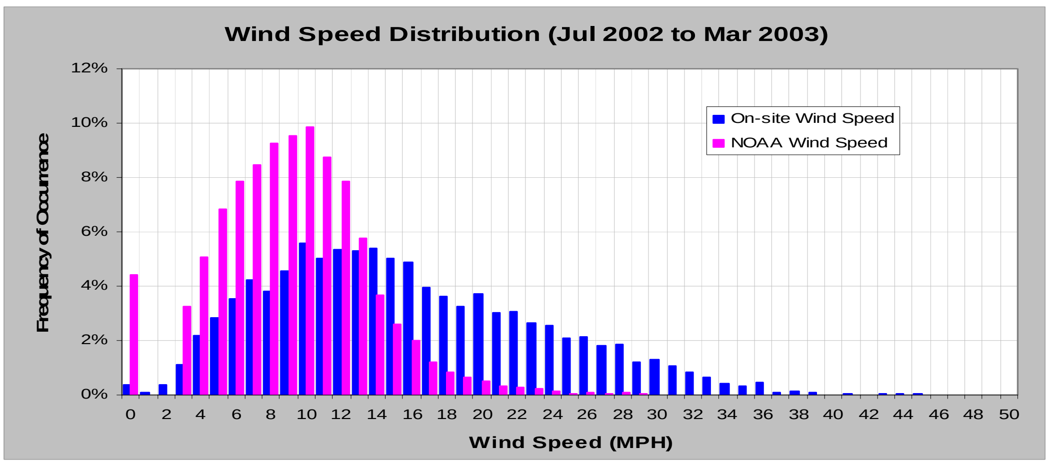

Figure 52: Comparison of NOAA-FST and On-site Wind Speed Distribution

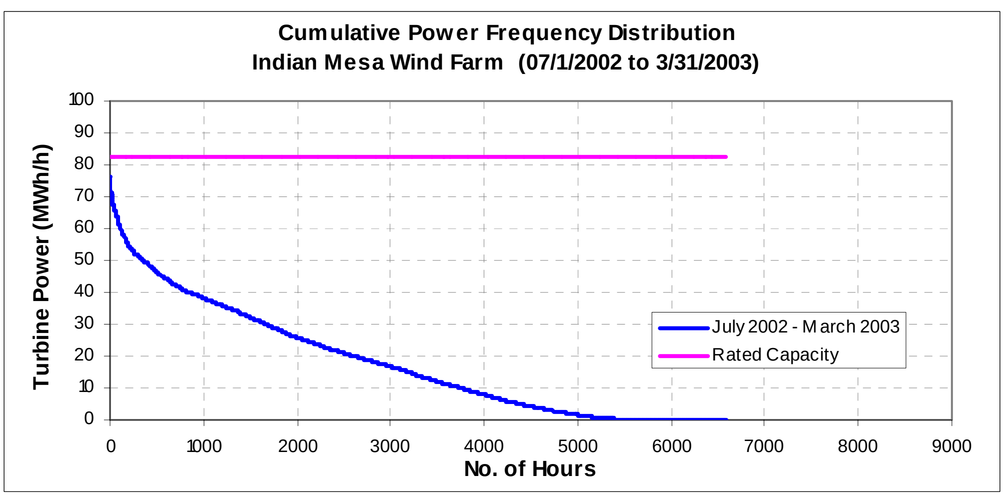

Figure 53: Cumulative Frequency Distribution (7/2002-3/2003), Pecos, Texas.

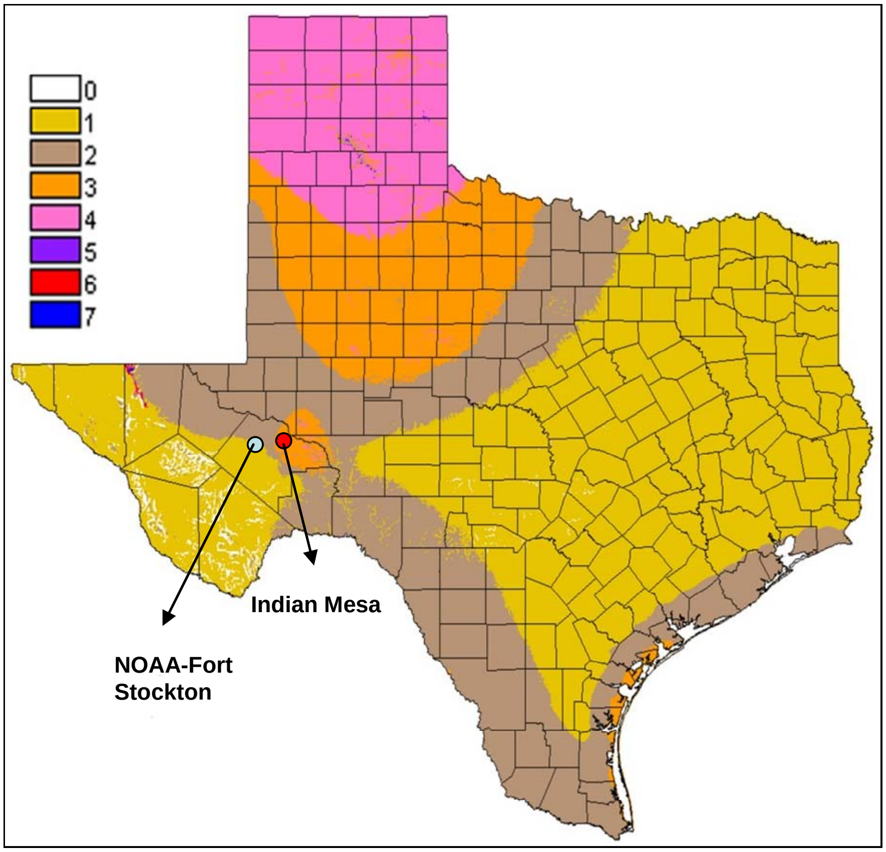

Figure 54: Wind Class Map – Texas

6.2 Wind Power Data

In Figure 55 the hourly electricity produced and measured through the ERCOT power grid from this wind farm is shown in time series for the July 2002 to March 2003 period. Figure 56 shows the daily turbine power generation summed from the hourly data. In Figure 57, the hourly wind power data were plotted against hourly, NOAA wind measurements. In Figure 58 the same hourly electricity data were plotted against the coincident on-site hourly wind data. In Figure 59, the average power was calculated for each "bin" of wind speed. This analysis shows significant deviation for wind speeds greater than 20 MPH. This is not surprising when considering multiple wind turbines in this wind farm and the regulation from the ERCOT.

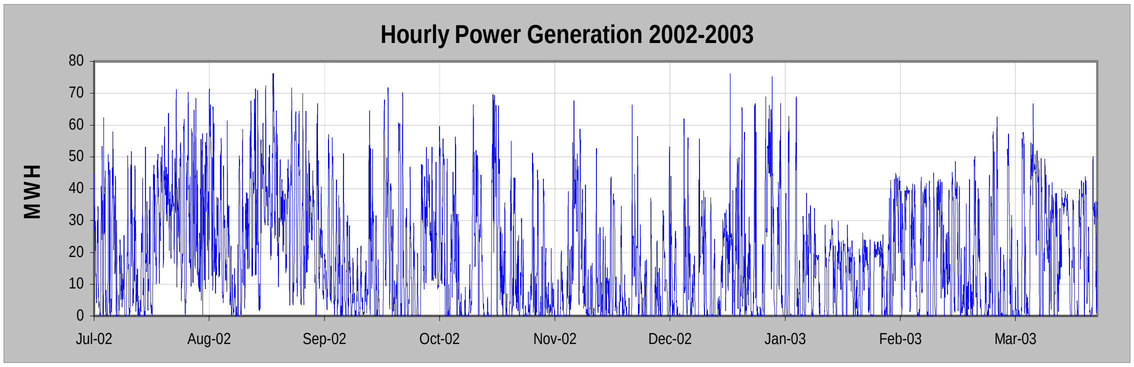

Figure 55: Measured Hourly Wind Power (2002-2003)

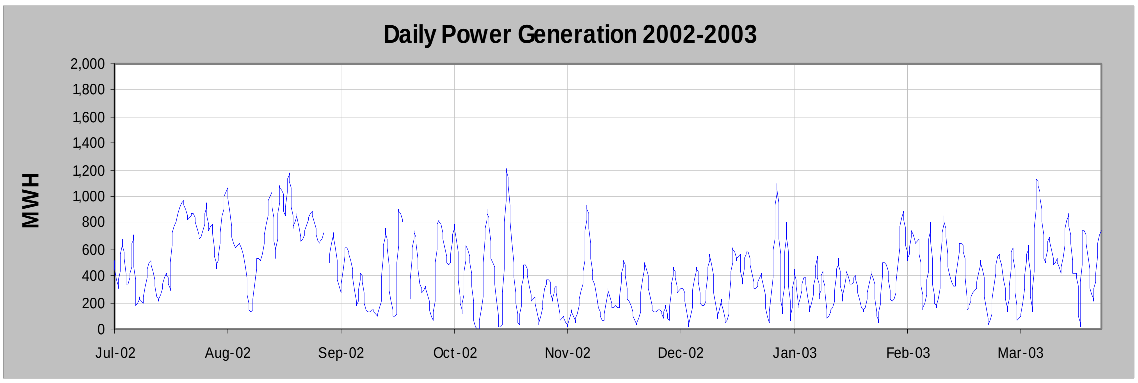

Figure 56: Measured Daily Wind Power (2002-2003)

In Figure 60 the hourly electricity produced by the wind farm were summed to daily totals and plotted against the daily average wind speed using the NOAA measurements. In Figure 61 the same hourly electricity produced by the wind farm was summed to daily totals and plotted against the daily average wind speed using on-site measurements. These two plots begin to show the variations in using the on-site versus NOAA wind speed data, in particular, the inability of the 3P model to track the change point. This is clear in Figure 60 and Figure 61. In Figure 61 the 3P model more accurately tracks the change point when regressed against the on-site wind speed data.

In Figure 62 the monthly average daily electricity produced by the wind farm were plotted against the average monthly wind speed per day from NOAA measurements, and in Figure 63 the same monthly average daily electricity produced were plotted against the average monthly wind speed per day from on-site measurements. In contrast to Figure 60 and Figure 61, Figure 62 and Figure 63 show better agreement in the two models, although there is still a variation in the slopes of the model. This feature was seen as a key to the development of the average daily model for a site with multiple wind turbines.

As seen in Figure 57 and Figure 58, the hourly wind power plotted against NOAA wind speed shows considerably more scatter due to differences in the wind velocity measurements, and physical separation of wind measurements from the wind farm[28]. As expected, these differences become less pronounced when one compares average daily electricity production against average daily wind measurements[29], as shown in Figure 60 and Figure 61[30]. Comparisons of the average daily production from monthly data have a similar

[28] The data shown in this plot represent the base data set received from ERCOT, which contain known meter problems. The data for the problematic data fall on the right of the normal performance cluster.
[29] Similar trends had been previously observed by Crowley and Haberl (1994).
[30] The predictions shown include reductions metered output due to curtailment and/or maintenance.

convergence as shown in Figure 62 and Figure 63 although there is a noticeable shift in the trend which is due to the higher recorded daily wind speeds for the average data versus the average-day, monthly data.

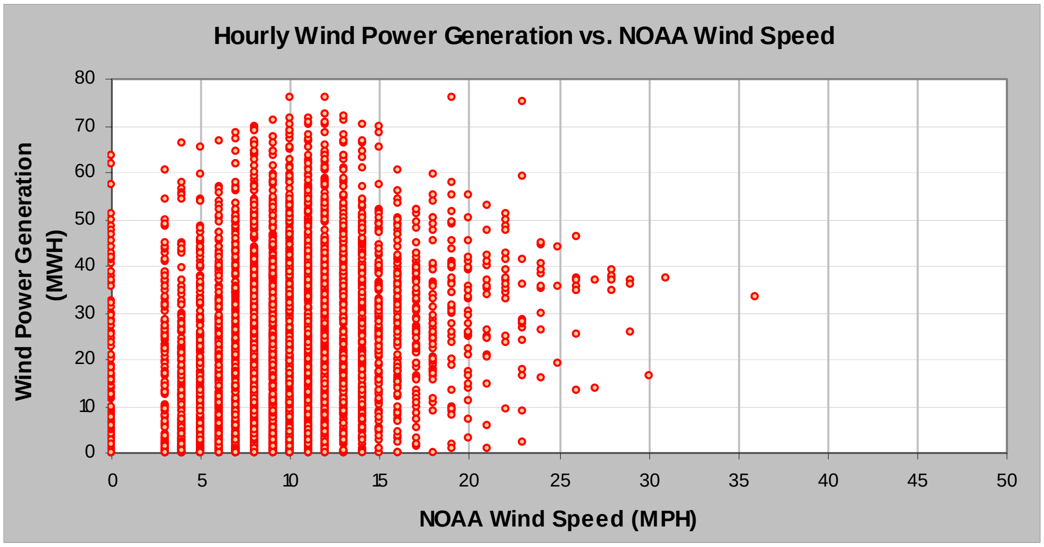

Figure 57: Hourly Wind Power vs. NOAA-FST Wind Speed

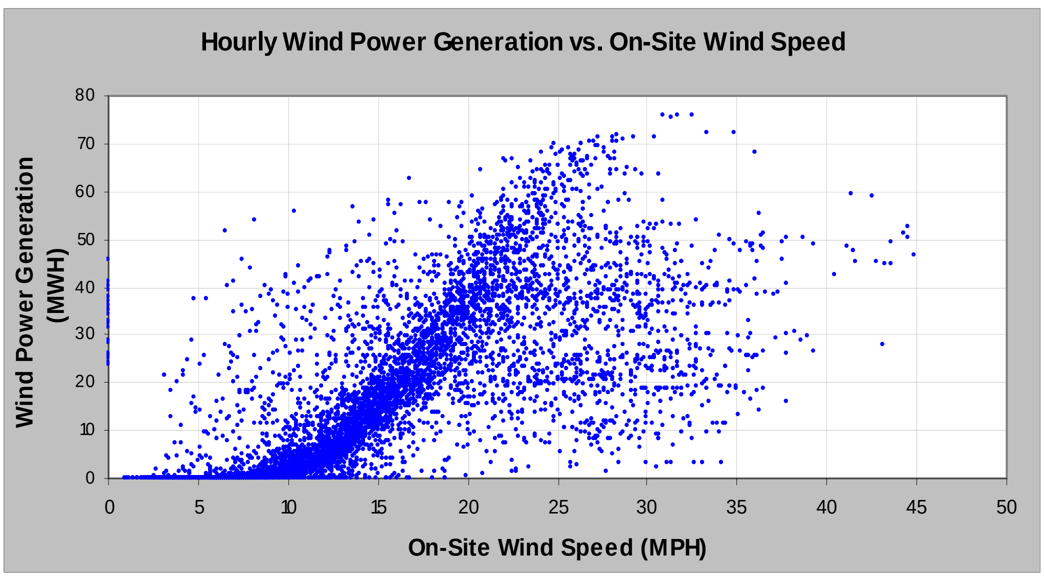

Figure 58: Hourly Wind Power vs. On-site Wind Speed

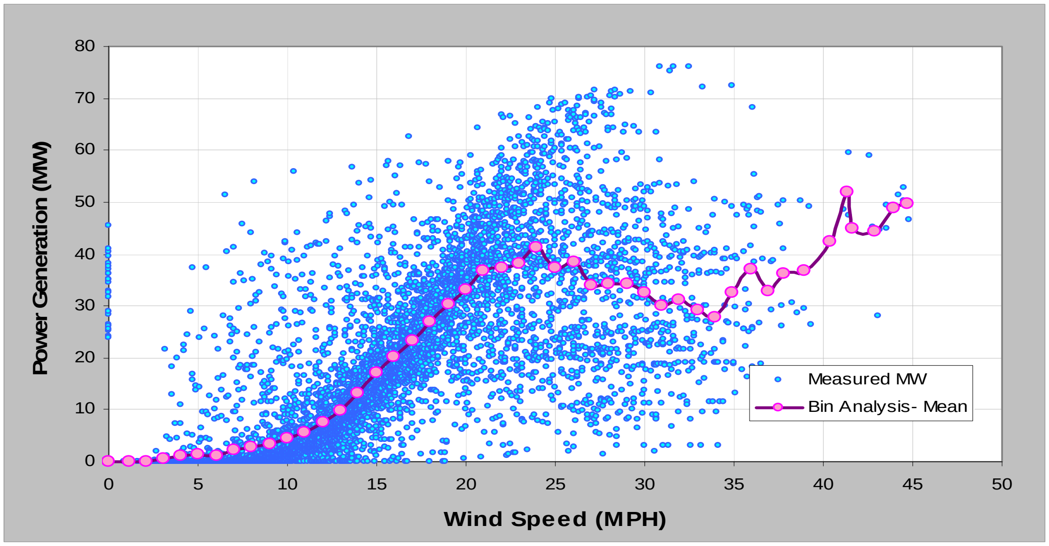

Figure 59: Hourly Wind Power Bin Analysis (On-site wind speed)

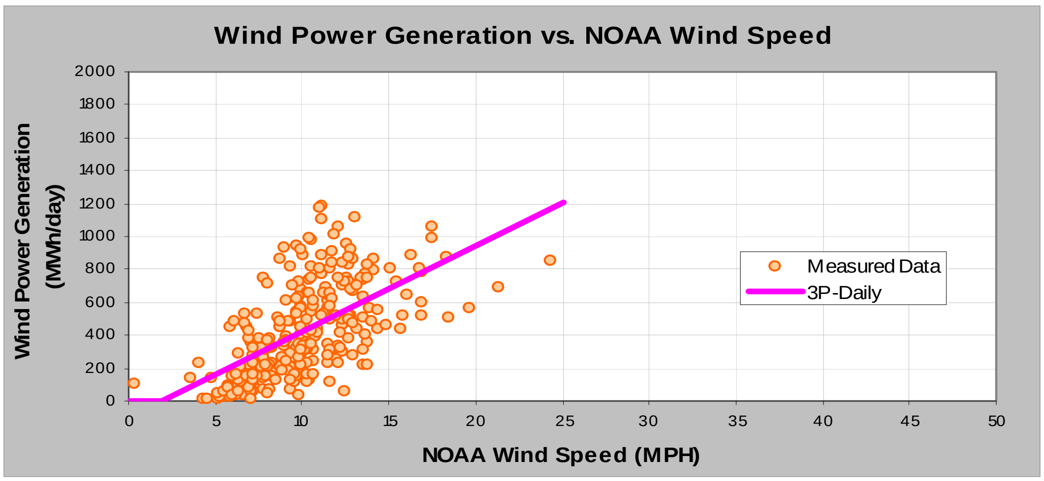

Figure 60: Daily Wind Power vs. NOAA-FST Wind Speed

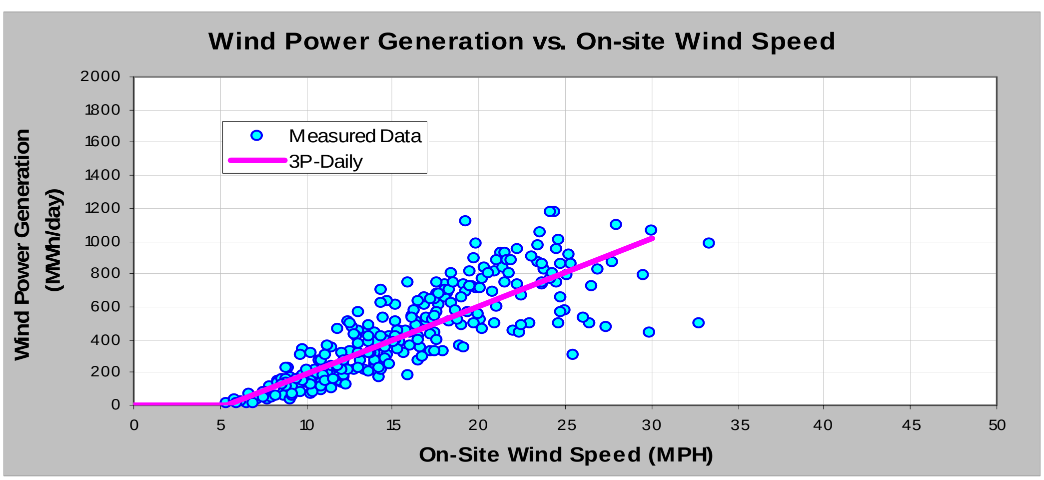

Figure 61: Daily Wind Power vs. On-site Wind Speed

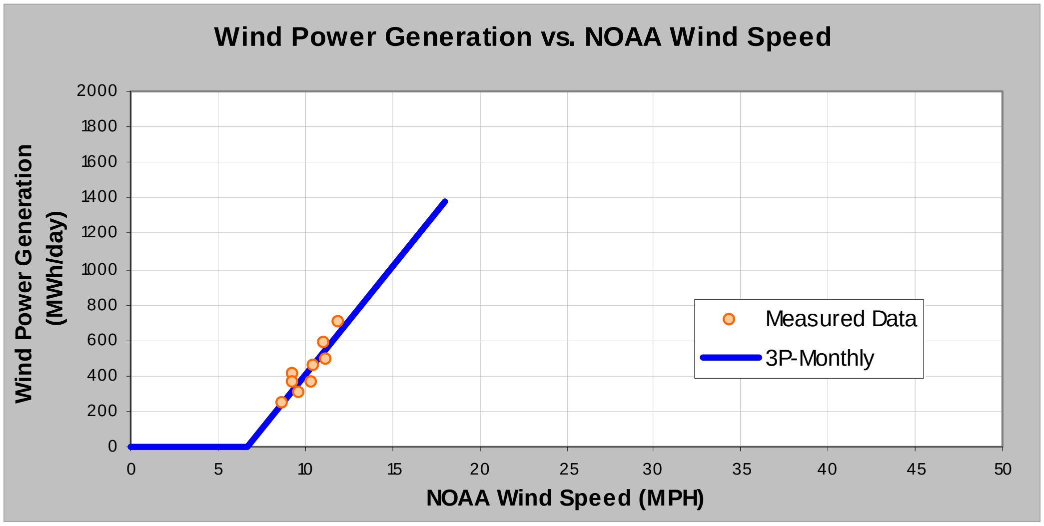

Figure 62: Monthly Daily Wind Power vs. NOAA-FST Wind Speed

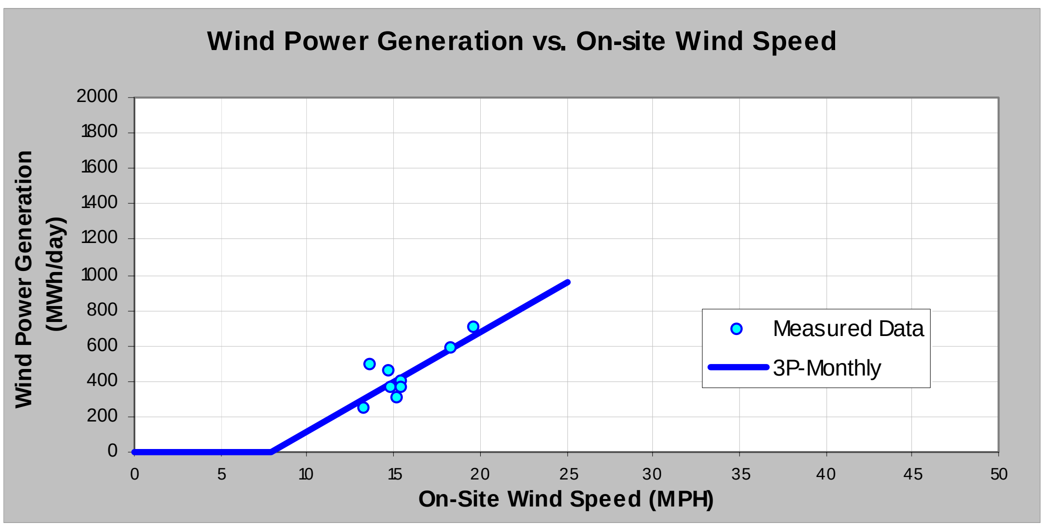

Figure 63: Monthly Daily Wind Power vs. On-site Wind Speed

6.3 Modeling of Turbine Power vs. Wind Speed

Application of a three-parameter change-point linear regression to the average daily wind power output versus average daily wind speeds using ASHRAE's IMT is shown in Figure 60 and Figure 61. The three-parameter change-point linear regression to the monthly average daily turbine power versus average monthly wind speeds per day are shown super-imposed on the monthly data in Figure 62 and Figure 63.

In Figure 64 and Figure 65, the monthly daily average models developed using NOAA and on-site wind measurements were applied to the average daily wind speed to compare against the corresponding daily models. For the NOAA daily and monthly models, there is a significant difference between the two models on change point and slope (Figure 64). Although this model appears to do a good job tracking the change-point and average daily wind speeds in the range of 5 to 15 mph it can significantly over-predict at wind speeds above 15 mph. Because of the much larger slope in the monthly model, when the wind speed exceeds about 17 mph, a maximum wind power output from the measured data was used to cap the model (i.e., the flattened slope on the top of the model) to help improve the model performance. For the on-site models, a smaller difference between the daily and monthly model was observed, but was not considered to be significant. The summary of the model coefficients from the daily and monthly daily models using NOAA and on-site wind measurements are listed in Table 16.

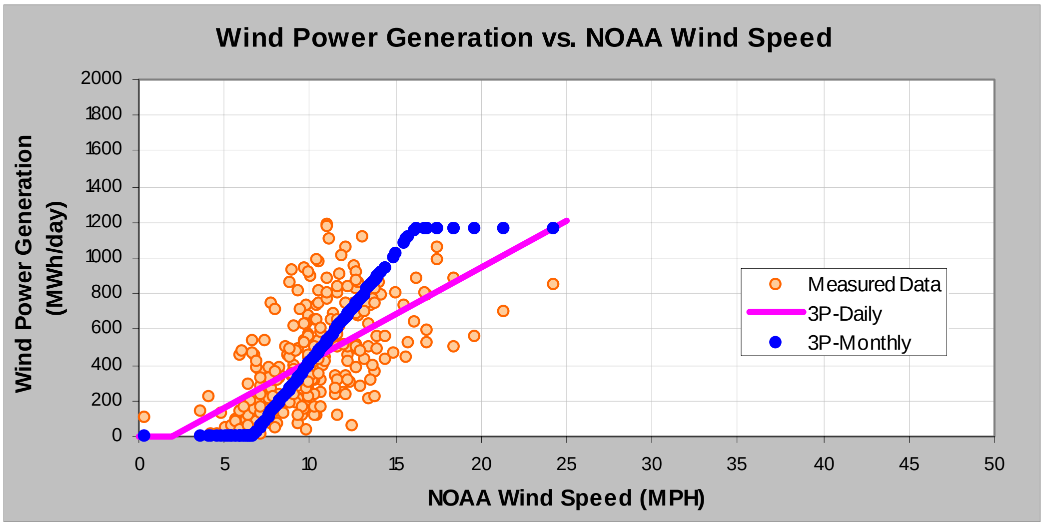

Figure 64: Comparison of Daily and Monthly Daily Models (NOAA-FST Wind Speed)

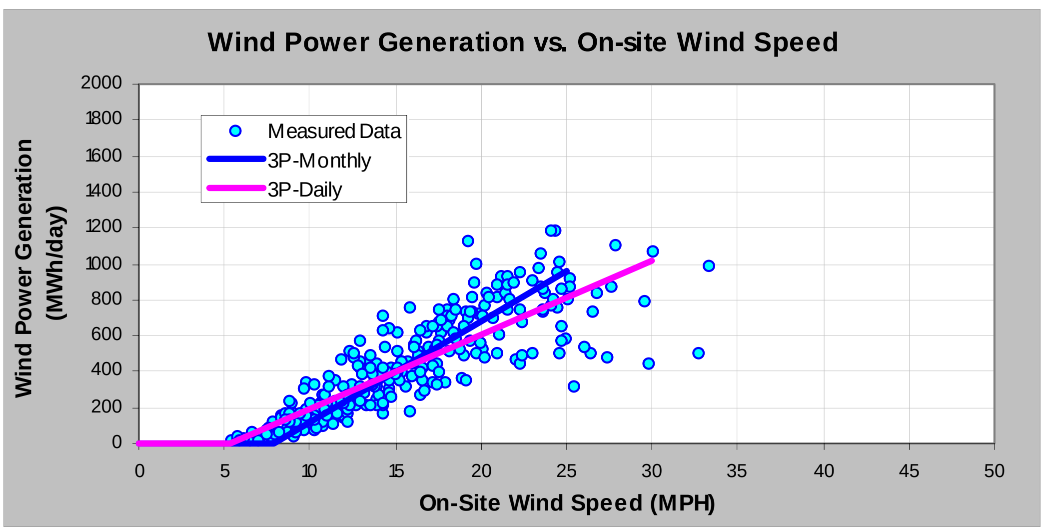

Figure 65: Comparison of Daily and Monthly Daily Models (On-site Wind Speed)

Table 16: Model Coefficients

IMT Coefficients	NOAA Daily Model	On-site Daily Model	NOAA Monthly Model	On-site Monthly Model
Ycp (MWh/day)	-0.0582	0.2017	0.0188	0.0188
Slope (MWh/mph-day)	52.2777	41.4171	122.6085	55.8136
Change Point (mph)	1.9440	5.3437	6.7080	7.8765
RMSE (MWh/day)	223.61	157.12	271.57	173.71

6.4 Prediction of Wind Power

The resultant coefficients (Table 16) from the 3-parameter models were sufficiently robust to allow for their use in projecting the daily average wind production into other weather base years. In Table 17 the predicted electricity production using the 3-parameter, change-point linear daily NOAA model and daily on-site model is shown for the 2002 to 2003 period to compare against the measured monthly electricity for the same period. The results showed that the NOAA daily model is moderately well described (Table 16) with a root-mean-squared error (RMSE) of 223.61 MWh/day for the 2002 to 2003 period for the NOAA daily model. The on-site daily model was better determined with a RMSE of 157.12 MWh/day for the 2002 to 2003 period. Table 17 shows that, on average, the models perform well, but still contain significant month-to-month variations, i.e., November 2002 and January 2003.

Table 18 shows the comparison of the measured and predicted electricity using the 3-paramter, change-point linear monthly daily NOAA model and monthly daily on-site model. The NOAA monthly average daily model shows an acceptable prediction when compared to the NOAA daily models.

In Figure 66 and Figure 67, the daily wind power output in November 2002 and March 2003 are shown in different color (blue) to help explain the month to month variation in the prediction using the daily or monthly models. In November, the data can be seen clustering nearer to the bottom of the plot (Figure 66) whereas in March (Figure 67), the data can be seen to be more distributed around the model predictions.

Figure 68 shows the predicted electricity production from the wind farm as a time-series trace for the Ozone Season Period (i.e., July 15 to September 15), using NOAA daily and monthly models. The measured power output for the same period is also presented for comparison. Figure 69 shows the predicted electricity production from the wind turbine as a time-series trace for the Ozone Season Period using on-site daily and monthly models.

Table 17: Predicted Wind Power Using Daily Models

Month	Avg. Daily Wind Speed (MPH) On-site	Avg. Daily Wind Speed (MPH) NOAA	Adjusted Measured Power (MWh/Mo) NOAA	Predicted Power Using Daily Model (MWh/mo) NOAA	Diff. NOAA	Adjusted Measured Power (MWh/Mo) On-site	Predicted Power Using Daily Model (MWh/mo) On-site	Diff. On-site
Jul-02	18.36	11.11	18,120	14,854	18.03%	18,120	16,706	9.52%
Aug-02	19.69	11.90	20,996	15,567	25.86%	20,996	18,588	15.47%
Sep-02	15.51	9.30	11,797	11,152	5.46%	11,973	12,638	-5.96%
Oct-02	14.82	9.36	11,194	12,015	-7.34%	11,194	12,173	-8.15%
Nov-02	13.32	8.76	7,282	10,695	-46.86%	7,042	9,575	-23.69%
Dec-02	15.44	10.39	11,086	13,688	-23.47%	11,086	12,963	-13.71%
Jan-03	15.18	9.70	9,602	12,569	-30.91%	9,602	12,624	-24.04%
Feb-03	14.72	10.46	12,674	12,472	1.59%	12,674	10,875	14.42%
Mar-03	13.72	11.24	13,771	13,601	1.24%	13,771	9,711	29.85%
Total			116,523	116,614	-0.08%	116,458	115,854	0.65%

Table 18: Predicted Wind Power Using Monthly Average Daily Models

Month	No. Of Days	Avg. Daily Wind Speed (MPH) On-site	Avg. Daily Wind Speed (MPH) NOAA	Adjusted Measured Power (MWh/day) NOAA	Adjusted Measured Power (MWh/ day) On-site	Predicted Power Using Monthly Model (MWh/mo) NOAA	Diff. NOAA	Predicted Power Using Monthly Model (MWh/ mo) On-site	Diff. On-site
Jul-02	31	18.36	11.11	585	585	16,730	7.67%	18,131	-0.06%
Aug-02	31	19.69	11.90	700	700	18,665	11.10%	20,809	0.89%
Sep-02	30	15.51	9.30	407	393	9,391	20.39%	12,790	-6.82%
Oct-02	31	14.82	9.36	361	361	10,690	4.50%	12,489	-11.57%
Nov-02	30	13.32	8.76	243	251	9,396	-29.02%	8,930	-26.81%
Dec-02	31	15.44	10.39	358	358	13,698	-23.56%	13,156	-18.67%
Jan-03	31	15.18	9.70	310	310	11,741	-22.28%	12,647	-31.71%
Feb-03	28	14.72	10.46	453	453	13,030	-2.81%	10,812	14.69%
Mar-03	28	13.72	11.24	492	492	13,947	-1.28%	9,301	32.46%
Total						117,288	-0.66%	119,064	-2.24%

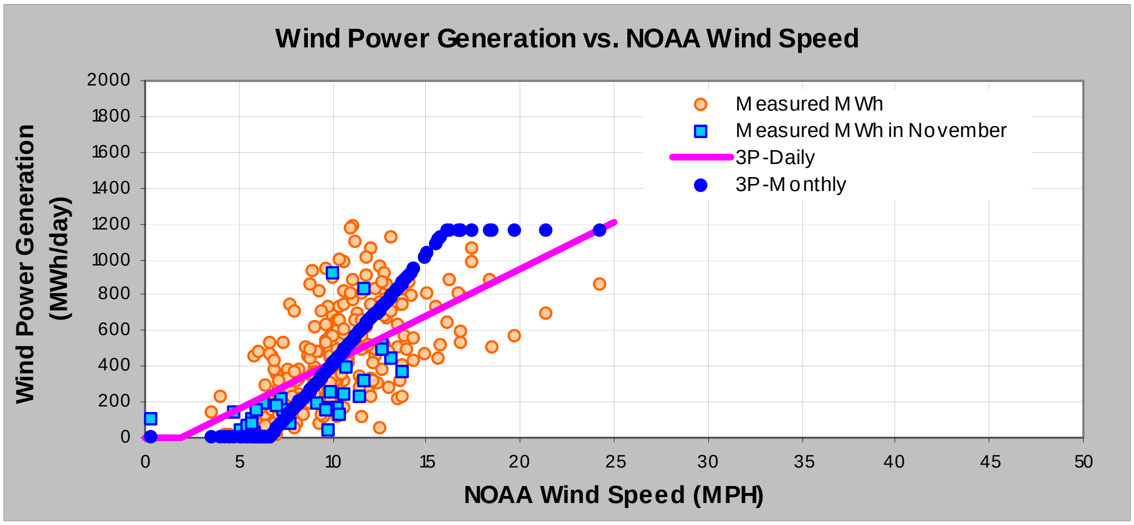

Figure 66: Measured Daily Wind Power – November 2002 (NOAA-FST Wind Speed)

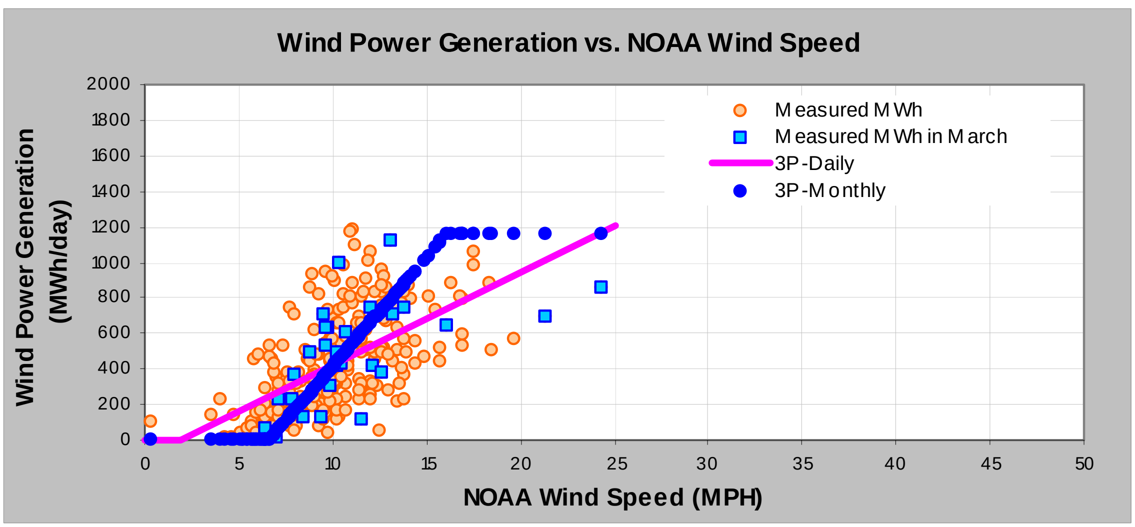

Figure 67: Measured Daily Wind Power – March 2003 (NOAA-FST Wind Speed)

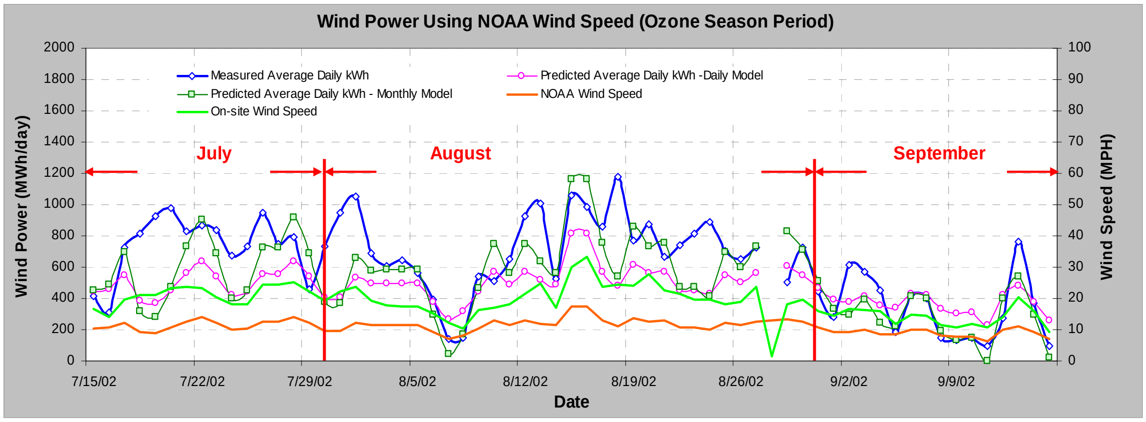

Figure 68: Predicted Wind Power in OSD Using NOAA-FST Wind Speed

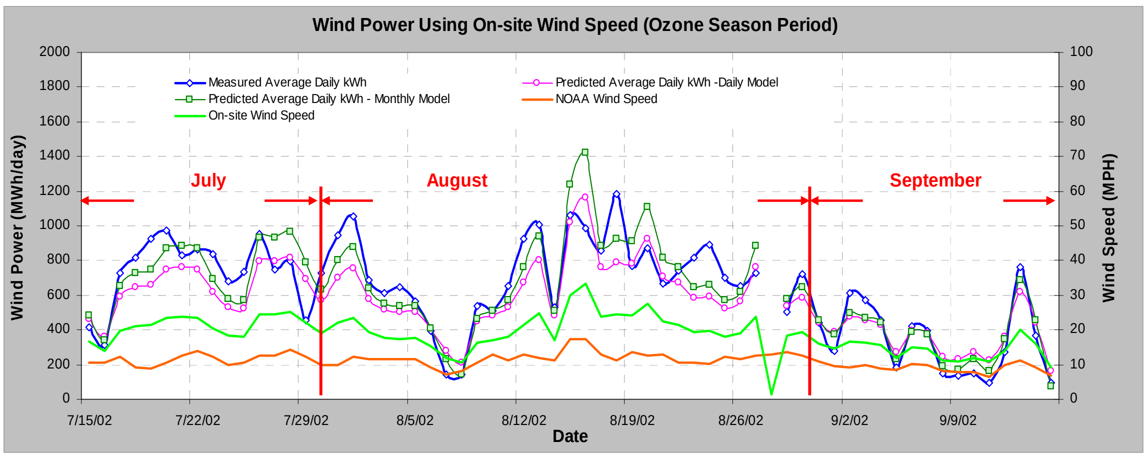

Figure 69: Predicted Wind Power in OSD Using On-site Wind Speed

7 TESTING OF THE MODELS

To test the performance of the NOAA daily and monthly model, these two models were applied to 2002, 2003, and 2004 NOAA daily wind speed to predict the daily wind power generation for these three years. The predicted daily wind power were then summed to monthly to compare against the monthly measurements from ERCOT, as shown in Table 19, Table 20, and Table 21. The test results show that both models are robust enough to allow for their use in projecting wind production into other weather base years, although significant outliers remain in either model.

Table 19: Predicted vs. Measured Wind Power in 2002

Month	2002 Predicted MWh/mo Using Daily Model	2002 Predicted MWh/mo Using Monthly Model	2002 Measured-ERCOT MWh/mo	2002 Diff. Daily Model	2002 Diff. Monthly Model
Jan	13,215	13,396	14,466	8.7%	7.4%
Feb	13,490	15,125	12,667	-6.5%	-19.4%
Mar	15,887	18,885	16,185	1.8%	-16.7%
Apr	17,239	21,504	16,446	-4.8%	-30.8%
May	19,935	25,350	19,069	-4.5%	-32.9%
Jun	18,350	23,755	18,579	1.2%	-27.9%
Jul	14,848	16,716	18,120	18.1%	7.8%
Aug	16,123	19,380	21,795	26.0%	11.1%
Sep	9,715	9,439	11,973	18.9%	21.2%
Oct	12,007	10,697	11,194	-7.3%	4.4%
Nov	11,182	9,765	7,282	-53.5%	-34.1%
Dec	12,739	11,748	11,086	-14.9%	-6.0%
Total	174,729	195,758	178,865	2.3%	-9.4%

Table 20: Predicted vs. Measured Wind Power in 2003

Month	2003 Predicted MWh/mo Using Daily Model	2003 Predicted MWh/mo Using Monthly Model	2003 Measured-ERCOT MWh/mo	2003 Diff. Daily Model	2003 Diff. Monthly Model
Jan	12,563	11,726	9,602	-30.8%	-22.1%
Feb	12,472	13,036	12,674	1.6%	-2.9%
Mar	14,823	15,056	14,680	-1.0%	-2.6%
Apr	16,459	20,673	17,306	4.9%	-19.5%
May	13,493	13,537	13,409	-0.6%	-1.0%
Jun	15,633	18,882	16,950	7.8%	-11.4%
Jul	15,542	18,300	20,673	24.8%	11.5%
Aug	14,327	15,541	16,798	14.7%	7.5%
Sep	13,001	13,706	14,385	9.6%	4.7%
Oct	12,168	10,974	10,978	-10.8%	0.0%
Nov	13,049	13,513	15,214	14.2%	11.2%
Dec	14,635	15,796	19,478	24.9%	18.9%
Total	168,163	180,741	182,145	7.7%	0.8%

Table 21: Predicted vs. Measured Wind Power in 2004

Month	2004 Predicted MWh/mo Using Daily Model	2004 Predicted MWh/mo Using Monthly Model	2004 Measured-ERCOT MWh/mo	2004 Diff. Daily Model	2004 Diff. Monthly Model
Jan	12,133	11,780	14,646	17.2%	19.6%
Feb	14,381	15,203	14,342	-0.3%	-6.0%
Mar	15,029	16,390	16,545	9.2%	0.9%
Apr	15,383	17,975	19,587	21.5%	8.2%
May	17,911	23,278	25,836	30.7%	9.9%
Jun	15,896	19,295	20,270	21.6%	4.8%
Jul	16,267	19,790	13,609	-19.5%	-45.4%
Aug	12,216	10,562	9,702	-25.9%	-8.9%
Sep	11,913	10,916	14,154	15.8%	22.9%
Oct	11,333	9,313	12,235	7.4%	23.9%
Nov	12,092	10,911	13,604	11.1%	19.8%
Dec	12,588	11,775	18,737	32.8%	37.2%
Total	167,144	177,187	193,268	13.5%	8.3%

7.1 Capacity Factor Analysis

The predicted monthly capacity factors for the period July 2002 to March 2003 using the daily NOAA and on-site models and monthly NOAA and on-site models, as well as the measured monthly capacity factors for the same period are shown in Figure 70 and Figure 71. Figure 72 and Figure 73 show the predicted monthly capacity factors from January to December for the periods 1999 through 2005, as well as the measured monthly capacity factor during 2002 to 2003 and the average monthly capacity factors for these seven years, using daily NOAA model and monthly NOAA model. In Figure 70 and Figure 71 both models show good agreement tracking the measured capacity factor. In comparison, in Figure 72 and Figure 73, it can be seen that there is more variation in the year to year wind speeds than the uncertainty from the model. Figure 72 and Figure 73 also show the importance of weather normalizing the wind speeds back to the base year.

As sheen in Table 22, if predicted with NOAA daily model, the annual capacity factors for these years vary from 20.3% to 28.1%, with an average of 23.8%. The highest electricity production occurs in the spring months. It is interesting to note that the variation across the same month of these years can be more than 10%, for example, August, due to the significantly different wind conditions. On average, the wind farm has a 20% to 28% capacity factor, varying from a low of 20% in September to almost 28% in April. In general, the capacity factors predicted with the NOAA monthly model are higher than the prediction using the NOAA daily model. The variations from the model-predicted monthly use are well within the variation of the wind farm's measured output, which can be seen by comparing the measured 2002-2003 production against the modeled production.

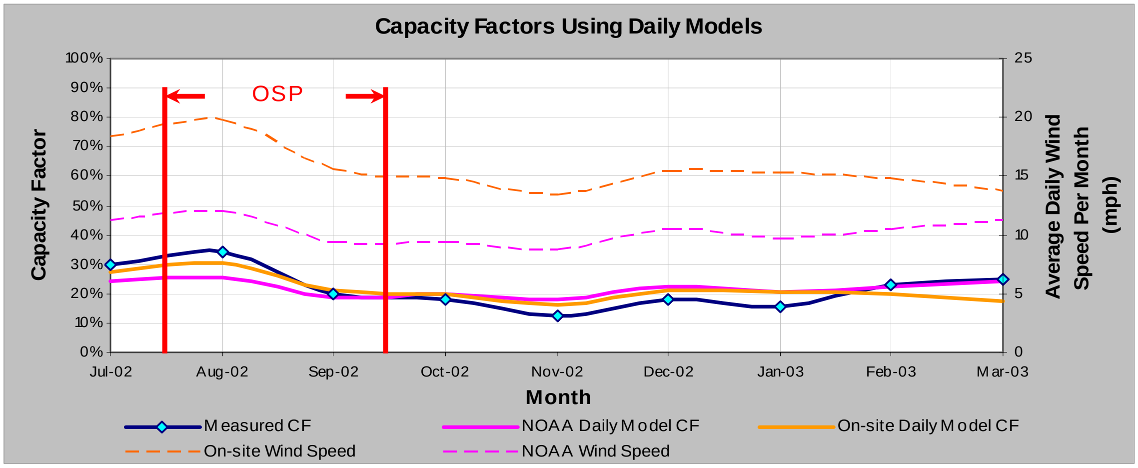

Figure 70: Predicted Capacity Factors Using Daily Models (2002-2003)

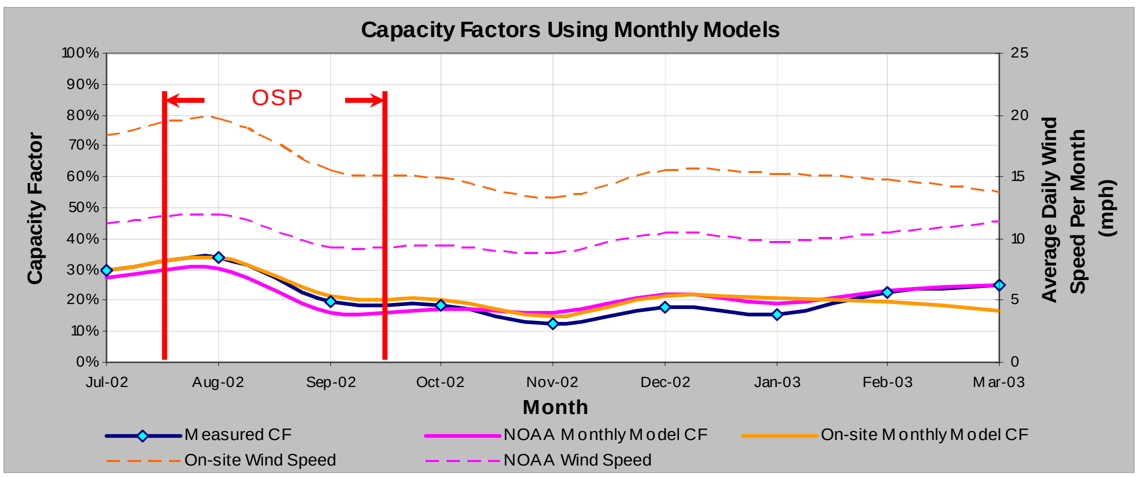

Figure 71: Predicted Capacity Factors Using Monthly Daily Models (2002-2003)

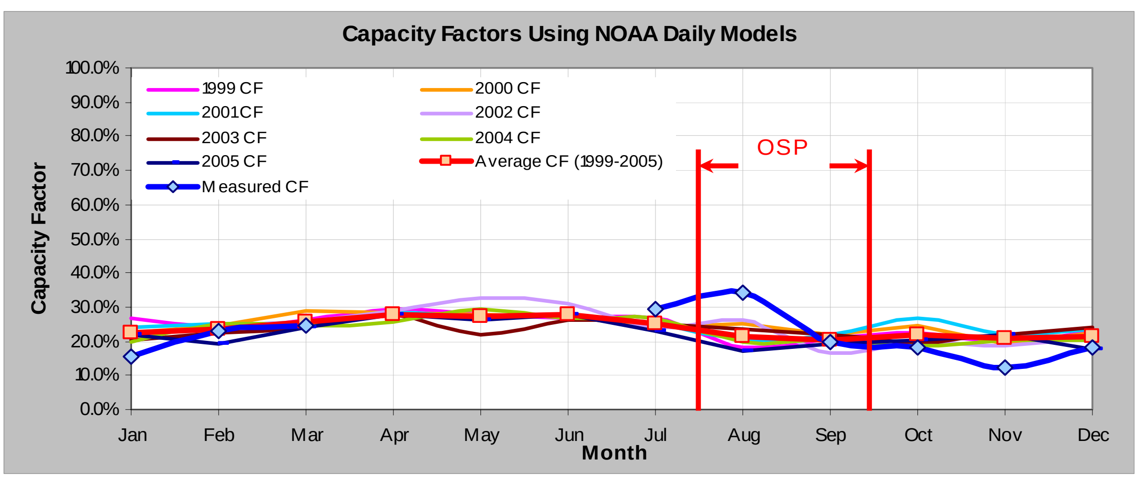

Figure 72: Predicted Capacity Factors Using Daily Models (1999-2005)

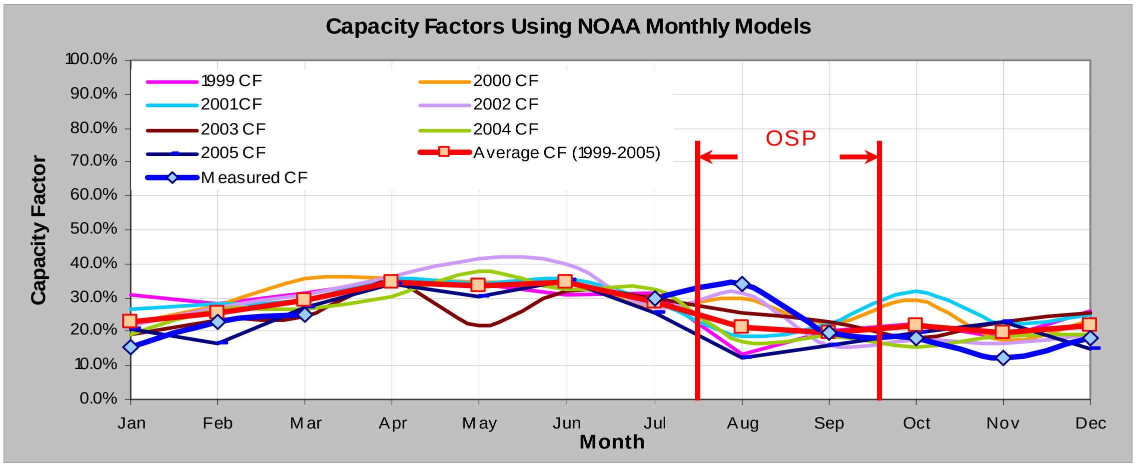

Figure 73: Predicted Capacity Factors Using Monthly Daily Models (1999-2005)

Table 22: Summary of Capacity Factors (1999-2005)

	NOAA Annual Average Wind Speed (MPH)	Annual Capacity Factor - NOAA Daily Model	Annual Capacity Factor - NOAA Monthly Model
1999	10.5	24.3%	26.8%
2000	11.0	24.7%	28.2%
2001	11.3	24.8%	28.2%
2002	8.9	24.2%	27.1%
2003	10.8	23.3%	25.0%
2004	10.7	23.1%	24.5%
2005	10.3	22.2%	22.9%
Measured (Jul. 02-Mar. 03)	10.2	21.7%	21.9%
Average (1999-2005)	10.5	23.8%	26.1%

7.2 Corrections to NOAA Wind Data.

As discussed in the previous section, the NOAA wind measurements at Fort Stockton Pecos County Airport were found to vary significantly from on-site measurements, as shown in Figure 50, Figure 51 and Figure 52. Therefore, to improve the projection of the site's wind speed, a linear regression was performed to find a correlation between the airport and the site, as shown in Figure 74. Since the hourly and daily wind speeds are often too erratic to establish a correlation between the two sites, average weekly speeds were used in the regression to correct the NOAA wind speeds to more accurately reflect the on-site wind speeds.

Figure 75 shows the comparison between the on-site average daily wind measurements and the projected average daily wind speed for the site. The wind distribution from the projected site wind speed was shown in Figure 76 and Figure 77 to compare against the distribution of on-site wind speed. In these figures, the shift in the bins can be clearly seen when compared to Figure 52.

Figure 78 shows the developed three parameter regression models based on the corrected daily wind data and corrected average daily monthly data. In Table 23, the predicted wind power using daily and monthly model developed using corrected NOAA wind speed were compared against the predicted wind power using daily and monthly model developed using NOAA wind speed. Unfortunately, this analysis showed that using the corrected NOAA wind speed for the modeling did not substantially improve the accuracy of the prediction on this training data set. Therefore, further analysis with other testing data sets will be needed to determine if the performance of the model can be improved with more sophisticated correction methods, for example, neural networks.

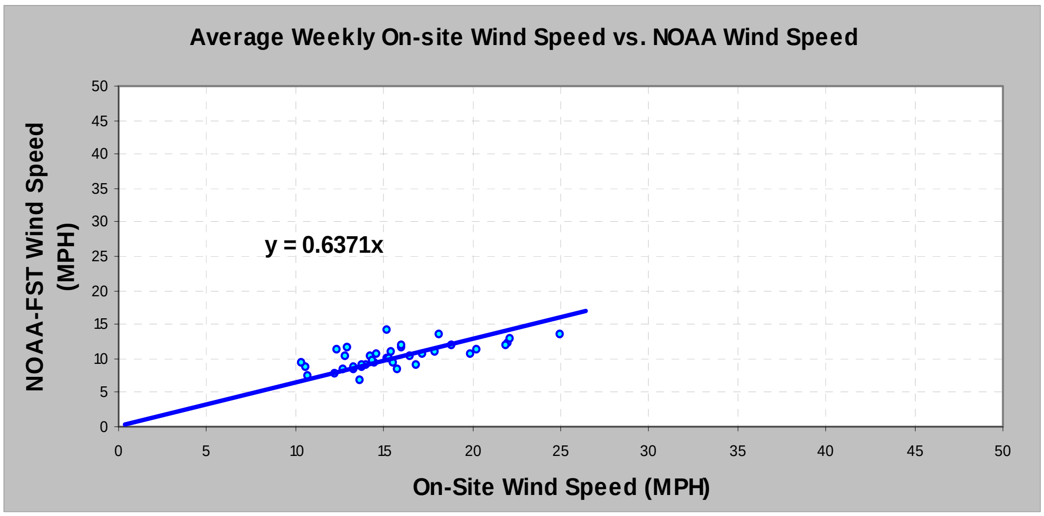

Figure 74: Linear Regression Model to Project Site Wind Speed

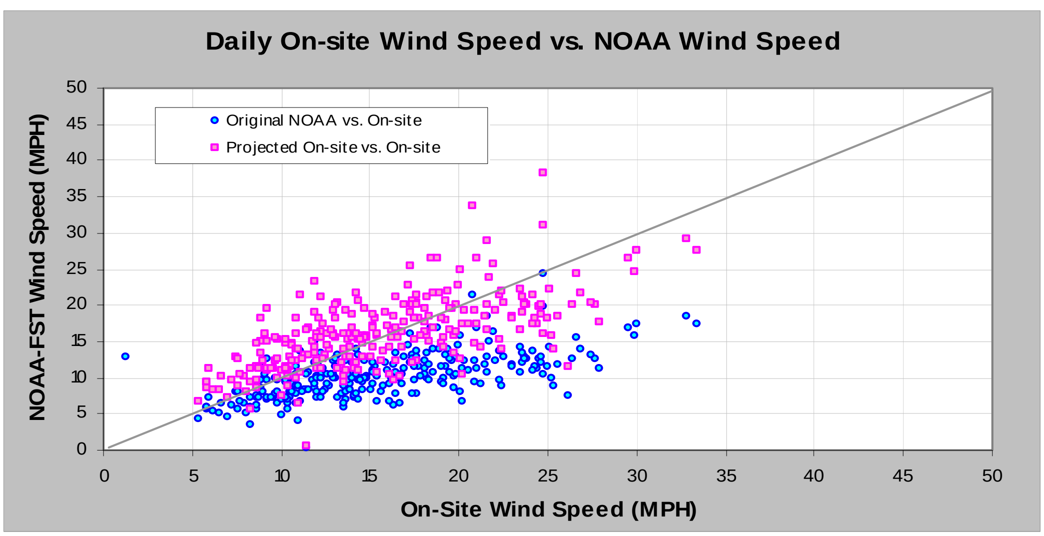

Figure 75: Projected Site Wind Speed vs. On-site Measurement

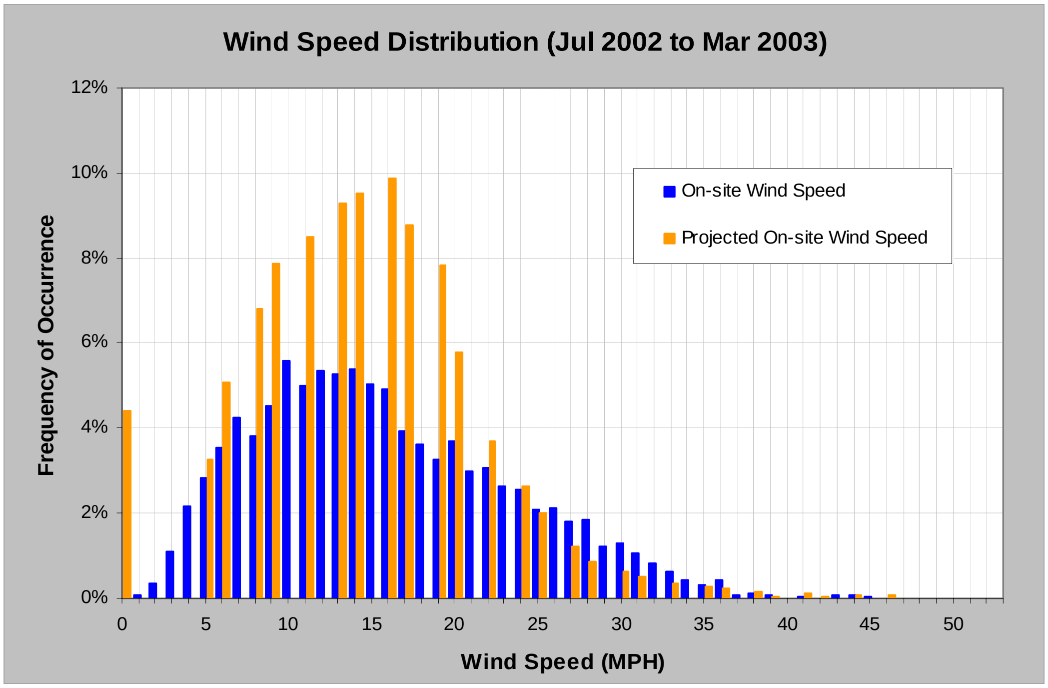

Figure 76: Wind Distribution Using 1MPH Bin

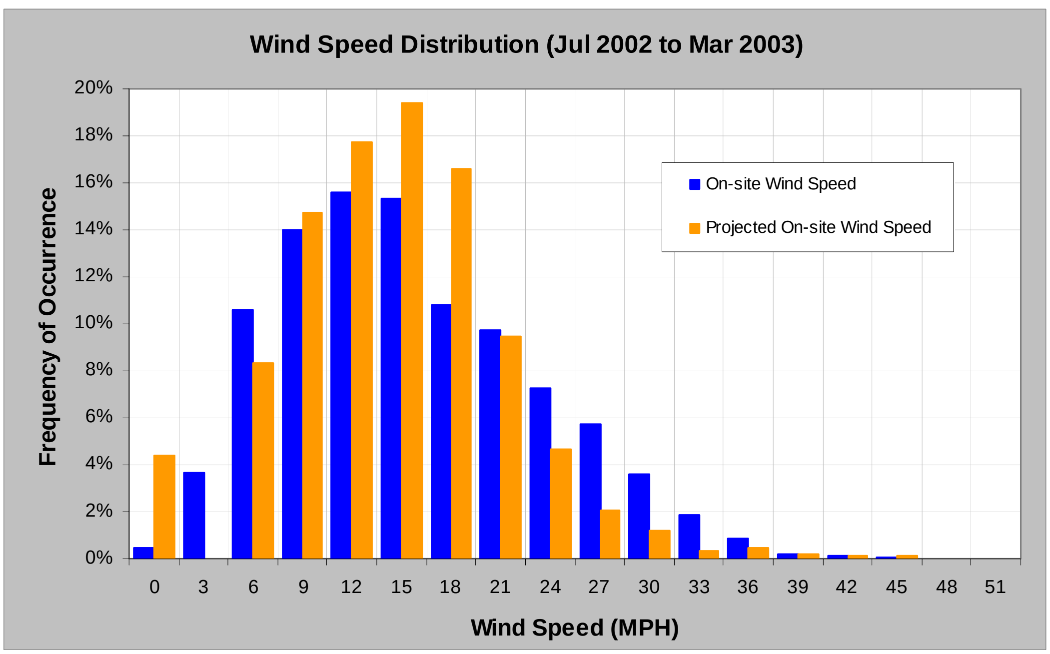

Figure 77: Wind Distribution Using 3 MPH Bin

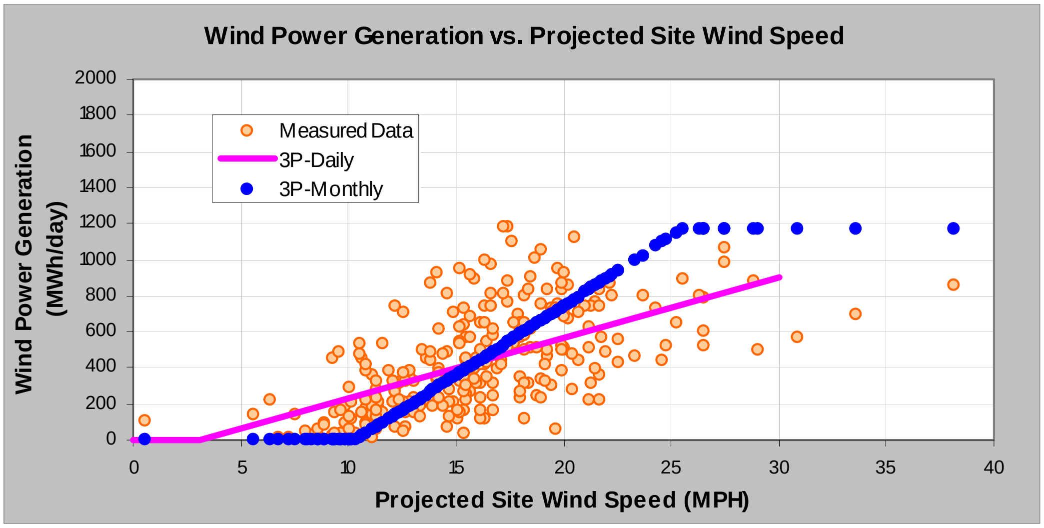

Figure 78: 3P Monthly and Daily Models Developed Using Corrected NOAA Wind Speed

Table 23: Comparison of Corrected Prediction on Wind Power

Month	No. Of Days	Avg. Daily Wind Speed (MPH) Projected	Average Daily Wind Speed (MPH) NOAA	Measured Power Generation (MWh/day)	Diff - Projected vs. Measured Daily Model	Diff - NOAA vs. Measured Daily Model	Diff - Projected vs. Measured Monthly Model	Diff - NOAA vs. Measured Monthly Model
Jul-02	31	17.44	11.11	585	18.14%	18.03%	7.75%	7.67%
Aug-02	31	18.63	11.90	700	25.96%	25.86%	11.25%	11.10%
Sep-02	30	14.60	9.30	407	5.59%	5.46%	19.93%	20.39%
Oct-02	31	14.69	9.36	361	-7.19%	-7.34%	4.21%	4.50%
Nov-02	30	13.76	8.76	243	-46.66%	-46.86%	-29.27%	-29.02%
Dec-02	31	16.31	10.39	358	-23.30%	-23.47%	-24.02%	-23.56%
Jan-03	31	15.23	9.70	310	-30.73%	-30.91%	-22.75%	-22.28%
Feb-03	28	16.42	10.46	453	1.73%	1.59%	-2.91%	-2.81%
Mar-03	28	17.64	11.24	492	1.37%	1.24%	-1.39%	-1.28%
Total	271				0.06%	-0.08%	-0.81%	-0.66%

8 WEATHER DATA

8.1 Expansion of the weather data to include all ERCOT counties using 17 Weather Stations.

In order to calculate the NO_x emissions from energy efficiency and renewable energy (EE/RE) projects in non-attainment and affected counties in Texas (Figure 79) data from several weather data sets were required from the many different weather sources (Figure 80, Figure 81, Table 24, and Figure 82), to generate hourly weather data sets. These weather data sets were then used for the wind energy analysis as wall as the other analysis, for example the DOE-2 simulations and daily average weather data for analysis that used monthly utility billing data.

To accomplish this, the counties were grouped according to the nearest TMY2 weather station as shown in Table 25. Next, for each group, weather files were determined for F-CHART, PV F-CHART, ASHRAE 90.1-1989, and ASHRAE 90.1-1999 analysis. Finally, as shown in Table 26, weather files were assigned for NOAA data (temperature, humidity, wind speed) and NREL (solar radiation). In some instances, where solar radiation data were not available from the NREL database, TCEQ solar data were used. For NREL solar sources, solar data included global horizontal, direct normal beam, and diffuse solar radiation. Unfortunately, for TCEQ solar sources, only global horizontal solar radiation data were available which required synthesis of direct normal beam and diffuse radiation using the Erbs' correlation (1982). Synthetic beam and diffuse solar data were also used to fill missing NREL data.

In 2005, at the request of the TCEQ, the 9 weather stations assembled for calculating emissions from the non-attainment and affected counties were expanded to include all counties in ERCOT (Figure 83). To accomplish this, 8 additional weather stations were added to the original 9 stations for a total of 17 weather stations (Table 27). Assignment of weather stations was then performed as shown in Table 28, with additional details provided in Table 29. Figure 80 shows an updated map of Texas showing the available weather files, 2000/2001 IECC weather zones, and ERCOT county outline. Figure 81 shows the clustering of the counties around their chosen TMY2 and NOAA weather stations. Figure 82 shows the 2000/2001 and 2006 IECC weather zones and available weather files.

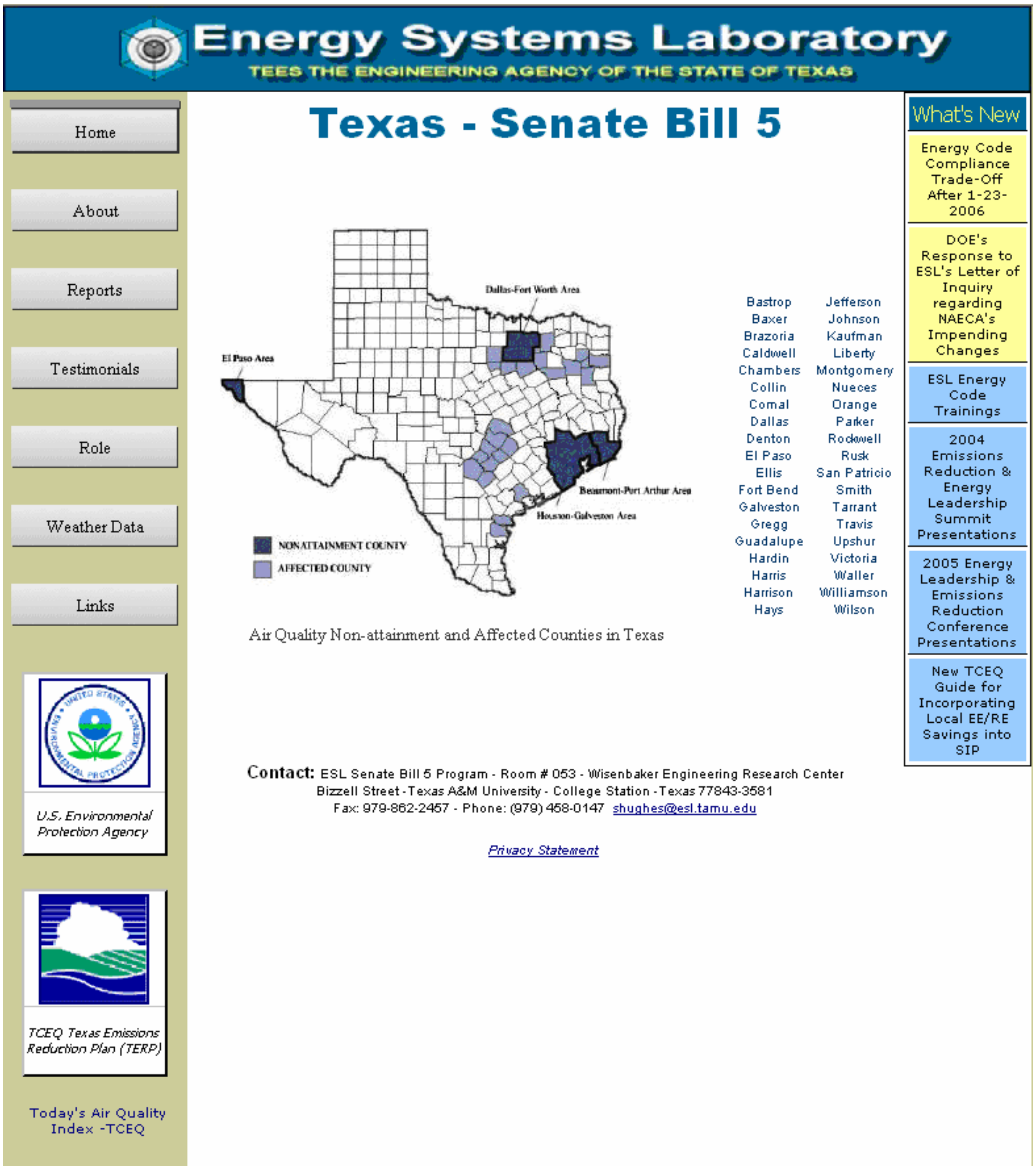

Figure 79 Main screen of the Senate Bill 5 web page showing the new Weather Data button

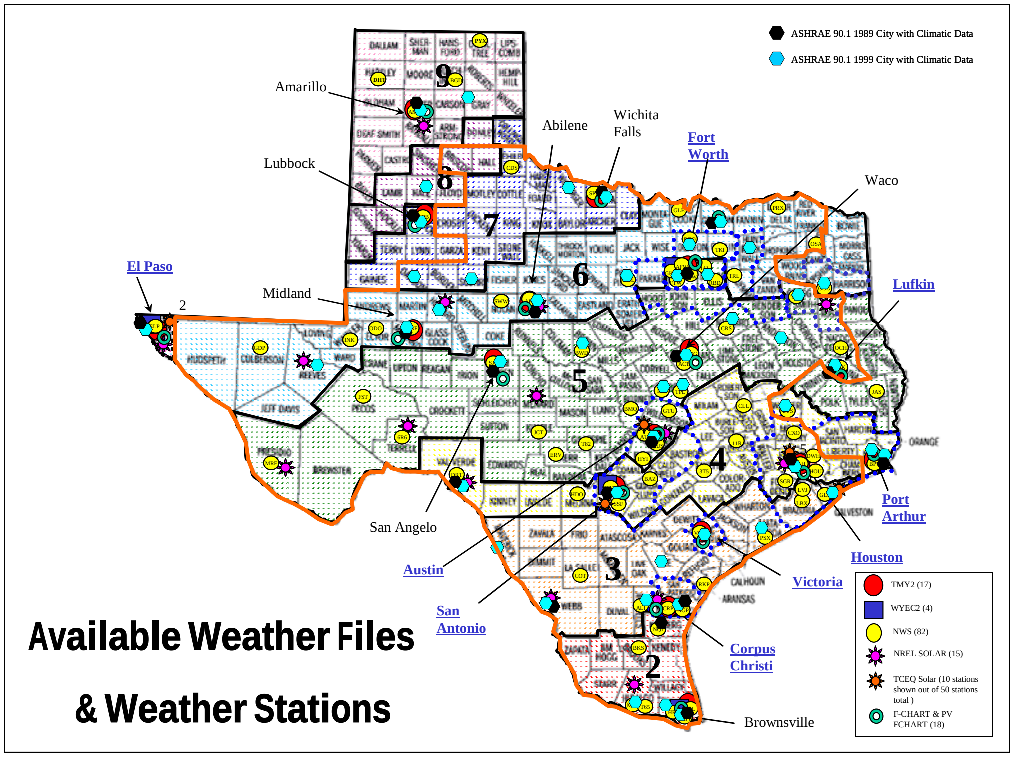

Figure 80: Available Weather Stations in Texas for all ERCOT Counties.

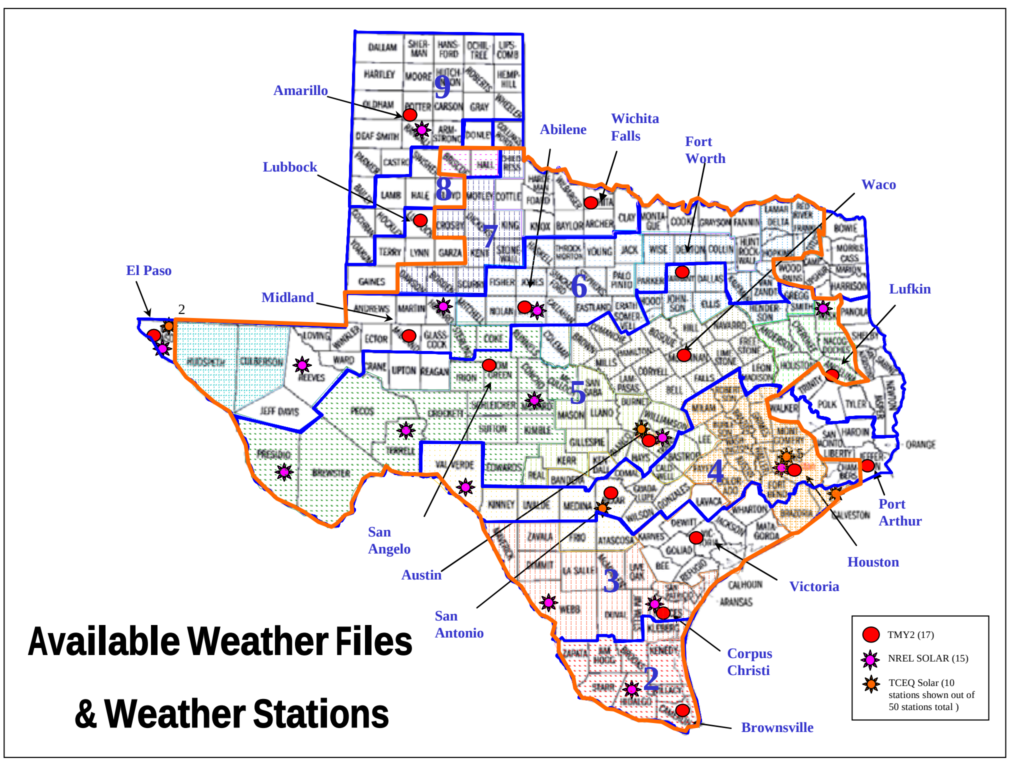

Figure 81: Grouping of Weather Stations in Texas for all ERCOT Counties.

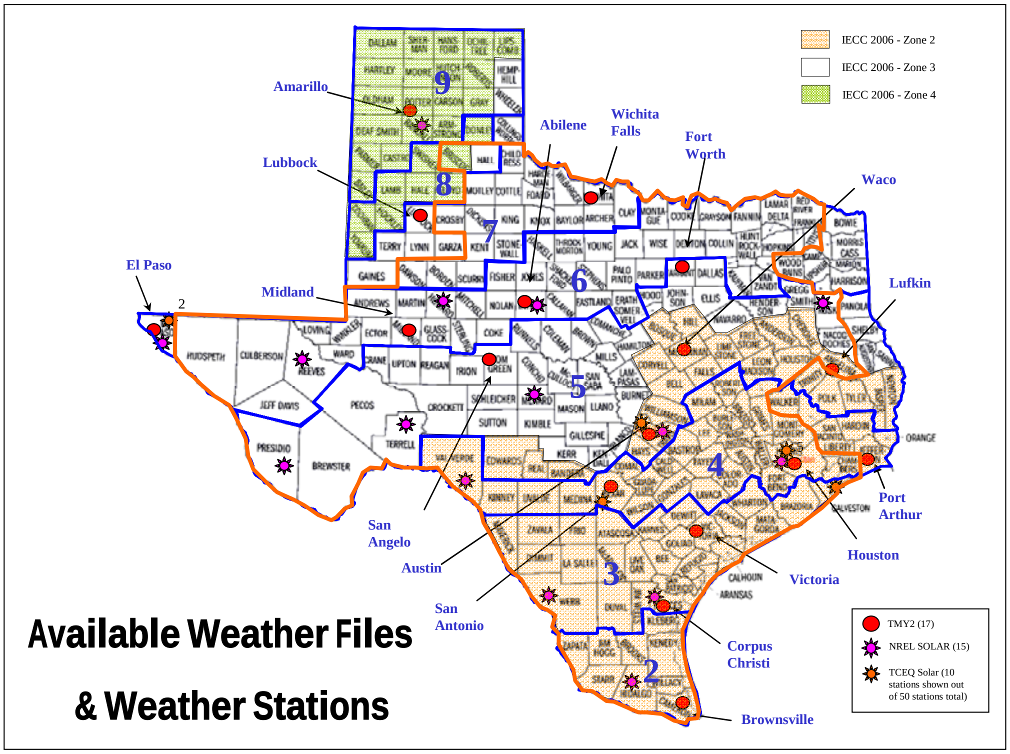

Figure 82 Available Weather Stations in Texas for all ERCOT Counties Showing 2000/2001 and 2006 Climate Zones.

Table 24: Symbols Description of the Available Weather Stations in Texas Maps.

List of Available Weather Files and Weather Stations of Texas

Texas Weather Stations (NOAA)

1	Abilene Regional Airport (ABI)
2	Alice International Airport (ALI)
3	Amarillo International Airport (AMA)
4	Angleton / Lake Jackson Brazori (LBX)
5	Arlington Municipal Airport (GKY)
6	Austin - Bergstrom International (AUS)
7	Austin Camp Mabry (ATT)
8	Borger Hutchinson County Airport (BGD)
9	BRENHAM: BRENHAM MUNICIPAL AIRPORT (11R)
10	Brownsville S Padre Isl International (BRO)
11	BROWNWOOD: BROWNWOOD REGIONAL AIRPORT (BWD)
12	Burnet Municipal Airport (BMQ)
13	Childress Municipal Airport (CDS)
14	College Station (CLL)
15	Conroe Montgomery County Airport (CXO)
16	Corpus Christi International Airport (CRP)
17	CORPUS CHRISTI: CORPUS CHRISTI NAS/TRUAX FIELD ARPT (NGP)
18	Corsicana Campbell Field (CRS)
19	Cotulla La Salle Co Airport (COT)
20	Dalhart Municipal Airport (DHT)
21	Dallas - Fort Worth International Airport (DFW)
22	Dallas Love Field (DAL)
23	Dallas Redbird Airport (RBD)
24	Del Rio International Airport (DRT)
25	Denton Municipal Airport (DTO)
26	Dryden Terrell County Airport (6R6)
27	El Paso International Airport (ELP)
28	FALFURRIAS : BROOKS COUNTY AIRPORT (BKS)
29	Fort Stockton Pecos County Airport (FST)
30	Fort Worth Alliance Airport (AFW)
31	Fort Worth Meacham (FTW)
32	FREDERICKSBURG: GILLESPIE COUNTY AIRPORT (T82)
33	GAINESVILLE : GAINESVILLE MUNICIPAL AIRPORT (GLE)
34	Galveston Scholes Field (GLS)
35	GEORGETOWN : GEORGETOWN MUNICIPAL AIRPORT (GTU)
36	Harlingen Rio Grande Valley I (HRL)
37	Hondo Municipal Airport (HDO)
38	Houston Bush Intercontinental (IAH)
39	Houston Clover Field (LVJ)
40	Houston Hooks Memorial Airport (DWH)
41	Houston Sugarland Mem (SGR)
42	Houston William P Hobby Airport (HOU)
43	Huntsville Municipal Airport (UTS)
44	JASPER : JASPER COUNTY-BELL FIELD AIRPORT (JAS)
45	Junction Kimble County Airport (JCT)
46	KERRVILLE : KERRVILLE MUNI/LOUIS SCHREINER FLD AIRPORT (ERV)
47	KILLEEN : KILLEEN MUNICIPAL AIRPORT (ILE)
48	KINGSVILLE : KINGSVILLE NAS AIRPORT (NQI)
49	LA GRANGE : FAYETTE REGIONAL AIR CENTER AIRPORT (3T5)
50	Longview E Tx Rgnl Airport (GGG)
51	Lubbock International Airport (LBB)
52	Lufkin Angelina Cty Airport (LFK)
53	MARFA : MARFA MUNICIPAL AIRPORT (MRF)
54	McAllen Miller International Airport (MFE)
55	McKinney Municipal Airport (TKI)
56	Midland International Airport (MAF)
57	Mineral Wells Airport (MWL)
58	MOUNT PLEASANT : MOUNT PLEASANT REGIONAL AIRPORT (OSA)
59	NACOGDOCHES : A L MANGHAM JR REGIONAL AIRPORT (OCH)
60	New Braunfels Municipal Airport (BAZ)
61	Odessa Schlemeyer Field (ODO)
62	Palacios Municipal Airport (PSX)
63	PARIS : COX FIELD AIRPORT (PRX)
64	PERRYTON : PERRYTON OCHILTREE COUNTY AIRPORT (PYX)
65	Pine Springs Guadalupe Mounta (GDP)
66	Port Arthur Se Tx Rgnl Airport (BPT)
67	Port Isabel Cameron County Airport (PIL)
68	Rockport Aransas Co Airport (RKP)
69	San Angelo Mathis Field (SJT)
70	San Antonio International Airport (SAT)
71	San Antonio Stinson Municipal Airport (SSF)
72	SAN MARCOS : SAN MARCOS MUNICIPAL AIRPORT (HYI)
73	SWEETWATER : AVENGER FIELD AIRPORT (SWW)
74	TEMPLE: DRAUGHON-MILLER CNTRL TEXAS REGIONAL ARPT (TPL)
75	Terrell Municipal Airport (TRL)
76	Tyler Pounds Field (TYR)
77	Victoria Regional Airport (VCT)
78	WACO : MC GREGOR EXECUTIVE AIRPORT (PWG)
79	Waco Regional Airport (ACT)
80	WESLACO : MID VALLEY AIRPORT (T65)
81	Wichita Falls Municipal Airport (SPS)
82	Wink Winkler Co Airport (INK)

Texas TMY2 Weather Files

1	Abilene
2	Amarillo
3	Austin
4	Brownsville
5	Corpus Christi
6	El Paso
7	Fort Worth
8	Houston
9	Lubbock
10	Lufkin
11	Midland
12	Port Arthur
13	San Angelo
14	San Antonio
15	Victoria
16	Waco
17	Wichita Falls

Texas WYEC2 Weather Files

1	El Paso
2	Brownsville
3	Fort Worth
4	San Antonio

NREL Solar Stations

1	Abilene
2	Austin
3	Big Spring
4	Canyon
5	Clear Lake
6	Corpus Christi
7	Del Rio
8	Edinburg
9	El Paso
10	Laredo
11	Menard
12	Overton
13	Pecos
14	Presidio
15	Sanderson

TCEQ Solar Stations

1	Bexar
2	Travis
3	El Paso (2)
4	Galveston
5	Harris (5)

FCHART and PV FCHART (New Weather File)

1	ABILENE
2	AMARILLO
3	AUSTIN
4	BROWNSVILLE
5	CORPUS CHRISTI
6	EL PASO
7	FORT WORTH
8	HOUSTON
9	LUBBOCK
10	LUFKIN
11	MIDLAND-ODESSA
12	PORT ARTHUR
13	SAN ANGELO
14	SAN ANTONIO
15	SHERMAN
16	VICTORIA
17	WACO
18	WICHITA FALLS

Table 25: Assignment of Weather Stations for 41 Non-attainment and Affected Counties (NOAA, TMY2, F-CHART, PV F-CHART, NAHB, Climate Zone, HDD, CDD, 90.1-1989, 90.1-1999).

Area	No.	County	NOAA Weather Station		Solar Station		TMY2		FCHART		PV-FCHART		DOE Include File	Weather File	DOE TRY weather file name	East or West Texas	Climate Zone	HDD		CDD		AHSRAE 90.1-1989		AHSRAE 90.1-1999		County
			WBAN No.	Weather Station	Source	File	WBAN No.	File										1989	1999	1989	1999	Nearest City	Table 8A (10, 12, 16)	Nearest City	Table B (5, 6, 8, 10)	
	ID	County	WBAN No.	Weather Station	x	x	x	TMY2File	Fchart	FchartID	PVFChart	PVFChartID	DOE_INC	x	DOE_WF	PRECODE	CZ									County
Austin	22	Bastrop	13958	Austin Camp Mabry (ATT)	NREL	Austin	13958	Austin	Austin	14	Austin	18	BAS	Austin	ATT	West	4					Austin	12	Austin	6	Bastrop
	26	Caldwell	13958	Austin Camp Mabry (ATT)	NREL	Austin	13958	Austin	Austin	14	Austin	18	CAL	Austin	ATT	West	4					Austin	12	Austin	6	Caldwell
	8	Hays	13958	Austin Camp Mabry (ATT)	NREL	Austin	13958	Austin	Austin	14	Austin	18	HAY	Austin	ATT	West	5					Austin	12	Austin	6	Hays
	40	Travis	13958	Austin Camp Mabry (ATT)	NREL	Austin	13958	Austin	Austin	14	Austin	18	TRA	Austin	ATT	West	5	1735	1688	6873	7171	Austin	12	Austin	6	Travis
	41	Williamson	13958	Austin Camp Mabry (ATT)	NREL	Austin	13958	Austin	Austin	14	Austin	18	WLL	Austin	ATT	West	5					Austin	12	Kileen/Robert-gray or **Austin**	6	Williamson
Corpus	38	Nueces	12924	Corpus Christi International Airport (CRP)	NREL	Corpus Christi	12924	Corpus Christi	Corpus Christi	52	Corpus Christi	58	NUE	Corpus Christi	CRP	East	3	889	1016	8200	8023	Corpus Christi	16	Corpus Christi or Alice	5	Nueces
	15	San Patricio	12924	Corpus Christi International Airport (CRP)	NREL	Corpus Christi	12924	Corpus Christi	Corpus Christi	52	Corpus Christi	58	SAP	Corpus Christi	CRP	East	3					Corpus Christi	16	Corpus Christi or Alice	5	San Patricio
El Paso	30	El Paso	23044	El Paso International Airport (ELP)	TCEQ	C12-El Paso UTEP	23044	El Paso	El Paso	68	El Paso	70	ELP	El Paso	ELP	West	6	2605	2708	5617	5488	El Paso	12	El Paso	10	El Paso
Dallas-Ft. Worth	27	Collin	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	COL	Fort Worth	DFW	West	6					Sherman or Fort Worth	12	**Denton,** Greenville or Sherman	8	Collin
	4	Dallas	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	DAL	Fort Worth	DFW	West	5		2259		6587	Fort Worth	12	Dallas	8	Dallas
	29	Denton	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	DEN	Fort Worth	DFW	West	6					Shermanor Fort Worth	12	Denton	8	Denton
	31	Ellis	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	ELL	Fort Worth	DFW	West	5					Fort Worth	12	Fort Worth, Dallas or Corsicana	8	Ellis
	23	Hood	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	HOD	Fort Worth	DFW	West	5					Fort Worth	12	Mineral Wells or Fort Worth	8	Hood
	24	Hunt	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	HNT	Fort Worth	DFW	West	6					Shermanor Fort Worth	12	Greenville	10	Hunt
	36	Johnson	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	JOH	Fort Worth	DFW	West	5					Fort Worth	12	Mineral Wells or Fort Worth	8	Johnson
	10	Kaufman	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	KAU	Fort Worth	DFW	West	6					Fort Worth	12	Greenville, **Dallas** or Corsicana	8	Kaufman
	39	Parker	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	PAR	Fort Worth	DFW	West	6					Fort Worth	12	Mineral Wells or Fort Worth	8	Parker
	13	Rockwall	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	ROC	Fort Worth	DFW	West	6					Shermanor Fort Worth	12	**Dallas** or Greeenville	8	Rockwall
	17	Tarrant	03927	Dallas - Fort Worth International Airpor (DFW)	NREL	Overton	03927	Fort Worth	Fort Worth	78	Fort Worth	83	TAR	Fort Worth	DFW	West	5	2354		6174		Fort worth	12	Fort worth	8	Tarrant
Houston/Galveston	2	Brazoria	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	BRA	Houston	IAH	East	3					Houston	10	Houston, Galveston or Bay City	5	Brazoria
	5	Fort Bend	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	FOB	Houston	IAH	East	4					Houston	10	Houston or Bay City	5	Fort Bend
	32	Galveston	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	GAL	Houston	IAH	East	3		1263		7378	Houston	10	Galveston	5	Galveston
	34	Harris	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	HAR	Houston	IAH	East	4	1346	1371	7125	7357	Houston	10	Houston	5	Harris
	37	Montgomery	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	MOG	Houston	IAH	East	4					Houston	10	Huntsville or **Houston**	5	Montgomery
	20	Waller	12960	Houston Bush Intercontinental (IAH)	NREL	Clear Lake	12960	Houston	Houston	96	Houston	102	WAL	Houston	IAH	East	4					Houston	10	Houston	5	Waller
Tyler/Longview	33	Gregg	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	GRE	Lufkin	GGG	East	6					Lufkin	12	Longview	8	Gregg
	35	Harrison	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	HAN	Lufkin	GGG	East	6					Lufkin	12	Longview	8	Harrison
	9	Henderson	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	HDS	Lufkin	GGG	East	5					Lufkin, Waco or Fort Worth	12	Tyler, Palestine or Corsicana	8	Henderson
	14	Rusk	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	RUS	Lufkin	GGG	East	5					Lufkin	12	Tyler or Longview	8	Rusk
	16	Smith	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	SMI	Lufkin	GGG	East	5		1296		6562	Lufkin	12	Tyler	8	Smith
	18	Upshur	03901	Longview E Tx Rgnl Airport (GGG)	NREL	Overton	93987	Lufkin	Lufkin	125	Lufkin	131	UPS	Lufkin	GGG	East	6					Lufkin	12	Tyler or Longview	8	Upshur
Beaumont Pt. Arthur	3	Chambers	12917	Port Arthur Se Tx Rgnl Airport (BPT)	TCEQ	C34-Galveston Airport	12917	Port Arthur	Port Arthur	166	Port Arthur	172	CHA	Port Arthur	BPT	East	4					Houston or Port Arthur	10	Beaumont or **Houston**	5	Chambers
	7	Hardin	12917	Port Arthur Se Tx Rgnl Airport (BPT)	TCEQ	C34-Galveston Airport	12917	Port Arthur	Port Arthur	166	Port Arthur	172	HAD	Port Arthur	BPT	East	4					Port Arthur	10	Beaumont	6	Hardin
	25	Jefferson	12917	Port Arthur Se Tx Rgnl Airport (BPT)	TCEQ	C34-Galveston Airport	12917	Port Arthur	Port Arthur	166	Port Arthur	172	JEF	Port Arthur	BPT	East	4	1416	1677	6888	6703	Port Arthur	10	Beaumont	6	Jefferson
	11	Liberty	12917	Port Arthur Se Tx Rgnl Airport (BPT)	TCEQ	C34-Galveston Airport	12917	Port Arthur	Port Arthur	166	Port Arthur	172	LIB	Port Arthur	BPT	East	4					Houston or Port Arthur	10	Beaumont, Galveston or **Houston**	5	Liberty
	12	Orange	12917	Port Arthur Se Tx Rgnl Airport (BPT)	TCEQ	C34-Galveston Airport	12917	Port Arthur	Port Arthur	166	Port Arthur	172	ORA	Port Arthur	BPT	East	4					Port Arthur	10	Beaumont	6	Orange
San Antonio	1	Bexar	12921	San Antonio International Airport (SAT)	TCEQ	C58-Camp Bullis	12921	San Antonio	San Antonio	187	San Antonio	194	BEX	San Antonio	SAT	West	4	1579	1644	7170	7142	San Antonio	12	San Antonio	6	Bexar
	28	Comal	12921	San Antonio International Airport (SAT)	TCEQ	C58-Camp Bullis	12921	San Antonio	San Antonio	187	San Antonio	194	COM	San Antonio	SAT	West	4					San Antonio	12	San Antonio	6	Comal
	6	Guadalupe	12921	San Antonio International Airport (SAT)	TCEQ	C58-Camp Bullis	12921	San Antonio	San Antonio	187	San Antonio	194	GUA	San Antonio	SAT	West	4					San Antonio	12	San Antonio	6	Guadalupe
	21	Wilson	12921	San Antonio International Airport (SAT)	TCEQ	C58-Camp Bullis	12921	San Antonio	San Antonio	187	San Antonio	194	WIL	San Antonio	SAT	West	4					San Antonio	12	San Antonio	6	Wilson
Victoria	19	Victoria	12912	Victoria Regional Airport (VCT)	TCEQ	C58-Camp Bullis	12912	Victoria	Victoria	347	Victoria	225	VIC	Victoria	VCT	East	3	Hou	1296	Hou	7507			Victoria	5	Victoria

Table 26: Availability of Weather Data for 41 Non-attainment and Affected Counties (NOAA, NREL, TCEQ, ESL).

County No.	County	Affected = A, Non Attain = N, Others = 0	WBAN No.	NOAA	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	Elev. (m)
1	Bastrop	A							
2	Bexar	A	12921	San Antonio International Airport (SAT)	N 29	32	W 98	28	246.3
2	Bexar	A	12970	San Antonio Stinson Municipal Airport (SSF)	N 29	20	W 98	28	175.3
3	Caldwell	A							
4	Comal	A							
5	Ellis	A							
5	Ellis	A							
6	Gregg	A	13901	Longview E. Tx Rgnl Airport (GGG)	N 32	23	W 94	43	111.3
7	Guadalupe	A	12971	New Braunfels Municipal Airport (BAZ)	N 29	43	W 98	3	196.3
8	Harrison	A							
9	Hays	A	-	SAN MARCOS : SAN MARCOS MUNICIPAL AIRPORT (HYI)	-	-	-	-	-
10	Johnson	A							
11	Kaufman	A	53911	Terrell Municipal Airport (TRL)	N 32	43	W 96	16	144.3
12	Nueces	A	12924	Corpus Christi International Airport (CRP)	N 27	46	W 97	31	12.5
12	Nueces	A	-	CORPUS CHRISTI : CORPUS CHRISTI NAS/TRUAX FIELD ARPT (NGP)	-	-	-	-	-
13	Parker	A							
14	Rockwall	A							
15	Rusk	A							
16	San Patricio	A							
17	Smith	A	13972	Tyler Pounds Field (TYR)	N 32	21	W 95	24	165.3
18	Travis	A	13904	Austin - Bergstrom International (AUS)	N 30	11	W 97	41	146.3
18	Travis	A	13958	Austin Camp Mabry (ATT)	N 30	19	W 97	46	[illegible]
18	Travis	A							
19	Upshur	A							
20	Victoria	A	12912	Victoria Regional Airport (VCT)	N 28	52	W 96	56	35.1
21	Williamson	A	-	GEORGETOWN : GEORGETOWN MUNICIPAL AIRPORT (GTU)	-	-	-	-	-
22	Wilson	A							
23	Henderson	A							
24	Hood	A							
25	Hunt	A							
26	Brazoria	N	12976	Angleton / Lake Jackson Brazos (LBX)	N 29	7	W 95	28	76.0
26	Brazoria	N	12975	Houston Clover Field (LVJ)	N 29	31	W 95	15	[illegible]
27	Chambers	N							
28	Collin	N	53914	McKinney Municipal Airport (TKI)	N 33	11	W 96	35	176.3
28	Collin	N							
29	Dallas	N	[illegible]	Dallas Love Field (DAL)	N 32	51	W 96	51	134.1
29	Dallas	N	03971	Dallas Redbird Airport (RBD)	N 32	41	W 96	52	200.3
29	Dallas	N							
30	Denton	N	03991	Denton Municipal Airport (DTO)	N 33	12	W 97	12	195.7
31	El Paso	N	23044	El Paso International Airport (ELP)	N 31	49	W 106	23	1194.2
31	El Paso	N							
31	El Paso	N							
32	Fort Bend	N	12977	Houston Sugarland Mem (SGR)	N 29	37	W 95	39	25.0
33	Galveston	N	12923	Galveston Scholes Field (GLS)	N 29	16	W 94	52	1.5
34	Hardin	N							
35	Harris	N	12960	Houston Bush Intercontinental (IAH)	N 29	59	W 95	22	29.0
35	Harris	N	53910	Houston Hooks Memorial Airport (DWH)	N 30	4	W 95	33	46.3
35	Harris	N	12918	Houston William P Hobby Airport (HOU)	N 29	38	W 95	17	[illegible]
35	Harris	N							
35	Harris	N							
35	Harris	N							
35	Harris	N							
35	Harris	N							
35	Harris	N							
35	Harris	N							
35	Harris	N							
36	Jefferson	N	12917	Port Arthur Se Tx Rgnl Airport (BPT)	N 29	57	W 94	1	4.9
36	Jefferson	N							
36	Jefferson	N							
36	Jefferson	N							
37	Liberty	N							
38	Montgomery	N	53902	Conroe Montgomery County Airport (CXO)	N 30	21	W 95	25	74.7
39	Orange	N							
40	Tarrant	N	53907	Arlington Municipal Airport (GKY)	N 32	40	W 97	6	192.3
40	Tarrant	N	03927	Dallas - Fort Worth International Airport (DFW)	N 32	54	W 97	1	170.7
40	Tarrant	N	53909	Fort Worth Alliance Airport (AFW)	N 32	58	W 97	19	208.3
40	Tarrant	N	13961	Fort Worth Meacham (FTW)	N 32	49	W 97	22	209.4
40	Tarrant	N							
41	Waller	N							

County No.	County	NREL Station No.	NREL	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	Elev. (m)	CAMS No.	TCEQ	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	Elev. (m)
1	Bastrop														
2	Bexar								C58	Camp Bullis	N 29	38	W 98	34	
2	Bexar														
3	Caldwell														
4	Comal														
5	Ellis								C30	El Paso East	N 31	45	W 106	25	
5	Ellis								C94	Midlothian Tower	N 32	26	W 97	1	
6	Gregg														
7	Guadalupe														
8	Harrison														
9	Hays														
10	Johnson								C77	Cleburne Airport	N 32	21	W 97	26	
11	Kaufman								C71	Kaufman	N 32	34	W 96	11	
12	Nueces	6	Corpus Christi						C4	Corpus Christi West	N 27	46	W 97	26	
12	Nueces														
13	Parker								C76	Parker County (Fort Worth)	N 32	52	W 97	54	
14	Rockwall								C69	Rockwall Heath	N 32	56	W 96	28	
15	Rusk	12	Overton												
16	San Patricio														
17	Smith								C82	Tyler Airport relocated	N 32	21	W 95	25	
18	Travis	2	Austin						C38	Austin Audubon Society	N 30	29	W 97	52	
18	Travis														
18	Travis														
19	Upshur														
20	Victoria								C87	Victoria	N 28	50	W 97	0	
21	Williamson														
22	Wilson														
23	Henderson														
24	Hood								C73	Granbury	N 32	27	W 97	48	
25	Hunt								C1006	Greenville	N 33	9	W 96	7	
26	Brazoria								C1011	Lake Jackson	N 29	3	W 95	28	
26	Brazoria														
27	Chambers														
28	Collin								C31	Frisco C31	N 33	8	W 96	47	
28	Collin								C68	Anna	N 33	21	W 96	30	
29	Dallas								C63	Dallas North #2 (Dallas)	N 32	55	W 96	48	
29	Dallas								C74	Sunnyvale Long Creek (Dallas)	N 32	46	W 96	32	
29	Dallas								C401	Dallas Hinton St	N 32	49	W 96	52	
30	Denton								C56	Denton Airport South	N 33	12	W 97	12	
31	El Paso	9	El Paso						C12	El Paso UTEP	N 31	46	W 106	30	
31	El Paso								C37	Ascarate Park SE	N 31	45	W 106	24	
31	El Paso								C41	El Paso Chamizal	N 31	46	W 106	27	
32	Fort Bend														
33	Galveston								C34	Galveston Airport	N 29	16	W 94	51	
34	Hardin														
35	Harris	5	Clear Lake						C8	Aldine	N 29	54	W 95	20	
35	Harris								C15	Channelview	N 29	48	W 95	8	
35	Harris								C26	Northwest Harris County	N 30	2	W 95	40	
35	Harris								C35	Deer Park #2	N 29	40	W 95	8	
35	Harris								C45	Seabrook Friendship Park	N 29	35	W 95	1	
35	Harris								C53	Houston Bayland Park	N 29	42	W 95	30	
35	Harris								C81	Houston Regional Office	N 29	44	W 95	15	
35	Harris								C85	Karnack	N 32	40	W 94	10	
35	Harris								C403	Clinton (CEC, Houston)	N 29	44	W 95	15	
35	Harris								C617	Wallisville Road	N 29	49	W 94	59	
35	Harris								C1015	Lynchburg Ferry	N 29	46	W 95	5	
36	Jefferson								C20	Port Arthur West	N 29	54	W 93	58	
36	Jefferson								C2	Beaumont Downtown	N 30	2	W 94	4	
36	Jefferson								C64	Hamshire	N 29	52	W 94	19	
36	Jefferson								C643	SETRPC 43 Jefferson County Airport	N 29	57	W 94	0	0
37	Liberty														
38	Montgomery								C78	Conroe Airport Relocated	N 30	21	W 95	29	
39	Orange								C9	West Orange	N 30	5	W 93	46	
40	Tarrant								C61	Arlington Municipal Airport	N 32	39	W 97	5	
40	Tarrant								C70	Grapevine Fairway	N 32	59	W 97	4	
40	Tarrant								C13	Fort Worth Northwest	N 32	48	W 97	21	
40	Tarrant								C17	Keller (Fort Worth)	N 32	55	W 97	17	
40	Tarrant								C75	Eagle Mountain Lake (Fort Worth)	N 32	59	W 97	26	
41	Waller														

County No.	County	Site No.	ESL	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	Elev. (m)	WBAN No.	TMY2	Latitude Deg.	Latitude Min.	Latitude Deg.	Latitude Min.	Elev. (m)
1	Bastrop								13958	Austin	N 30	18	W 97	42	189
2	Bexar	140	UTHSC						12921	San Antonio	N 29	32	W 98	28	242
2	Bexar								12922	San Antonio	N 29	32	W 98	28	242
3	Caldwell								13968	Austin	N 30	18	W 97	42	189
4	Comal								12923	San Antonio	N 29	32	W 98	28	242
5	Ellis								03936	Fort Worth	N 32	50	W 97	3	164
5	Ellis								03937	Fort Worth	N 32	50	W 97	3	164
6	Gregg								93987	Lufkin	N 31	14	W 94	45	96
7	Guadalupe								12924	San Antonio	N 29	32	W 98	28	242
8	Harrison								93988	Lufkin	N 31	14	W 94	45	96
9	Hays								93989	Lufkin	N 31	14	W 94	45	96
10	Johnson								03930	Fort Worth	N 32	50	W 97	3	164
11	Kaufman								03939	Fort Worth	N 32	50	W 97	3	164
12	Nueces								12924	Corpus Christi	N 27	46	W 97	30	13
12	Nueces								12924	Corpus Christi	N 27	46	W 97	30	13
13	Parker								03940	Fort Worth	N 32	50	W 97	3	164
14	Rockwall								03941	Fort Worth	N 32	50	W 97	3	164
15	Rusk								93987	Lufkin	N 31	14	W 94	45	96
16	San Patricio								12924	Corpus Christi	N 27	46	W 97	30	13
17	Smith								93900	Lufkin	N 31	14	W 94	45	90
18	Travis	202	S.F. Austin Building (SFA)						93990	Lufkin	N 31	14	W 94	45	96
18	Travis	217	Rober E. Johnson Elec. Rcom. (West Solar)						93991	Lufkin	N 31	14	W 94	45	96
18	Travis	217	Rober E. Johnson Elec. Rcom. (South Solar)						93992	Lufkin	N 31	14	W 94	45	96
19	Upshur								93989	Lufkin	N 31	14	W 94	45	96
20	Victoria								12912	Victoria	N 28	51	W 96	56	32
21	Williamson								93993	Lufkin	N 31	14	W 94	45	96
22	Wilson								12925	San Antonio	N 29	32	W 98	28	242
23	Henderson														
24	Hood														
25	Hunt														
26	Brazoria								12960	Houston	N 29	59	W 95	22	33
26	Brazoria								12960	Houston	N 29	59	W 95	22	33
27	Chambers								12917	Port Arthur	N 29	57	W 94	1	7
28	Collin								03937	Fort Worth	N 32	50	W 97	3	164
28	Collin								03938	Fort Worth	N 32	50	W 97	3	164
29	Dallas	194	Federal Reserve - Weather Station (FRW)						03927	Fort Worth	N 32	50	W 97	3	164
29	Dallas								03928	Fort Worth	N 32	50	W 97	3	164
29	Dallas								03929	Fort Worth	N 32	50	W 97	3	164
30	Denton								03942	Fort Worth	N 32	50	W 97	3	164
31	El Paso	325	Valle Verde Campus (ECV)						23044	El Paso	N 31	48	W 106	24	1194
31	El Paso								23045	El Paso	N 31	48	W 106	24	1194
31	El Paso								23046	El Paso	N 31	48	W 106	24	1194
32	Fort Bend								12969	Houston	N 29	59	W 95	22	33
33	Galveston								12960	Houston	N 29	59	W 95	22	33
34	Hardin								12918	Port Arthur	N 29	57	W 94	1	7
35	Harris	121	UT Health Science Center						12960	Houston	N 29	59	W 95	22	33
35	Harris	931	Habitat Humanity Houses						12960	Houston	N 29	59	W 95	22	33
35	Harris								12960	Houston	N 29	59	W 95	22	33
35	Harris								12961	Houston	N 29	59	W 95	22	33
35	Harris								12962	Houston	N 29	59	W 95	22	33
35	Harris								12963	Houston	N 29	59	W 95	22	33
35	Harris								12964	Houston	N 29	59	W 95	22	33
35	Harris								12965	Houston	N 29	59	W 95	22	33
35	Harris								12966	Houston	N 29	59	W 95	22	33
35	Harris								12967	Houston	N 29	59	W 95	22	33
35	Harris								12968	Houston	N 29	59	W 95	22	33
36	Jefferson								12919	Port Arthur	N 29	57	W 94	1	7
36	Jefferson								12920	Port Arthur	N 29	57	W 94	1	7
36	Jefferson								12921	Port Arthur	N 29	57	W 94	1	7
36	Jefferson								12922	Port Arthur	N 29	57	W 94	1	7
37	Liberty								12923	Port Arthur	N 29	57	W 94	1	7
38	Montgomery								12970	Houston	N 29	59	W 95	22	33
39	Orange								12924	Port Arthur	N 29	57	W 94	1	7
40	Tarrant	111	University Hall (UT Arlington)						03931	Fort Worth	N 32	50	W 97	3	164
40	Tarrant								03932	Fort Worth	N 32	50	W 97	3	164
40	Tarrant								03933	Fort Worth	N 32	50	W 97	3	164
40	Tarrant								03934	Fort Worth	N 32	50	W 97	3	164
40	Tarrant								03935	Fort Worth	N 32	50	W 97	3	164
41	Waller								12971	Houston	N 29	59	W 95	22	33

County No.	County	NOAA 99	NOAA 00	NOAA 01	NOAA 02	NOAA 03	NREL 99	NREL 00	NREL 01	NREL 02	NREL 03	TCEQ 99	TCEQ 00	TCEQ 01	TCEQ 02	TCEQ 03	ESL 99	ESL 00	ESL 01	ESL 02	ESL 03
1	Bastrop																				
2	Bexar	Y	Y	Y	Y	Y						Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Bexar	Y	Y	Y	Y	Y															
3	Caldwell																				
4	Comal																				
5	Ellis											Y									
5	Ellis												Y	Y	Y	Y					
6	Gregg	Y	Y	Y	Y	Y															
7	Guadalupe	Y	Y	Y	Y	Y															
8	Harrison																				
9	Hays				Y	Y															
10	Johnson														Y	Y					
11	Kaufman	Y	Y	Y	Y	Y							Y	Y	Y	Y					
12	Nueces	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y	Y					
12	Nueces	Y	Y	Y	Y	Y															
13	Parker														Y	Y					
14	Rockwall														Y	Y					
15	Rusk						Y	Y	Y	Y	Y										
16	San Patricio																				
17	Smith	Y	Y	Y	Y	Y									Y	Y					
18	Travis	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
18	Travis	Y	Y	Y	Y	Y												Y	Y	Y	Y
18	Travis																	Y	Y	Y	Y
19	Upshur																				
20	Victoria	Y	Y	Y	Y	Y									Y	Y					
21	Williamson				Y	Y															
22	Wilson																				
23	Henderson																				
24	Hood														Y	Y					
25	Hunt															Y					
26	Brazoria	Y	Y	Y	Y	Y										Y					
26	Brazoria	Y	Y	Y	Y	Y															
27	Chambers																				
28	Collin	Y	Y	Y	Y	Y									Y	Y					
28	Collin														Y	Y					
29	Dallas	Y	Y	Y	Y	Y									Y	Y				Y	Y
29	Dallas	Y	Y	Y	Y	Y									Y	Y					
29	Dallas											Y	Y	Y	Y	Y					
30	Denton	Y	Y	Y	Y	Y							Y	Y	Y	Y					
31	El Paso	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
31	El Paso												Y	Y	Y	Y					
31	El Paso											Y	Y	Y	Y	Y					
32	Fort Bend		Y	Y	Y	Y															
33	Galveston	Y	Y	Y	Y	Y						Y	Y	Y	Y	Y					
34	Hardin																				
35	Harris	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
35	Harris	Y	Y	Y	Y	Y									Y	Y	Y	Y	Y	Y	Y
35	Harris	Y	Y	Y	Y	Y						Y	Y	Y	Y	Y					
35	Harris											Y	Y	Y	Y	Y					
35	Harris														Y	Y					
35	Harris											Y	Y	Y	Y	Y					
35	Harris														Y	Y					
35	Harris														Y	Y					
35	Harris											Y	Y	Y	Y	Y					
35	Harris											-	-	-	-	-					
35	Harris															Y					
36	Jefferson	Y	Y	Y	Y	Y									Y	Y					
36	Jefferson														Y	Y					
36	Jefferson														Y	Y					
36	Jefferson											Y	Y	Y	Y	Y					
37	Liberty																				
38	Montgomery	Y	Y	Y	Y	Y									Y	Y					
39	Orange														Y	Y					
40	Tarrant	Y	Y	Y	Y	Y									Y	Y	Y	Y	Y	Y	Y
40	Tarrant	Y	Y	Y	Y	Y							Y	Y	Y	Y					
40	Tarrant	Y	Y	Y	Y	Y							Y	Y	Y	Y					
40	Tarrant	Y	Y	Y	Y	Y									Y	Y					
40	Tarrant														Y	Y					
41	Waller																				

Note:

	County No.	The affected and non attainment county numbers are listed orderly using table 19, p. 101, of the TERP Technical Report 2003.
		The other county numbers are listed alphabetically.
NOAA	**WBAN No.**	Station's Weather Bureau Army Navy number
TMY2	**WBAN No.**	Station's Weather Bureau Army Navy number
NREL	**Station No.**	The station numbers are listed alphabetically.
TECQ	**CAMS No.**	The numbers are from TECQ.
ESL	**Site No.**	ESL's site numbers.
	Y in black:	The whole years data is available
	Y in red	The data is available for partial year

Table 27: Main NOAA weather stations used in eCALC

ABI	Abilene Regional Airport
AMA	Amarillo International Airport
BRO	Brownsville S. Padre Island International
LBB	Lubbock International Airport
MAF	Midland International Airport
SJT	San Angelo Mathis Field
ACT	Waco Regional Airport
SPS	Wichita Falls Municipal Airport
ATT	Austin Camp Mabry
BPT	Port Arthur Se TX Rgnl Airport
CRP	Corpus Christi International Airport
DFW	Dallas - Fort Worth International Airport
ELP	El Paso International Airport
GGG	Longview E TX Rgnl Airport
IAH	Houston Bush Intercontinental
SAT	San Antonio International Airport
VCT	Victoria Regional Airport

Table 28: Summary of Weather Data Assignments for ERCOT Counties.

ERCOT COUNTY	ASSIGNED WEATHER STATION	ERCOT COUNTY	ASSIGNED WEATHER STATION	ERCOT COUNTY	ASSIGNED WEATHER STATION
ANDERSON	GGG	FRANKLIN	DFW	MIDLAND	MAF
ANDREWS	MAF	FREESTONE	ACT	MILAM	IAH
ANGELINA	GGG	FRIO	SAT	MILLS	ACT
ARANSAS	CRP	GALVESTON	IAH	MITCHELL	ABI
ARCHER	SPS	GILLESPIE	ATT	MONTAGUE	SPS
ATASCOSA	SAT	GLASSCOCK	MAF	MONTGOMERY	IAH
AUSTIN	IAH	GOLIAD	VCT	MOTLEY	LBB
BANDERA	SAT	GONZALES	SAT	NACOGDOCHES	GGG
BASTROP	ATT	GRAYSON	SPS	NAVARRO	ACT
BAYLOR	SPS	GRIMES	IAH	NOLAN	ABI
BEE	VCT	GUADALUPE	SAT	NUECES	CRP
BELL	ACT	HALL	AMA	PALO PINTO	ABI
BEXAR	SAT	HAMILTON	ACT	PARKER	DFW
BLANCO	ATT	HARDEMAN	SPS	PECOS	SJT
BORDEN	LBB	HARRIS	IAH	PRESIDIO	SJT
BOSQUE	ACT	HASKELL	ABI	RAINS	DFW
BRAZORIA	IAH	HAYS	ATT	REAGAN	MAF
BRAZOS	IAH	HENDERSON	DFW	REAL	ATT
BREWSTER	SJT	HIDALGO	BRO	RED RIVER	DFW
BRISCOE	AMA	HILL	ACT	REEVES	MAF
BROOKS	BRO	HOOD	DFW	REFUGIO	VCT
BROWN	ACT	HOPKINS	DFW	ROBERTSON	IAH
BURLESON	IAH	HOUSTON	GGG	ROCKWALL	DFW
BURNET	ATT	HOWARD	MAF	RUNNELS	SJT
CALDWELL	ATT	HUDSPETH	ELP	RUSK	GGG
CALHOUN	VCT	HUNT	SPS	SAN PATRICIO	CRP
CALLAHAN	ABI	IRION	SJT	SAN SABA	ATT
CAMERON	BRO	JACK	ABI	SCHLEICHER	SJT
CHAMBERS	BPT	JACKSON	VCT	SCURRY	LBB
CHEROKEE	GGG	JEFF DAVIS	MAF	SHACKELFORD	ABI
CHILDRESS	LBB	JIM HOGG	BRO	SMITH	DFW
CLAY	SPS	JIM WELLS	CRP	SOMERVELL	DFW
COKE	SJT	JOHNSON	DFW	STARR	BRO
COLEMAN	ABI	JONES	ABI	STEPHENS	ABI
COLLIN	DFW	KARNES	VCT	STERLING	SJT
COLORADO	IAH	KAUFMAN	DFW	STONEWALL	LBB
COMAL	SAT	KENDALL	SAT	SUTTON	SJT
COMANCHE	ACT	KENEDY	BRO	TARRANT	DFW
CONCHO	SJT	KENT	LBB	TAYLOR	ABI
COOKE	SPS	KERR	ATT	TERRELL	SJT
CORYELL	ACT	KIMBLE	SJT	THROCKMORTON	ABI
COTTLE	SPS	KING	LBB	TITUS	DFW
CRANE	MAF	KINNEY	SAT	TOM GREEN	SJT
CROCKETT	SJT	KLEBERG	CRP	TRAVIS	ATT
CROSBY	LBB	KNOX	SPS	UPTON	MAF
CULBERSON	ELP	LA SALLE	CRP	UVALDE	SAT
DALLAS	DFW	LAMAR	DFW	VAL VERDE	SAT
DAWSON	LBB	LAMPASAS	ACT	VAN ZANDT	DFW
DE WITT	VCT	LAVACA	VCT	VICTORIA	VCT
DELTA	DFW	LEE	ATT	WALLER	IAH
DENTON	DFW	LEON	ACT	WARD	MAF
DICKENS	LBB	LIMESTONE	ACT	WASHINGTON	IAH
DIMMIT	CRP	LIVE OAK	CRP	WEBB	CRP
DUVAL	CRP	LLANO	ATT	WHARTON	VCT
EASTLAND	ABI	LOVING	MAF	WICHITA	SPS
ECTOR	MAF	MADISON	IAH	WILBARGER	SPS
EDWARDS	SJT	MARTIN	MAF	WILLACY	BRO
ELLIS	DFW	MASON	ATT	WILLIAMSON	ATT
ERATH	ABI	MATAGORDA	VCT	WILSON	SAT
FALLS	ACT	MAVERICK	CRP	WINKLER	MAF
FANNIN	SPS	MCCULLOCH	SJT	WISE	DFW
FAYETTE	IAH	MCLENNAN	ACT	YOUNG	ABI
FISHER	ABI	MCMULLEN	CRP	ZAPATA	BRO
FOARD	SPS	MEDINA	SAT	ZAVALA	CRP
FORT BEND	IAH	MENARD	SJT		

Table 29: Assignment of NWS Weather Stations for all ERCOT Counties.

No.	The City TMY2 Weather File is Available	County with TMY2 Weather Station: County Name	Weather Zone	HDD	Table	Weather Station Assigned	Adjacent Counties: No.	County Name	Weather Zone	HDD	Table	Weather Station Assigned	Nearest Counties: No.	County Name	Nearest Cities with TMY2 Files	Weather Zone	HDD	Table	Weather Station Assigned
1	Abilene	TAYLOR	6B	2584	B-8	ABI	1	CALLAHAN	6B			ABI	1	EASTLAND	Abilene (6B)	6B			ABI
							2	COLEMAN	5B			ABI	2	ERATH	Abilene (6B), Fort Worth (5B)	6B			ABI
							3	FISHER	6B			ABI	3	HASKELL	Abilene (6B), Wichita Falls (7B)	6B			ABI
							4	JONES	6B			ABI	4	JACK	Fort Worth (5B), Abilene (6B)	6B			ABI
							5	NOLAN	6B			ABI	5	MITCHELL	Abilene (6B), Midland (6B)	6B			ABI
							6	SHACKELFORD	6B			ABI	6	PALO PINTO	Fort Worth (5B), Abilene (6B)	6B	2625	B-8	ABI
													7	STEPHENS	Abilene (6B)	6B			ABI
													8	THROCKMORTON	Abilene (6B), Wichita Falls (7B)	6B			ABI
													9	YOUNG	Wichita Falls (7B), Abilene (6B), Fort Worth (5B)	6B			ABI
2	Amarillo	POTTER	9B	4258	B-13	AMA							10	BRISCOE	Amarillo (9B), Lubbock (7B)	8			AMA
													11	HALL	Amarillo (9B), Lubbock (7B)	8			AMA
3	Austin	TRAVIS	5B	1688	B-6	ATT	7	BASTROP	4B			ATT	12	GILLESPIE	San Antonio (4B), Austin (5B)	5A			ATT
							8	BLANCO	5A			ATT	13	KERR	San Antonio (4B), Austin (5B)	5A			ATT
							9	BURNET	5A			ATT	14	LEE	Austin (5B), Houston (4B)	4B			ATT
							10	CALDWELL	4B			ATT	15	LLANO	Austin (5B), San Antonio (4B),	5B			ATT
							11	HAYS	5B			ATT	16	MASON	Austin (5B), San Antonio (4B),	5B			ATT
							12	WILLIAMSON	5B			ATT	17	REAL	San Antonio (4B), Austin (5B), San Angelo (5B)	5A			ATT
													18	SAN SABA	Austin (5B), San Angelo (5B), Waco (5B)	5B			ATT
4	Brownsville	CAMERON	2B	635	B-3	BRO	13	HIDALGO	2B	778	B-3	BRO	19	BROOKS	Brownsville (2B), Corpus Christie (3B)	2B			BRO
							14	WILLACY	2B			BRO	20	JIM HOGG	Brownsville (2B), Corpus Christie (3B)	2B			BRO
													21	KENEDY	Brownsville (2B), Corpus Christie (3B)	2B			BRO
													22	STARR	Brownsville (2B)	2B			BRO
													23	ZAPATA	Brownsville (2B), Corpus Christie (3B)	2B			BRO
5	Corpus Christi	NUECES	3B	1016	B-5	CRP	15	ARANSAS	3B			CRP	24	DIMMIT	Corpus Christi (3B), San Anotonio (4B)	3C			CRP
							16	JIM WELLS	3C	1062	B-5	CRP	25	DUVAL	Corpus Christi (3B)	3C			CRP
							17	KLEBERG	2B			CRP	26	LA SALLE	Corpus Christi (3B)	3C			CRP
							18	SAN PATRICIO	3C			CRP	27	LIVE OAK	Corpus Christi (3B), Victoria (3B)	3C			CRP
													28	MAVERICK	San Anotonio (4B), Corpus Christi (3B)	3C	1441	B-5	CRP
													29	MCMULLEN	Corpus Christi (3B), Victoria (3B)	3C			CRP
													30	WEBB	Corpus Christi (3B)	3C	1025	B-5	CRP
													31	ZAVALA	San Anotonio (4B), Corpus Christi (3B)	3C			CRP
6	El Paso	EL PASO	6B	2708	B-10	ELP	19	HUDSPETH	6B			ELP	32	CULBERSON	El Paso (6B)	6B			ELP
7	Fort Worth	TARRANT	5B	2304	B-8	DFW	20	COLLIN	6B			DFW	33	DELTA	Fort Worth (5B)	6B			DFW
							21	DALLAS	5B	2259	B-8	DFW	34	FRANKLIN	Fort Worth (5B)	6B			DFW
							22	DENTON	6B	2665	B-8	DFW	35	HENDERSON	Fort Worth (5B), Lufkin (5A), Waco (5B)	5B			DFW
							23	ELLIS	5B			DFW	36	HOOD	Fort Worth (5B), Waco (5B)	5B			DFW
							24	JOHNSON	5B			DFW	37	HOPKINS	Fort Worth (5B)	6B			DFW
							25	PARKER	6B			DFW	38	KAUFMAN	Fort Worth (5B)	6B			DFW
							26	WISE	6B			DFW	39	LAMAR	Fort Worth (5B)	6B			DFW
													40	RAINS	Fort Worth (5B)	6B			DFW
													41	RED RIVER	Fort Worth (5B)	6B			DFW
													42	ROCKWALL	Fort Worth (5B)	6B			DFW
													43	SMITH	Fort Worth (5B), Lufkin (5A)	5B	2194	B-8	DFW
													44	SOMERVELL	Fort Worth (5B), Waco (5B)	5B			DFW
													45	TITUS	Fort Worth (5B)	6B			DFW
													46	VAN ZANDT	Fort Worth (5B)	6B			DFW
8	Houston	HARRIS	4B	1371	B-5	IAH	27	BRAZORIA	3B			IAH	47	AUSTIN	Houston (4B)	4B			IAH
							28	FORT BEND	4B			IAH	48	BRAZOS	Houston (4B), Austin (5B), Waco (5B)	4B			IAH
							29	GALVESTON	3B	1263	B-5	IAH	49	BURLESON	Austin (5B), Waco (5B), Houston (4B)	4B			IAH
							30	MONTGOMERY	4B			IAH	50	COLORADO	Houston (4B), Victoria (3B)	4B			IAH
							31	WALLER	4B			IAH	51	FAYETTE	Houston (4B), San Antonio (4B)	4B			IAH
													52	GRIMES	Houston (4B)	4B			IAH
													53	MADISON	Houston (4B), Waco (5B), Lufkin (5A)	4B			IAH
													54	MILAM	Austin (5B), Waco (5B), Houston (4B)	4B			IAH
													55	ROBERTSON	Waco (5B), Houston (4B)	4B			IAH
													56	WASHINGTON	Houston (4B), Austin (5B)	4B			IAH
9	Lubbock	LUBBOCK	7B	3431	B-11	LBB	32	CROSBY	7B			LBB	57	BORDEN	Lubbock (7B), Abilene (6B), Midland (6B)	7B			LBB
													58	CHILDRESS	Lubbock (7B), Wichita Falls (7B)	7B			LBB
													59	DAWSON	Lubbock (7B), Midland (6B)	7B	3159	B-11	LBB
													60	DICKENS	Lubbock (7B)	7B			LBB
													61	KENT	Lubbock (7B), Abilene (6B)	7B			LBB
													62	KING	Lubbock (7B), Abilene (6B), Wichita Falls (7B)	7B			LBB
													63	MOTLEY	Lubbock (7B)	7B			LBB
													64	SCURRY	Lubbock (7B), Midland (6B), Abilene (6B)	7B	3185	B-11	LBB
													65	STONEWALL	Abilene (6B), Lubbock (7B), Wichita Falls (7B)	7B			LBB
10	Lufkin	ANGELINA	5A	1951	B-8	GGG	33	CHEROKEE	5A			GGG	66	ANDERSON	Lufkin (5A)	5A	2005	B-8	GGG
							34	HOUSTON	5A			GGG	67	RUSK	Lufkin (5A)	5B			GGG
							35	NACOGDOCHES	5A			GGG	67						
11	Midland	MIDLAND	6B	2751	B-10	MAF	36	ANDREWS	6B			MAF	68	HOWARD	Midland (6B)	6B	2772	B-10	MAF
							37	CRANE	5B			MAF	69	JEFF DAVIS	Midland (6B), El Paso (6B)	6B			MAF
							38	ECTOR	6B			MAF	70	LOVING	Midland (6B)	6B			MAF
							39	GLASSCOCK	6B			MAF	71	REEVES	Midland (6B)	6B	2505	B-8	MAF
							40	MARTIN	6B			MAF	72	WARD	Midland (6B)	6B			MAF
							41	REAGAN	5B			MAF	73	WINKLER	Midland (6B)	6B			MAF
							42	UPTON	5B			MAF	73						
12	Port Arthur	JEFFERSON	4B	1677	B-6	BPT	43	CHAMBERS	4B			BPT	73						
13	San Angelo	TOM GREEN	5B	2414	B-8	SJT	44	COKE	6B			SJT	74	BREWSTER	El Paso (6B), San Angelo (5B)	5A			SJT
							45	CONCHO	5B			SJT	75	CROCKETT	San Angelo (5B)	5B			SJT
							46	IRION	5B			SJT	76	EDWARDS	San Angelo (5B)	5A			SJT
							47	MENARD	5B			SJT	77	KIMBLE	San Angelo (5B), Austin (5B)	5A			SJT
							48	RUNNELS	5B			SJT	78	MCCULLOCH	San Angelo (5B)	5B			SJT
							49	SCHLEICHER	5B			SJT	79	PECOS	San Angelo (5B)	5A			SJT
							50	STERLING	6B			SJT	80	PRESIDIO	El Paso (6B), San Angelo (5B)	5A			SJT
													81	SUTTON	San Angelo (5B)	5A			SJT
													82	TERRELL	San Angelo (5B)	5A			SJT
14	San Antonio	BEXAR	4B	1644	B-6	SAT	51	ATASCOSA	3C			SAT	83	FRIO	San Antonio (4B), Corpus Christi (3B)	3C			SAT
							52	BANDERA	5A			SAT	84	GONZALES	San Antonio (4B), Victoria (3B)	4B			SAT
							53	COMAL	4B			SAT	85	KINNEY	San Antonio (4B)	4B			SAT
							54	GUADALUPE	4B			SAT	86	UVALDE	San Antonio (4B)	4B			SAT
							55	KENDALL	5A			SAT	87	VAL VERDE	San Anotonio (4B), San Angelo (5B)	4B	1565	B-5	SAT
							56	MEDINA	4B			SAT	87						SAT
							57	WILSON	4B			SAT	87						
15	Victoria	VICTORIA	3B	1296	B-5	VCT	58	CALHOUN	3B			VCT	88	BEE	Corpus Christi (3B), Victoria (3B)	3B	1372	B-5	VCT
							59	DE WITT	3C			VCT	89	KARNES	Victoria (3B), San Antonio (4B), Corpus Christi (3B)	3C			VCT
							60	GOLIAD	3B			VCT	90	MATAGORDA	Victoria (3B)	3B	1370	B-5	VCT
							61	JACKSON	3B			VCT	91	WHARTON	Victoria (3B), Houston (4B)	3B			VCT
							62	LAVACA	4B			VCT	91						
							63	REFUGIO	3B			VCT	91						
16	Waco	MCLENNAN	5B	2179	B-8	ACT	64	BELL	5B	2127	B-8	ACT	92	BROWN	Abilene (6B), Waco (5B), San Angelo (5B)	5B	2199	B-8	ACT
							65	BOSQUE	5B			ACT	93	COMANCHE	Waco (5B), Abilene (6B)	5B			ACT
							66	CORYELL	5B			ACT	94	FREESTONE	Waco (5B)	5B			ACT
							67	FALLS	5B			ACT	95	HAMILTON	Waco (5B)	5B			ACT
							68	HILL	5B			ACT	96	LAMPASAS	Waco (5B), Austin (5B)	5B			ACT
							69	LIMESTONE	5B			ACT	97	LEON	Waco (5B), Lufkin (5A)	5B			ACT
													98	MILLS	Waco (5B), Austin (5B)	5B			ACT
													99	NAVARRO	Waco (5B), Fort Worth (5B)	5B	2396	B-8	ACT
17	Wichita Falls	WICHITA	7B	3042	B-10	SPS	70	ARCHER	7B			SPS	100	COOKE	Fort Worth (5B), Wichita Falls (7B)	6B			SPS
							71	BAYLOR	7B			SPS	101	COTTLE	Witchita Falls (7B), Lubbock (7B)	7B			SPS
							72	CLAY	7B			SPS	102	FANNIN	Fort Worth (5B), Wichita Falls (7B)	6B			SPS
							73	WILBARGER	7B	3186	B-10	SPS	103	FOARD	Witchita Falls (7B)	7B			SPS
													104	GRAYSON	Fort Worth (5B), Wichita Falls (7B)	6B	2890	B-10	SPS
													105	HARDEMAN	Witchita Falls (7B)	7B			SPS
													106	HUNT	Fort Worth (5B), Wichita Falls (7B)	6B	2953	B-10	SPS
													107	KNOX	Wichita Falls (7B)	7B			SPS
													108	MONTAGUE	Wichita Falls (7B), Fort Worth (5B)	6B			SPS

8.2 Development of a web-based data archive

To facilitate the wide usage of the assembled weather files, a weather data archive was established on the Energy Systems Laboratory's Senate Bill 5 webpage (Figure 79), where a "Weather Data" button was added for interested parties to go to find the assembled weather data files for 1999 through 2004. In 2005 and 2006 this site was significantly expanded to include wind and solar data for all 17 sites. When the users select the "Weather Data" button they are directed to the page shown in Figure 83. The selection of one of the weather files (right side) on the webpage provides the user with a choice of files as shown in Figure 84, including daily average and hourly time intervals. Time series plots (daily and hourly), TRY format and packed TRY format (i.e., binary) files are also provided for each site for each of the years shown.

Examples of the files for Amarillo are shown in Table 30 through Table 32. Figure 85 shows an example of the hourly time series plots for Amarillo, TX. Figure 86 shows an example of the daily time series plots for Amarillo. Table 30 provides an example of the daily average weather data in CSV (comma separated variable). Table 31 provides an example of the hourly weather data in CSV format. Table 32 provides an example of the data in TRY format, which can be used directly by the DOE-2 simulation program. Similar information is provided for each of the 17 sites shown in Figure 83

Table 33 contains a list of the files that are included on the CD that accompanies this report. These files contain all the weather data contained on the Laboratory's Senate Bill 5 web site.

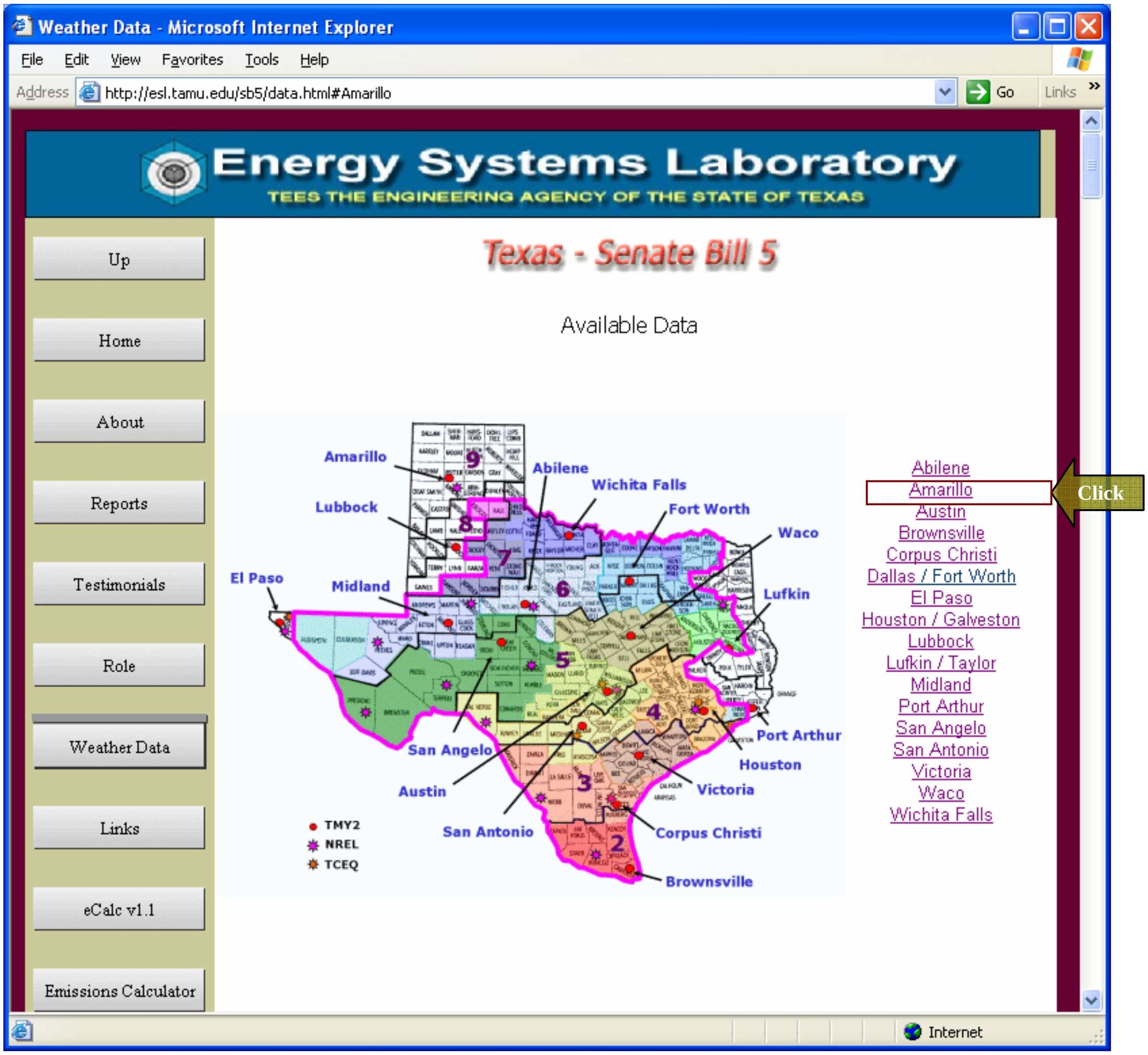

Figure 83 Weather Data web page screenshot showing the ERCOT area and the available locations with data.

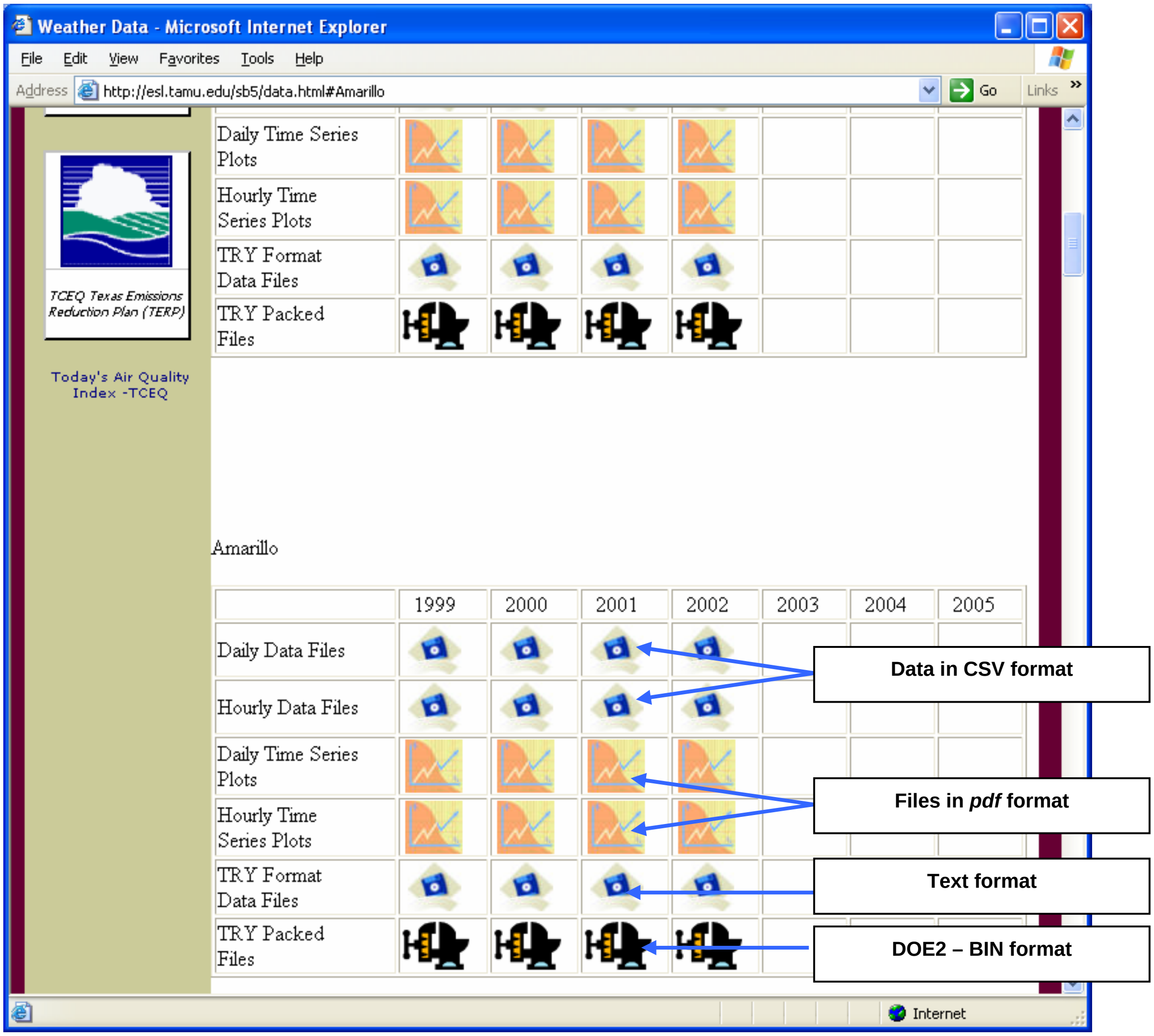

Figure 84 Available file types and years for each available location. The screenshot show the corresponding files for Amarillo, TX.

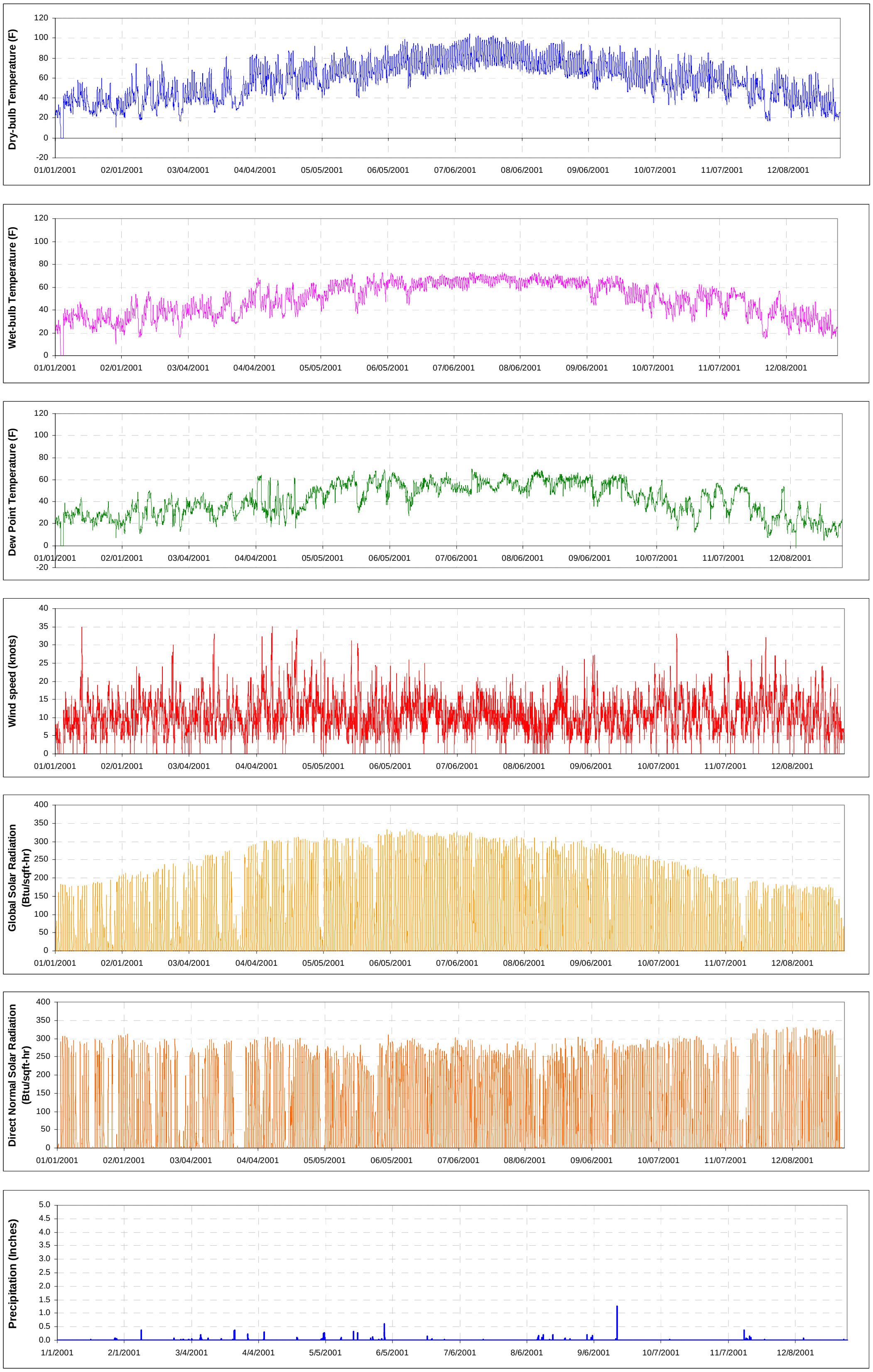

Figure 85: Hourly Data Set Time Series Plots for Amarillo, TX, in year 2001.

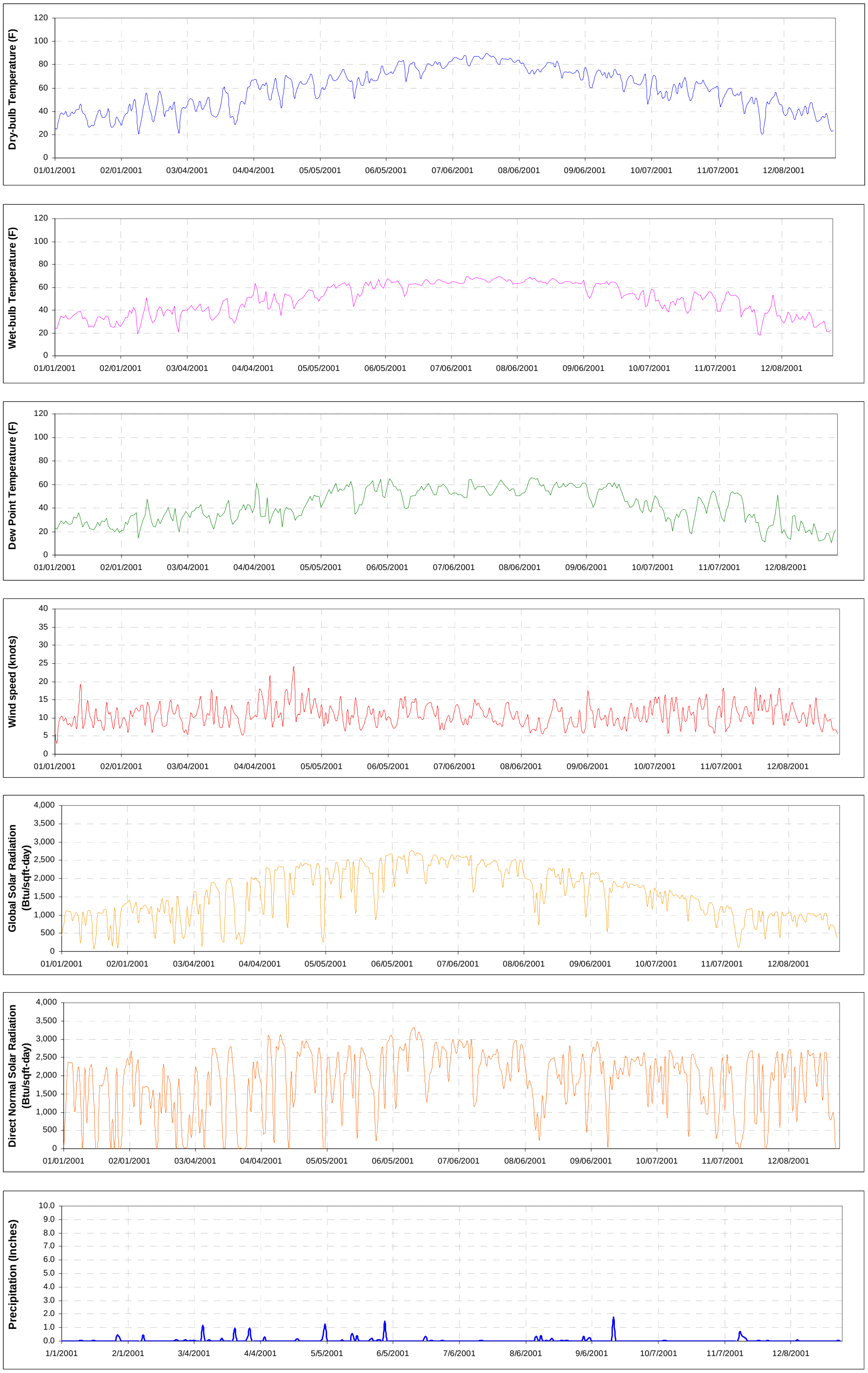

Figure 86: Data Set Time Series Plots for Amarillo, TX, in 2001.

Table 30: Example Data File for Amarillo, TX, daily data in CSV format

Date	Average Dry-Bulb Temperatur e (øF)	Average Wet-Bulb Temperatur e (øF)	Average Dew-Point Temperatur e (øF)	Average Wind Speed (knot)	Total Global Solar Radiation (Btu/day-sqft)	Total Direct Normal Solar Radiation (Btu/day-sqft)	Total Precipitation (in)
1/1/2001 0:00	25.5	24.7	23.3	6.4	421.1	35.2	0.0
1/2/2001 0:00	25.0	24.0	22.0	3.0	731.8	1073.0	0.0
1/3/2001 0:00	33.0	30.0	25.4	9.1	1095.5	2355.8	0.0
1/4/2001 0:00	38.4	34.5	29.2	10.5	1097.1	2350.1	0.0
1/5/2001 0:00	37.6	33.2	26.8	9.2	1087.5	2330.4	0.0
1/6/2001 0:00	40.1	35.3	29.0	9.9	832.0	1025.4	0.0
1/7/2001 0:00	36.0	32.2	26.5	8.0	982.3	1713.8	0.0
1/8/2001 0:00	36.6	32.3	26.2	8.4	1073.3	2242.6	0.0
1/9/2001 0:00	39.1	34.0	26.8	7.6	933.4	1369.4	0.0
1/10/2001 0:00	38.0	35.6	32.4	10.5	228.0	16.5	0.0
1/11/2001 0:00	41.4	37.0	31.5	6.9	1080.9	2216.3	0.0
1/12/2001 0:00	41.8	39.0	35.7	12.3	707.7	706.4	0.0
1/13/2001 0:00	46.0	39.1	30.0	19.3	1083.7	2184.6	0.0
1/14/2001 0:00	38.4	32.5	23.8	7.3	1112.9	2307.0	0.0
1/15/2001 0:00	37.8	33.4	27.4	8.7	971.5	1493.4	0.0
1/16/2001 0:00	32.8	31.2	28.5	14.8	92.6	0.0	0.1
1/17/2001 0:00	26.3	25.3	22.8	10.7	306.6	4.1	0.0
1/18/2001 0:00	28.1	26.0	22.2	9.6	1048.5	1733.7	0.0
1/19/2001 0:00	27.3	25.3	21.4	7.4	1050.8	1706.8	0.0
1/20/2001 0:00	32.9	29.3	24.0	12.6	1048.2	1805.7	0.0
1/21/2001 0:00	38.1	33.9	27.9	9.3	1151.9	2220.4	0.0
1/22/2001 0:00	41.0	34.1	24.7	9.4	1125.6	1710.6	0.0
1/23/2001 0:00	35.6	32.9	28.8	7.3	323.1	11.1	0.0
1/24/2001 0:00	34.3	31.8	28.5	6.8	708.3	812.6	0.0
1/25/2001 0:00	37.0	34.8	31.5	14.3	141.7	0.0	0.0
1/26/2001 0:00	42.0	34.7	24.5	11.2	1194.1	2211.9	0.0
1/27/2001 0:00	27.4	25.6	22.1	11.5	103.7	0.0	0.5
1/28/2001 0:00	26.5	25.1	22.2	7.0	575.2	106.9	0.3
1/29/2001 0:00	28.4	25.0	19.5	10.3	1194.1	1967.1	0.0
1/30/2001 0:00	35.3	30.4	22.5	12.7	1259.7	2227.7	0.0
1/31/2001 0:00	31.0	26.7	19.1	7.3	1304.1	2469.6	0.0
2/1/2001 0:00	28.2	25.6	20.7	8.1	1352.6	2285.4	0.0
2/2/2001 0:00	33.1	28.5	20.9	10.2	1394.8	2628.2	0.0
2/3/2001 0:00	37.2	33.2	27.7	8.8	1057.7	1157.3	0.0
2/4/2001 0:00	38.6	33.4	26.1	6.1	1228.0	1948.4	0.0
2/5/2001 0:00	46.3	40.0	33.0	11.8	1332.0	2376.7	0.0
2/6/2001 0:00	40.3	37.2	33.6	10.4	786.3	649.7	0.0
2/7/2001 0:00	50.3	42.4	34.3	11.7	1170.0	1674.4	0.0
2/8/2001 0:00	41.0	38.7	36.0	12.8	1176.3	1682.4	0.4
2/9/2001 0:00	20.9	18.9	14.6	11.8	1279.4	1705.5	0.0
2/10/2001 0:00	28.7	26.5	22.8	13.6	1201.7	1671.9	0.0
2/11/2001 0:00	37.6	34.2	30.0	13.4	1030.2	1094.5	0.0

Table 31: Example Data File for Amarillo, TX, hourly data in CSV format

Date Time	Dry-Bulb Temperature (øF)	Wet-Bulb Temperature (øF)	Dew-Point Temperature (øF)	Wind Speed (knot)	Global Solar Radiation (Btu/hr-sqft)	Direct Normal Solar Radiation (Btu/hr-sqft)	Precipitation (in)
1/1/2001 0:00	25.0	24.0	22.0	8.0	0.0	0.0	0.0
1/1/2001 1:00	25.0	24.0	23.0	8.0	0.0	0.0	0.0
1/1/2001 2:00	24.0	24.0	24.0	8.0	0.0	0.0	0.0
1/1/2001 3:00	24.0	24.0	24.0	8.0	0.0	0.0	0.0
1/1/2001 4:00	23.0	23.0	23.0	7.0	0.0	0.0	0.0
1/1/2001 5:00	24.0	24.0	23.0	7.0	0.0	0.0	0.0
1/1/2001 6:00	23.0	22.0	20.0	7.0	0.0	0.0	0.0
1/1/2001 7:00	24.0	23.0	21.0	8.0	0.0	0.0	0.0
1/1/2001 8:00	24.0	23.0	21.0	8.0	0.0	0.0	0.0
1/1/2001 9:00	25.0	24.0	21.0	6.0	7.0	0.0	0.0
1/1/2001 10:00	26.0	25.0	23.0	5.0	31.1	2.2	0.0
1/1/2001 11:00	26.0	25.0	23.0	6.0	48.5	2.9	0.0
1/1/2001 12:00	28.0	27.0	24.0	3.0	69.8	7.9	0.0
1/1/2001 13:00	28.0	27.0	26.0	5.0	81.5	11.4	0.0
1/1/2001 14:00	27.0	26.0	25.0	5.0	78.6	9.5	0.0
1/1/2001 15:00	26.0	25.0	24.0	7.0	51.0	1.3	0.0
1/1/2001 16:00	28.0	27.0	25.0	6.0	35.2	0.0	0.0
1/1/2001 17:00	26.0	25.0	24.0	6.0	16.8	0.0	0.0
1/1/2001 18:00	28.0	27.0	25.0	4.0	1.6	0.0	0.0
1/1/2001 19:00	28.0	27.0	25.0	5.0	0.0	0.0	0.0
1/1/2001 20:00	28.0	27.0	25.0	4.0	0.0	0.0	0.0
1/1/2001 21:00	25.0	25.0	25.0	8.0	0.0	0.0	0.0
1/1/2001 22:00	23.0	22.0	21.0	7.0	0.0	0.0	0.0
1/1/2001 23:00	23.0	22.0	21.0	7.0	0.0	0.0	0.0
1/2/2001 0:00	23.0	22.0	21.0	7.0	0.0	0.0	0.0
1/2/2001 1:00	23.0	23.0	22.0	7.0	0.0	0.0	0.0
1/2/2001 2:00	20.0	20.0	19.0	4.0	0.0	0.0	0.0
1/2/2001 3:00	20.0	20.0	20.0	0.0	0.0	0.0	0.0
1/2/2001 4:00	20.0	20.0	20.0	0.0	0.0	0.0	0.0
1/2/2001 5:00	20.0	20.0	20.0	0.0	0.0	0.0	0.0
1/2/2001 6:00	20.0	20.0	20.0	0.0	0.0	0.0	0.0
1/2/2001 7:00	21.0	21.0	21.0	0.0	0.0	0.0	0.0
1/2/2001 8:00	20.0	19.0	18.0	0.0	0.0	0.0	0.0
1/2/2001 9:00	23.0	22.0	20.0	3.0	3.2	0.0	0.0
1/2/2001 10:00	26.0	25.0	22.0	6.0	19.0	0.0	0.0
1/2/2001 11:00	27.0	26.0	23.0	9.0	48.2	2.9	0.0
1/2/2001 12:00	28.3	27.0	23.7	-99	64.7	5.1	-99.0
1/2/2001 13:00	29.7	28.0	24.3	-99	98.0	29.8	-99.0
1/2/2001 14:00	31.0	29.0	25.0	7.0	161.4	214.3	0.0
1/2/2001 15:00	32.0	30.0	26.0	-99	153.5	290.4	-99.0
1/2/2001 16:00	33.0	31.0	27.0	4.0	113.8	270.8	0.0
1/2/2001 17:00	29.0	28.0	25.0	3.0	60.2	216.6	0.0

Table 32: Example Data File using TRY format file needed for pack the DOE2 file

230470250220242700082654099999999999999999999999999999900000000	2001010100
230470250230242600082654099999999999999999999999999999900000000	2001010101
230470240240242300082654099999999999999999999999999999900000000	2001010102
230470240240242300082654099999999999999999999999999999900000000	2001010103
230470230230232300072652099999999999999999999999999999900000000	2001010104
230470240230242400072651099999999999999999999999999999900000000	2001010105
230470230200222500072651099999999999999999999999999999900000000	2001010106
230470240210232400082651099999999999999999999999999999900000000	2001010107
230470240210232200082653099999999999999999999999999999900000000	2001010108
230470250210242000062653099999999999999999999999999999900070001	2001010109
230470260230252000052654099999999999999999999999999999900310003	2001010110
230470260230251800062653099999999999999999999999999999900490004	2001010111
230470280240271700032652099999999999999999999999999999900700010	2001010112
230470280260271100052650099999999999999999999999999999900810014	2001010113
230470270250261400052651099999999999999999999999999999900790014	2001010114
230470260240251400072650099999999999999999999999999999900510003	2001010115
230470280250271500062651099999999999999999999999999999900350002	2001010116
230470260240251300062654099999999999999999999999999999900170002	2001010117
230470280250271200042656099999999999999999999999999999900020000	2001010118
230470280250271000052657099999999999999999999999999999900000000	2001010119
230470280250271300042659099999999999999999999999999999900000000	2001010120
230470250250251000082661099999999999999999999999999999900000000	2001010121
230470230210220900072663099999999999999999999999999999900000000	2001010122
230470230210220900072663099999999999999999999999999999900000000	2001010123
230470230210220900072666099999999999999999999999999999900000000	2001010200
230470230220230900072668099999999999999999999999999999900000000	2001010201
230470200190201200042669099999999999999999999999999999900000000	2001010202
230470200200200000002670099999999999999999999999999999900000000	2001010203
230470200200200000002671099999999999999999999999999999900000000	2001010204
230470200200200000002672099999999999999999999999999999900000000	2001010205
230470200200200000002676099999999999999999999999999999900000000	2001010206
230470210210210000002678099999999999999999999999999999900000000	2001010207
230470200180190000002680099999999999999999999999999999900000000	2001010208
230470230200222200032682099999999999999999999999999999900030000	2001010209
230470260220253000062683099999999999999999999999999999900190001	2001010210
230470270230262600092682099999999999999999999999999999900480004	2001010211
230470280240270009992682099999999999999999999999999999900650007	2001010212
230470300240280009992682099999999999999999999999999999900980034	2001010213
230470310250292800072676099999999999999999999999999999901610238	2001010214
230470320260300009992676099999999999999999999999999999901530280	2001010215
230470330270310500042675099999999999999999999999999999901140268	2001010216
230470290250282700032674099999999999999999999999999999900600225	2001010217
230470260240252700052674099999999999999999999999999999900100000	2001010218
230470240220232900052676099999999999999999999999999999900000000	2001010219
230470260220250000002675099999999999999999999999999999900000000	2001010220
230470260220252900042674099999999999999999999999999999900000000	2001010221
230470260210242600042673099999999999999999999999999999900000000	2001010222
230470260210242600032673099999999999999999999999999999900000000	2001010223
230470240210232900072672099999999999999999999999999999900000000	2001010300

Table 33: Weather Files Contained on the Distribution Disk Accompanying the Summary Report.

|__Data Files |__DOE2 Weather Data Files |__Packed Data Files |__1999 _DOE2 PACKED |__2000 _DOE2 PACKED |__2001 _DOE2 PACKED |__2002 _DOE2 PACKED |__2003 _DOE2 PACKED |__2004 _DOE2 PACKED |__TRY Formatted Files |__1999 _TRY FORMATTED |__2000 _TRY FORMATTED |__2001 _TRY FORMATTED |__2002 _TRY FORMATTED |__2003 _TRY FORMATTED |__2004 _TRY FORMATTED	|__Data Files |__Weather Data Files -Daily and Hourly |__CSV _WEATHER FILES |__Daily _CSV Weather Files |__1999 _DAY CSV |__2000 _DAY CSV |__2001 _DAY CSV |__2002 _DAY CSV |__2003 _DAY CSV |__2004 _DAY CSV |__Hourly _CSV Weather Files |__1999 _HOUR CSV |__2000 _HOUR CSV |__2001 _HOUR CSV |__2002 _HOUR CSV |__2003 _HOUR CSV	|__Data Files |__Weather Data Time Series Plots _pdf |__Daily pdf_TS-PLOT |__1999 _DAY TS-PLOT |__2000 _DAY TS-PLOT |__2001 _DAY TS-PLOT |__2002 _DAY TS-PLOT |__2003 _DAY TS-PLOT |__2004 _DAY TS-PLOT |__Hourly pdf_TS-PLOT |__1999 _HOUR TS-PLOT |__2000 _HOUR TS-PLOT |__2001 _HOUR TS-PLOT |__2002 _HOUR TS-PLOT |__2003 _HOUR TS-PLOT |__2004 _HOUR TS-PLOT

8.3 Procedure for filling in missing data

In order to assemble contiguous weather files for the Laboratory's emissions calculator weather data from several different sources were collected, and assembled into one file. Unfortunately, one of the problems with any source of data are missing data records. This can be due to a number of causes, many of which remain outside of the control of the users of the data (i.e., there is no way to fix the problem).

The general procedure for filling the gaps in the weather data files is presented in the Figure 87. It consists of a methodological identification of the quality of the data, using the following steps: 1) the files are first examined for time stamp, 2) the files are then inspected for real missing data, 3) a filtering process is next implemented, which labels the outliers as missing data, 4) the weather file is then restored by filling in of gaps. After these steps the file is ready for the next procedures, which include synthesizing direct normal solar radiation, etc.

Figure 88 shows the procedures that were followed for the filling in the gaps in the weather data files. To accomplish this, two types of procedures were developed: one for the outside air temperatures -- dry-bulb, dew-point and wet-bulb, in which gaps are possible to fill, and the variables with more random behavior such as the wind speed, its direction, rainfall, pressure and solar radiation components.

The temperature variables gaps can be filled in using an automated procedure, if the gap length is smaller or equal than 6 units (i.e., hours if hourly data) (Baltazar & Claridge 2006). The station pressure gaps, due to its quasi-steadiness, are filled with the last value that was previously recorded. Missing solar data is not filled due to the need for a special procedure, which is presented in next section.

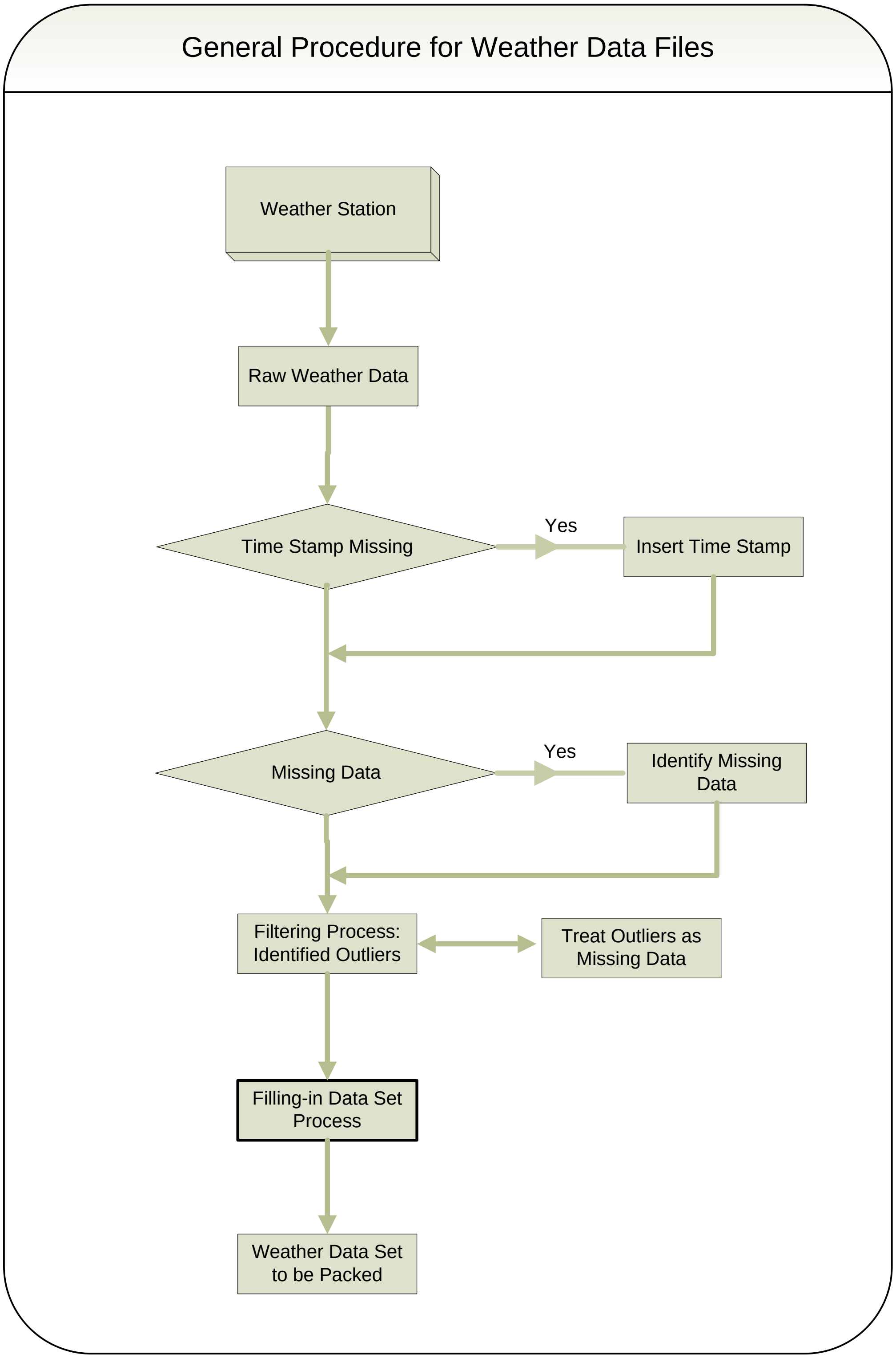

Figure 87: General procedure for processing the weather files before being packed

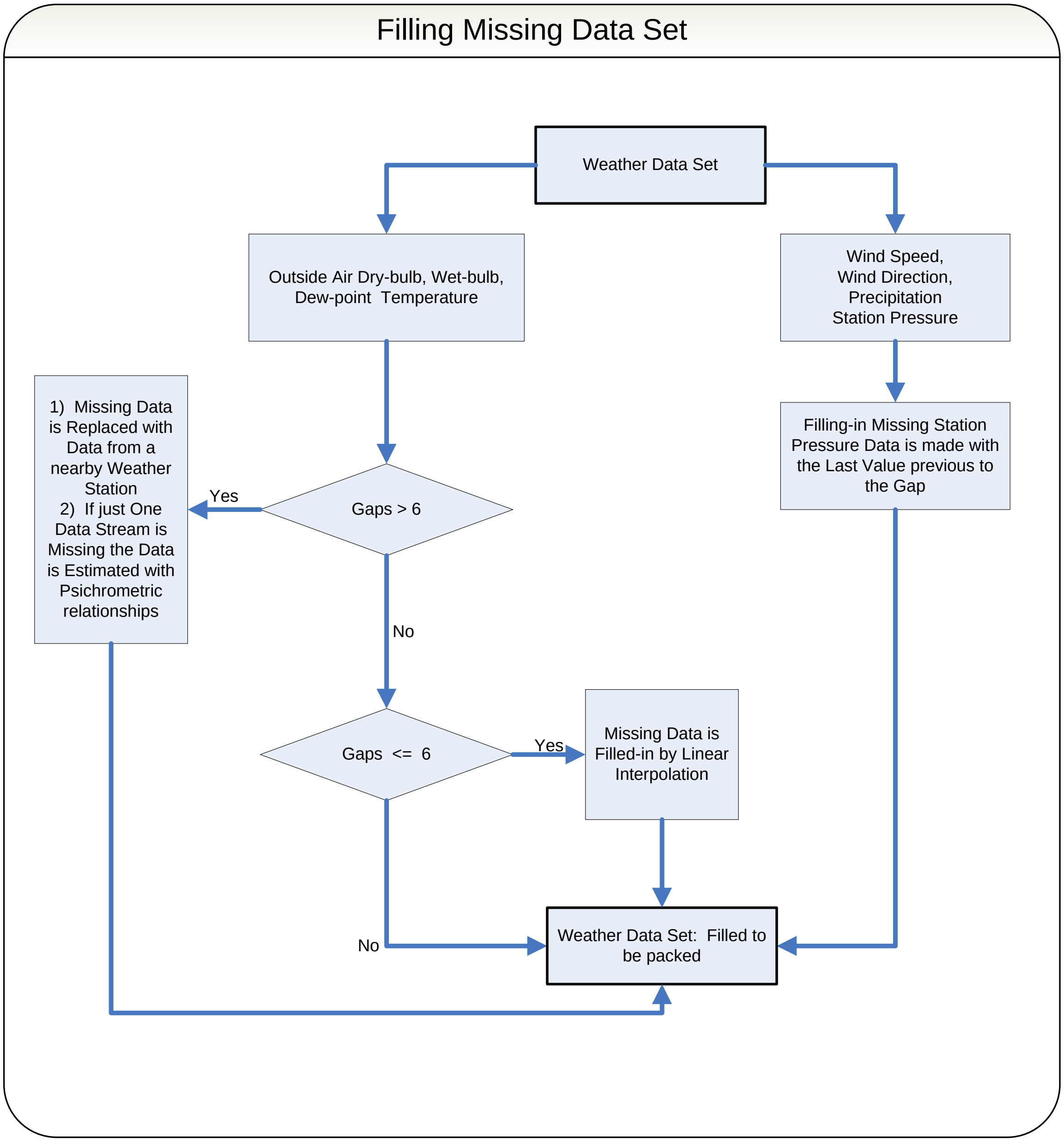

Figure 88: Specific procedures for filling-in gaps of temperature variables records.

8.4 Procedure for Generating Solar Radiation Components Data

Solar radiation data is a weather parameter that has not been regularly recorded in many locations. In Texas there is only one station for 40,000 ha of irrigated (Spokas and Forcella, 2006). In most countries the relation of the weather stations monitoring solar radiation compared with those that monitoring other ambient variables such as Tdb, Twb, Tdp, wind speed, etc. is 1:500 (Thornton and Running, 1999, in Spokas and Forcella, 2006). Furthermore, the quality control in locations that record solar radiation data is not always uniform. Another problem that is found in such stations is that this parameter is often recorded as only Global Horizontal solar radiation, which is very important but for some applications, but requires additional processing.

For example, analyses that use simulation programs, such as DOE-2, require a whole year of packed data. To pack the weather files all required meteorological parameters should be present. Therefore, in the case of solar radiation the global and the Direct-Normal components are required.

For the cases that need to compute the Direct-Normal Solar Radiation, provided Global Horizontal radiation is available, the Erbs correlation for the estimation of the Diffuse Solar Radiation fraction for hourly Global Solar Radiation is used.

Table 34 contains the basic equations that are utilized to generate the Direct-Normal Solar Radiation component based on the records of the Global Horizontal Solar Radiation. The constraints imposed on the specific steps are required to avoid abrupt behavior of the expressions and therefore avoiding physical misinterpretations. In comparison to measured values of the Direct-Normal solar radiation, from a Normal Incident Pyrheliometer (NIP), the values obtained from the Erbs' correlation are often underestimated for a large portion of the year. Though this outcome was expected due to the simplicity of the Erbs' correlation, its use is more advisable than the use of the Direct-Normal Solar Radiation for periods of mixed data (i.e., to fill-in missing data), which can produce significant variations that are not suitable for comparative studies that rely on this parameter. The proposed methodology for creating Direct Normal Solar Radiation would always use Global Horizontal solar radiation, with Direct-Normal Solar Radiation component always synthesized using a correlation.

8.5 Synthesis of hourly global solar radiation: preliminary procedure

The previous section described the methodology to synthesize the Direct Normal Solar Radiation components when the Global Solar Radiation is available. Another problem that occurs with solar data is when the Global Horizontal Solar Radiation. Some studies have recommended that if the Global Horizontal Solar Radiation is not available a manual filling of the data should be performed using data from previous "similar" years or from a nearby station. Missing Solar Radiation data often occurs in long or short periods. Short periods can be characterized as gaps with a length of days and hours, on the contrary long periods include gap lengths greater than one day to as long as one week. The worst case is the situation where the no data is available for months or years. Therefore, there is a need for a procedure to synthesis hourly Global Horizontal Solar Radiation that allows to fill the void of data in any place in Texas.

There are many procedures to determine hourly Global Horizontal Solar Radiation, and its components. Most of these are based upon data taken from other parts of the world. Also some methodologies are based on records that may not be available for the location where the Solar Radiation is needed. As a preliminary study the synthesis of Global Horizontal Solar Radiation was proposed to be determined from meteorological parameters available from NOAA –this was proposed to limit the scope of the number of locations to those taken account by NOAA.

One of the meteorological parameters that is available in all the NOAA station is the cloud cover. This parameter has been used since the eighties to determine hourly global solar radiation. Kasten and Czeplak (1980) proposed the synthesis of Global Horizontal Solar Radiation, I_G, from the total cloud amount, N, in oktas, through a relationship with the global solar radiation under a cloudless sky, I_{GC}, which depend of the elevation angle, and can be obtained via a linear parameterization as follows

$$I_{G_C} = A \sin\alpha - B$$

They also found that the ratio of global radiation for a given cloud amount to I_{GC}, is independent of the solar elevation and can be expressed as

$$I_G / I_{Gc} = 1 - C(N/8)^D$$

The diffuse component was found to be related to the estimated global irradiance by

$$I_d / I_{Gc} = 0.3 - 0.7(N/8)^2$$

The direct component will be then calculated as the difference of global and diffuse components. The coefficients A, B, C, and D involved in the procedure have to be fitted against enough measured global solar radiation data that account for all the conditions in the location –i.e. the procedure is site specific.

Table 35 contains the equations in the procedure to obtain the coefficients that are required for this methodology. The size of the data sample should be as large as possible to assure the integration of the range of variability of the solar radiation within the site weather conditions.

The preliminary results show that the cloud-cover model developed for Abilene, TX, required measured data to tune the model. Therefore, to accomplish this additional solar radiation data was obtained and the model tested. Figure 89 shows the global solar radiation synthesized for Abilene, TX, for the winter-spring season of 2001. Figure 90 is a comparison between the measured and the predicted global solar which shows a good fit for the clear days. However, on cloudy days the model performed less accurately, perhaps related to the amount of water in the ambient.

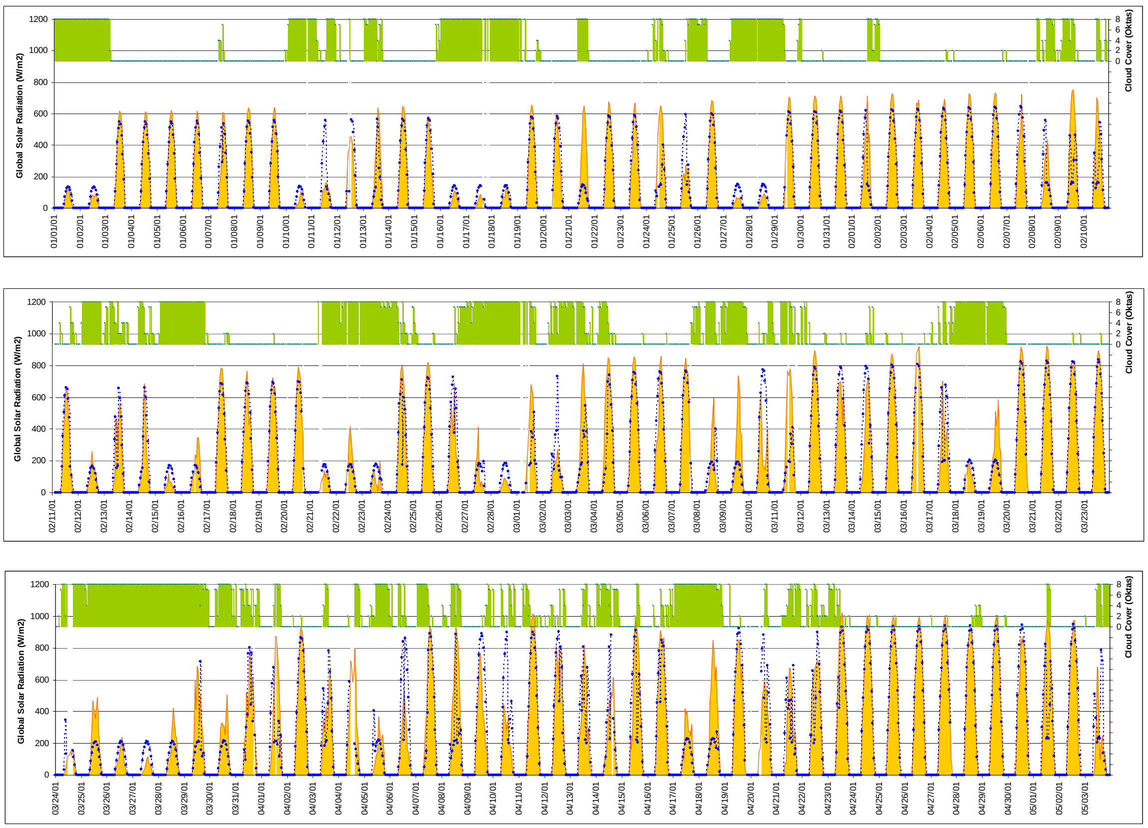

Figure 89: Output of the solar synthesized for Abilene, TX, 2001 in the winter-spring season.

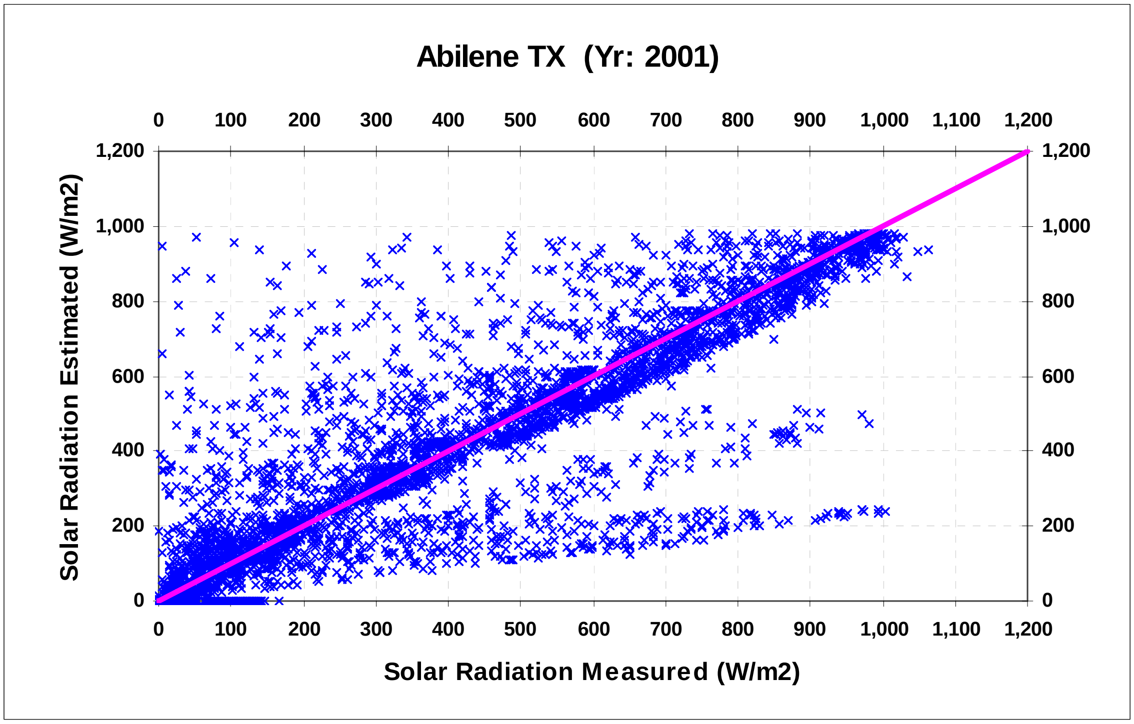

Figure 90: Global solar radiation comparison for Abilene, TX, in the year 2001.

Table 34: Numerical Procedure steps for Direct-Normal Solar Radiation Computation through Erbs Correlation.

$B = (n-1)360/365$

$E_t = 229.2(0.000075+(0.001868Cos(B))-(0.032077Sin(B))-(0.014615Cos(2B))-(0.04089Sin(2B)))$

$d = 23.45Sin((284+n)360/365)$

$h_{st} = (60t + 4(90 - l_{loc}) + E_t)/60$

$h_w = (h_{st}^{*} - 12)15$ $\qquad h_{st}^{*} = (h_{st}^{1} + h_{st}^{2})/2$

$I_o = I_{cs}((1+0.033\,Cos(n\,360/365))(Cos(f)\,Cos(d)\,Cos(h_w) + Sin(f)\,Sin(d))$

$(I_o < 10 \mid I_o < I) \rightarrow I_o = 0$

$K_t = I/I_o$

- $K_t <= 0.22$ $\quad I_d/I_o = 1 - 0.09K_t$
- $K_t > 0.80$ $\quad I_d/I_o = 0.165$
- Otherwise $\quad I_d/I_o = 0.9511 - 0.1604K_t + 4.388K_t^2 - 16.638K_t^3 + 12.336K_t^4$

$I_d = (I_d/I)_{ERBS} I$

$I_b = (1 - (I_d/I)_{ERBS})I$

$Cos(q) = Cos(f)\,Cos(d)\,Cos(h_w) + Sin(f)\,Sin(d)$ $\qquad 0 < Cos(q) < 0.1 \longrightarrow Cos(q)=0.085$

$I_{DN} = I_b/Cos(q)$

n - Day of the year [1, … , 365]
E_t - Equation of time [min]
d - Solar Declination [23.45°, -23.45°]
t - Local time [hrs]
l_{loc} - Longitude local [Degrees]
h_{st} - Decimal Solar Time
h_w - Hour angle [-180°, 180°]
f - Latitude local [Degrees]
I_{cs} - Solar Constat Irradiation [1367 W/m2]
I_o - Extraterrestrial Radiation [W/m2]
K_t - Clearness Index
$(I_d/I)_{ERBS}$ - Erbs' Correlations
I - Global Radiation [W/m2]
I_b - Bean Radiation Component [W/m2]
I_d - Diffuse Radiation Component [W/m2]
q - Incidence angle [Degrees]
I_{DN} - Direct Normal Radiation [W/m2]

Table 35: General mathematical depiction of the application of the cloud-cover model.

$$I_{G_C} = A\sin\alpha - B$$
$$u = mv + b$$
$$u = I_{G_C} \quad v = \sin\alpha \quad m = A \quad b = -B$$
$$\alpha = f(date, hour, \phi, l)$$

$$I_G / I_{G_c} = 1 - C(N/8)^D$$
$$C(N/8)^D = 1 - I_G / I_{G_c}$$
$$\ln\left(C(N/8)^D\right) = \ln\left(1 - I_G / I_{G_c}\right)$$
$$\ln(C) + \ln\left((N/8)^D\right) = \ln\left(1 - I_G / I_{G_c}\right)$$
$$\ln(C) + D\ln(N/8) = \ln\left(1 - I_G / I_{G_c}\right)$$
$$\ln\left(1 - I_G / I_{G_c}\right) = D\ln(N/8) + \ln(C)$$
$$y = mx + b$$
$$y = \ln\left(1 - I_G / I_{G_c}\right) \quad m = D \quad x = \ln(N/8) \quad b = \ln(C)$$

A, *B*, *C*, and *D* coefficients involved in the model presented above are to be calibrated (determined by regression) with measured data.

$$\sin\alpha = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$$

$$\delta = 23.45\sin(360(284+n)/365)$$

ω - Hour angle, the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour, morning negative, afternoon positive

α- Solar altitude angle (or solar elevation), the angle between the horizontal and the line to the sun. The complement of the zenith angle.

Solar time – Local standard time = 4(Lst – Lloc)+E

$$E = 229.2(0.000075 + 0.001868\cos B_E - 0.032077\sin B_E - 0.014615\cos 2B_E - 0.04089\sin 2B_E)$$

$B_E = (n-1)360/365$

N = Cloud amount **(okta)**

I_{Gc} = Solar radiation under Cloudless sky **(W/m^2)**

9 MODIFICATIONS OF EXISTING QUALITY ASSURANCE PLAN

9.1 Weather

Given the budget and time frame of the project, it was decided to use published government data, namely from NOAA, NREL, and TCEQ.

1. Integrate the best available Government data and models, with minimal additional model development. Thus leveraging prior Quality initiatives at NOAA, NREL, LBL, and DOE.
2. Demonstrate that the integrated components provide the same results as the stand alone components. Thus providing confidence that the integration is successful.

There were three operations conducted on the weather data.

1. Range limits, bad data filtering. The process was derived from the NOAA documentation on the weather file format. All records are processed for 100% confidence of identification of bad records. A query is then run to determine the gaps in the data for each month. Each data set used to process the data is kept and archived for future reference.
2. Conversion into seventeen Test Reference Year (TRY) tapes – mapped to NOAA weather stations. These replace the Typical Meteorological Year version 2 (TMY2) tapes for the same location. The Lawrence Berkeley National Labs (LBNL) Weather Packer software is used to perform this conversion. The data is also exported back out for use with Utility Bill and Water models.
3. Solar data is also imported for combination into the TRY tapes as used by the legacy simulation software model DOE-2.
4. In v2.0 the lab added 2005 data following the same procedures.

9.2 Data Sources and Usage

The various sources of data used for this effort are shown in Table 36. Each of these data sources were kept consistent throughout the data collection effort.

Table 36: Quality Assurance Plan Data Sources

Data Item	***Source***	***Updated***	***Models***					
			DOE-2	***Fchart***	***PVFChart***	***IMT***	***PAM***	***System***
NOAA Weather Data	***NOAA***	*Monthly*	Ind			Ind		
Solar Data	***NREL***	*Monthly*	Ind			Ind		
Ground Temp	***Synth***	*Monthly*	Ind			Ind		
DHW Water Inlet Tem	***Synth***	*Monthly*	Ind			Ind		
Fchart Env Data	***Fchart***	*Static*		y				
PVFChart Env Data	***Fchart***	*Static*			X			
PUC Data	***EPA***	*Static*					X	
DOE-2 Bldg DB	***ESL***	*w Vers*	X					
Test Scripts	***ESL***	*w Vers*	X	X	X	X	X	
System Perf Data	***eCalc***	*Run*						X
User Input Data	***User***	*Run*						X
User Output Data	***eCalc***	*Run*					X	X

Notes:

Code	Meaning
w Vers	With each Version change
Static	Doesn't change unless the model changes (i.e. new Project)

Synth	Synthesized as per original QAPP
Run	Updated with each run of the system
Ind	Indirectly used by the Model indicated

IMT Represents Lighting, Water, Utility Bills, and Wind

Source	Dry Bulb Temp	Wet Bulb Temp	Wind	Rainfall	Solar	Ground Temp	Ground Water Temp
NOAA	Hourly	Hourly °F	Hourly Max	Hourly Inches	None		
Solar	None	None	None	None	Hourly W/ m^2		
TRY 1999	Hourly °F	Hourly °F	Hourly Max	None	Hourly W/ m^2	Synth*	Synth*
IMT Weather Data 1999-2005	Hourly °F	Hourly °F	Hourly Max	Hourly Inches	Hourly W/ m^2		

9.3 Weather Data

Accuracy of the weather data relies on the source of the weather data. Weather data for eCalc comes from NOAA and NREL. In terms of US Weather data, it is widely accepted that NOAA is the only effective data source. NREL and TCEQ can/have provided limited solar data which is used to reduce the need to synthesize solar values used to build DOE-2 TRY2 weather data sets for 1999 data. Details of the filtering, checking, and filling are covered in the original QAPP for Project 1, which is included with this summary report. These data are used in every model except Street Lighting/Traffic Lights.

9.3.1 Solar Data

Solar data is from NREL's database. This is used to enhance the DOE-2 TRY2 weather data. It is not used for Utility Bill analysis and in Project 1. Similarly, it is not used to replace PV F-Chart or F-Chart solar observation data. See the Weather Mini-Spec in the original QAPP. However, the PV F-Chart data more closely matches the NOAA and NREL data so it has been used in F-Chart.

9.3.2 Ground Temp

This is synthesized as per the See the Weather Mini-Spec in the original QAPP and used as an input for the amount of heat difference between the building and the ground in DOE-2.

9.4 Systems Management

- Industry standard PC's running Microsoft products: Windows XP, Windows 2003, and Visual Studio .Net 2005 with the .NET Framework 2.0
- The servers are to be located in the dedicated TEES hosting facility in our building on the Texas A&M University campus.
- Our systems are protected by the Campus firewall, and running Windows firewall software.

9.4.1 Data Systems Management

- Use of mirrored hard disks (RAID) on the Development, Test, and Production servers.
- Regular backups of the SQL 2000 Database (SQL) and VSS databases to an ESL SE Group RAID 5 network share located on another server, as well as storage to an optical disk (DVD) via the burner located in the Development Server. The mySQL database that powers both the Wiki and Mantis is also backed up each night to the same directory as SQL Server and thus copied to tape and rotated out of the building.

- Regular tests of the tape backup of both the VSS store and the SQL Database are conducted. A tape is selected for restoration to a test directory. The applications then mount the restored data for confirmation of quality of the backup. Results of these are placed in the _QA folder in Exchange.
- Tape backup of the SE Group share, as well as regular imaging of the Application partitions
- Rotation of the tapes into a fire-proof safe and rotation from the site for storage off-site.
- Replication from the Production Server to both the Test and Development Servers (Figure 91):

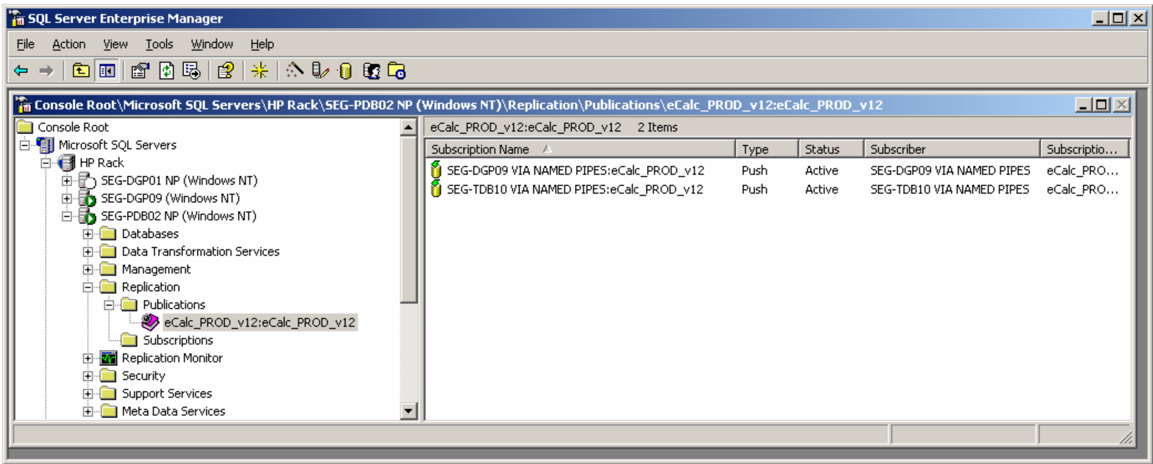

Figure 91: Replication Management

10 TECHNICAL ASSISTANCE AND TECHNOLOGY TRANSFER

The Laboratory provided technical assistance to the TCEQ, the PUC, SECO and ERCOT, as well as Stakeholders participating in the Energy Code and Renewables programs. In 2005 the Laboratory worked closely with the TCEQ to develop an integrated emissions calculation, that provided the TCEQ with a creditable NOx emissions reduction from energy efficiency and renewable energy (EE/RE) programs reported to the TCEQ in 2005 by the Laboratory, PUC, SECO, and Wind-ERCOT.

The Laboratory has also enhanced the previously developed emissions calculator by: expanding the capabilities to include all counties in ERCOT; including the collection and assembly of weather from 1999 to the present fro 17 NOAA weather stations; and enhancing the underlying computer platform for the calculator.

To accelerate the transfer of technology developed as part of the Senate Bill 5 program, the Laboratory: delivered an invited presentation to the US EPA's Air Innovations conference in Chicago, August, 2005; delivered six papers at International Conference on Enhanced Building Operation at Carnegie Mellon University in Pittsburg, PA, in October 2005; hosted the Emissions Reduction and Leadership Summit in Dallas, in November, developed an article for the *ibpsaNEWS* newsletter[31]; and published technical reports.

The Laboratory has and will continue to provide leading edge technical assistance to counties and communities working toward obtaining full SIP credit for the energy efficiency and renewable energy projects that are lowering the emissions and improving the air for all Texans. The Laboratory will continue to provide superior technology to the State of Texas through efforts with the TCEQ and US EPA. The efforts taken by the Laboratory have produced significant success in bringing EE/RE closer to US EPA acceptance in the SIP.

10.1 Presented Papers at the 5th International Conference for Enhanced Building Operation, Pittsburg, PA, October 2005.

Several papers were prepared and presented at the 5th International Conference for Enhanced Building Operation, in Pittsburg, PA, in October of 2005. Copies of these papers have been posted on the Laboratory's Senate Bill 5 web page. Titles and abstract for each of the papers are as follows.

Baltazar-Cervantes, J.C., Gilman, D., Haberl, J., Culp, C. 2005. "Development of a Web-based Emissions Reduction Calculator for Solar Thermal and Solar Photovoltaic Installations", *Proceedings of the 5th International Conference for Enhanced Building Operation*", Pittsburg, PA, published on CDROM (October).

This paper presents the procedure that have been developed and used to assess the potential emission reductions due to the electricity savings from the application of some of the most common solar thermal and solar photovoltaic systems. The methodology to estimate the potential NOx emission reduction integrates legacy analysis tools, including the F-CHART[32], PV F-CHART[33]. ASHRAE's Inverse Model Toolkit (IMT) [34] is used to perform the weather normalization, and for calculating peak-day electricity

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[31] ibpsaNEWS is the electronic newsletter for the International Building Performance Simulation Assocation, co-sponsored by the US DOE.

[32] F-CHART is the well known solar thermal design method, developed by the University of Wisconsin, which is used to select and analyze solar thermal systems. The program provides monthly-average performance for selected system, including: domestic water heating systems, space heating systems, pool heating systems and others (Klein and Beckman 1983).

[33] PV F-CHART is the well known solar photovoltaic system analysis and design program. The program provides an hourly performance profile for monthly-average days. The calculations are also based upon methods developed at the University of Wisconsin, which use the utilizability concept to account for the statistical variation of radiation and load (Klein and Beckman 1985).

[34] IMT, the Inverse Model Toolkit, is a FORTRAN 90 application that performs regression modeling of building energy use. Its development was sponsored by ASHRAE 1050-RP in support of ASHRAE GUIDELINE 14-2002. IMT is capable of identifying traditional linear, least-squares regression models. It is also capable of identifying special change-point and variable-base degree-day models that have been shown to be especially useful for modeling building energy use (Kissock et al. 2002).

savings. The EPA's Emissions and Generations Resource Integrated Database (eGRID)[35] is used for calculating the NO_x emissions reductions for the electric utility provider associated with the user.

Liu, Z., Baltazar-Cervantes, J.C., Gilman, D., Haberl, J., Culp, C. 2005. "Development of a Web-based Emissions Reduction Calculator for Green Power Purchases From Texas Wind Energy Providers", *Proceedings of the 5th International Conference for Enhanced Building Operation*", Pittsburg, PA, published on CDROM (October).

This paper provides a detailed description of the procedures that have been developed to calculate the emissions reductions from electricity provided by wind energy providers in the Texas ERCOT region, including an analysis of actual hourly wind power generated from a wind turbine in Randall County, Texas.

[35] eGRID, ver. 2, is the EPA's emissions and generation resource integrated database. This publicly available database can be found at *www.epa.gov/airmarkets/eGRID/*.

11 REFERENCES

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12 REPORTS AND DATA INCLUDED WITH THE 2005/2006 ANNUAL REPORT.

12.1 Quality Assurance Project Plan

12.2 Data Files for Wind Energy Production

12.3 Weather Data Files

12.4 ICEBO papers